C0000:?

THEODORE J. HOGAN & ASSOCIATES, INC. . . .THE SAFETY CHOICE ™

103 Stephen Street, Second Floor • Lemont, Illinois 60439 PHONE 630.257.3939 FAX 630.257.3121

89069

RECEIVED
APR 06 1998
de maximis, inc.

March 24, 1998

The Yeoman Creek PRP Steering Committee
c/o de maximis, inc.
4155 El Camino Way, Suite A
Palo Alto, CA 94306

Summary Exposure Risk Analysis for 1401-1451 W. Golf Rd., Waukegan, IL, Basements

Dear Committee Members:

Per your request, I analyzed the potential risk of organic vapor exposure from basement occupancy of the above referenced site. I have included a discussion about the previous U.S. EPA calculation of inhalation risk (12/5/96 letter of Jamey Bell to Yeoman Creek Technical Committee).

Current Status

This analysis is based on the recent sampling data collected January 20-22, 1998 (reference 1) (Data and references listed in Table 1 and 2). The sampling results were compared to: typical indoor and outdoor levels of the materials as found in the U.S. EPA's "Total Exposure Assessment Methodology (TEAM) Study" (2); the U.S. Department of Health and Human Services ATSDR "Toxicological Profiles" (3); and the U.S. EPA's most recent Integrated Risk Information System (IRIS) Substance Files (4, 5).

As you know, the IRIS lifetime inhalation reference concentrations are estimates of daily inhalation exposures to humans (including sensitive subgroups) that are likely to be without an appreciable risk of deleterious effects during a lifetime of exposure.

The highest indoor basement breathing zone of ethylbenzene, m,p-xylene, and o-xylene levels (found in the basement of the restaurant, 1451 W. Golf) were within the range of typical winter urban indoor air concentrations found in the EPA TEAM Study. The highest indoor basement toluene level was below the median indoor toluene concentration reported by ATSDR. The highest basement toluene level is 6.4% of the toluene IRIS lifetime inhalation reference concentration. The highest basement ethylbenzene level is 0.82% of the ethylbenzene IRIS lifetime inhalation reference concentration.

Based on these comparisons, I conclude that the measured basement breathing zone levels are within normal indoor exposure levels, are well below applicable IRIS reference concentrations, and do not pose a risk to human health for continuous occupancy.

The U.S. EPA, in the same document, recognizes that there are numerous indoor materials that cause the normal indoor environment to have pollutants at higher concentrations than outdoors:

> Many of the chemicals emitted by the materials are the same as chemicals released from Superfund and hazardous waste sites which severely complicates any attempt to determine the amount of any indoor air pollutant that is directly attributable to external sources (page 1-2).

The ATSDR documents identify a number of other common sources for the contaminants found in the basements, including:

> Toluene: smoking, auto emissions, paints, thinners, glues
> Ethylbenzene: cigarette smoke, auto emissions
> Xylenes: auto emissions, consumer products, cleaning agents, carpet adhesive

It is reasonable to presume that one of the sources of indoor organics in the basement of 1451 W. Golf may be cigarette smoke from the restaurant occupancy. Materials required for restaurant cleaning and sanitation might be another source. Auto emissions may be drawn into the basement by the basement ventilation system, or by seeping in from the adjacent parking areas when the basements are under negative pressure (EPA-451/R-92-002, page 2-8).

Therefore, based on the finding that the basement organic vapor levels are within normal ranges for indoor air, and that there are other reasonable sources inside that are likely contributing to any detectable concentrations in the basement, the measured indoor basement organic vapors may not be attributable to the Yeoman Creek site.

Summary

There are two sets of data, spanning a five year period, which indicate that there are no detectable carcinogens in the basement breathing zone samples. Further, the contaminants that are present are at levels typical of indoor air environments as measured in U.S. EPA's own studies. Those materials present are at levels well below U.S. EPA's own IRIS reference concentrations. Accordingly, based upon my extensive knowledge and experience of inhalation risk factors and standards, it is my expert opinion that there is no apparent acute or chronic health risk.

Sincerely,
Theodore J. Hogan & Associates, Inc.

Theodore J. Hogan, PhD, CIH
President

Table 1: January 1998 Breathing Zone Air Sample Results

Basement Readings at 1401-1451 W. Golf Rd., Waukegan, IL, Grouped by Location. FID Readings and Compounds Detected by GC/MS (1)

Date	Location	Basement Pressure	FID	toluene	ethylbenzene	m,p-xylene	o-xylene
1/20/98	1415	positive	88 ppm	6.0 ppb	ND ppb	2.8 ppb	1.1 ppb
1/22/98	1415	positive	48	5.4	ND	2.5	ND
1/20/98	1425	negative	30	2.9	ND	1.4	ND
1/20/98	1431	negative	28	4.6	ND	2.0	ND
1/22/98	1431	positive	220	4.8	ND	2.2	ND
1/20/98	1451	negative	420	3.9	ND	1.9	ND
1/21/98	1451	positive	410	**6.6**	**1.9**	**5.4**	**2.7**
				(highest organic vapor basement readings)			
1/22/98	1451	positive	460	6.3	ND	3.0	1.1

Data Sources

(1) de maximis data tabulations from January 1998 for Yeoman Creek Site

Table 2: Comparisons Between Highest January 1998 Breathing Zone Air Sample Results, TEAM Average Indoor/Outdoor Exposures, ATSDR Median Indoor Concentrations, and the IRIS Reference Concentrations for Chronic Inhalation Exposures

Comparisons (all values in ug/m3)			**toluene**	**ethylbenzene**	**m,p-xylene**	**o-xylene**
Conversion of highest basement readings to ug/m3 (ug/m3 = ppb X Molecular weight /24.45)			**24.9 ug/m3**	**8.2 ug/m3**	**23.4 ug/m3**	**11.7 ug/m3**
TEAM Winter Exposure Estimates (2) Weighted arithmetic mean overnight exposures						
Los Angeles	Feb 1984	Indoor	not sampled	11	28	13
		Outdoor	not sampled	9.7	24	11
New Jersey	Winter 1983	Indoor	not sampled	11	29	9.8
		Outdoor	not sampled	3.4	8.5	3.1
ATSDR Median Indoor Levels (3)			31.5			
Iris Lifetime Inhalation Reference Concentration (RfC) (4) (5)			400	1000	no data	no data

Data Sources

(1) de maximis data tabulations from January 1998 for Yeoman Creek Site
(2) "The Total Exposure Assessment Methodology (TEAM) Study: Summary and Analysis, Vol I": EPA/600/6-87/002a, June 1987. Table 22, page 37; and Table 27, page 55.
(3) "Toxicological Profile for Toluene": ATSDR, TP-93/14, May 1994. Table 5-2, page 127.
(4) "Toluene": U.S. EPA IRIS Substance File (on-line) last revised 03/01/97.
(5) "Ethylbenzene": U.S. EPA IRIS Substance File (on-line) last revised 03/01/97.

The Jeff Diver Group
environmental law

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VIA HAND DELIVERY

April 9, 1998

Mr. Stuart P. Hersh
Assistant Regional Counsel, **Attn.:** SE-5J
U.S. Environmental Protection Agency, Region 5
77 West Jackson Blvd.
Chicago, IL 60604-3590

Re: Yeoman Creek Facility, Lake County, Waukegan, Illinois
Our File No.: 0203

Dear Mr. Hersh:

I am enclosing two documents to be included in the Administrative Record for the above referenced Site. The first document is a March 24, 1998 report prepared by Dr. Theodore J. Hogan (5 pages), Project 198-03. This report summarizes Dr. Hogan's analysis of exposure risk from organic vapor in the basement occupancy of structures near the above referenced Site.

The second document I am enclosing is a March 25, 1998 report prepared by Dr. Russell A. Ogle of Packer Engineering, Inc., File No. N24266 (54 pages, not including bound cover). This report summarizes Dr. Ogle's assessment of the quality of monitoring data and the effectiveness of the air-exchange ventilation system at structures near the above referenced Site, and his determination that there is no risk of a landfill gas fire or explosion in the basements of 1401-1451 W. Golf Road building.

I will assume, unless I hear from you otherwise, that the enclosed documents have properly been added to the Administrative Record for the above referenced Site. Thank you for your help in this matter.

Sincerely yours,

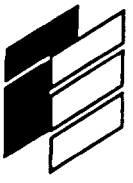
Jeffrey R. Diver, Chairman
Yeoman Creek Steering Committee

enclosures

PACKER

INVESTIGATION OF THE AIR EXCHANGE AND VENTILATION SYSTEM (AEVS) AT THE YEOMAN CREEK LANDFILL SUPERFUND SITE

SUBMITTED BY:



PACKER
ENGINEERING INC.

Submitted to:

Robin Robinson, Ph.D.
de maximis, inc.
4155 El Camino Way
Suite 1
Palo Alto, CA 94306

Date of Report: March 25, 1998
Packer Engineering File No. N24266

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PACKER ENGINEERING INC.

INVESTIGATION OF THE AIR EXCHANGE AND VENTILATION SYSTEM (AEVS) AT THE YEOMAN CREEK LANDFILL SUPERFUND SITE

INTRODUCTION

The Yeoman Creek Landfill (YCLF) is a closed municipal landfill located in Waukegan Illinois. It is one of a number of landfills that comprise the Yeoman Creek Facility Superfund site. The Remedial Investigation / Feasibility Study (RI/FS) was completed in April of 1995. The next phase, Remedial Design / Remedial Action (RD/RA), has not yet started. One of the concerns raised by the U.S. Environmental Protection Agency (USEPA) was the possibility of landfill gas migrating into adjacent buildings (1401 through 1451 West Golf Road) and causing a fire or explosion. Therefore, the Yeoman Creek Technical and Steering Committees implemented an interim response to guard against this hazard.

The interim response consists of both administrative and engineering controls. The administrative control is a basement air monitoring program designed to monitor for the presence of landfill gas. The engineering control is a ventilation system, called the Air Exchange and Ventilation System (AEVS), which ventilates the basement air space to prevent accumulation of flammable gas. In a letter dated January 16, 1998, USEPA questioned the effectiveness of the AEVS and asked the Yeoman Creek Technical and Steering Committee to reevaluate the system.

The opinions expressed in this report are based on the information available at this time. Packer Engineering reserves the right to supplement these opinions as new information becomes available.

OBJECTIVES

Packer Engineering was retained by the Yeoman Creek Technical and Steering Committees to investigate the AEVS with the following objectives:

- Assess the quality of the monitoring data
- Evaluate the effectiveness of the AEVS
- Determine the risk of a landfill gas fire or explosion in the basements of 1401 through 1451 West Golf Road (subject basements)

The methodology of this investigation is based on the reference Guidelines for Chemical Process Quantitative Risk Analysis, published by the American Institute of Chemical Engineers (AIChE). This document explicitly considers risk analysis techniques for accidents involving flammable gases.

INVESTIGATION

The investigation is based on a review of file materials, a site inspection and engineering analysis. The review of file materials included the RI/FS Final Report, the basement monitoring data, the Operation and Maintenance Plan for the AEVS, and all of the AEVS monthly reports and technical references. The site inspection included a visual inspection of the YCLF, the AEVS, the exterior of the subject building and its immediate surroundings, and the subject basements. The location of each basement monitoring location was observed and documented. An inventory of potential fuel and ignition sources in each basement was conducted and the condition of all gas-fired appliances was noted.

BACKGROUND

The following background material is included because it provides the foundation for the engineering analysis.

YCLF Setting and History

The YCLF is approximately 49.2 acres in area with an average refuse depth of 14 feet. The topography of the landfill is flat. The stratigraphy of the surrounding soil is a complex mix of glacial tills, clays and sand. Landfill operations began in 1963, and the landfill was closed in August 1969. A final cover was constructed and a vegetation layer established. Given the age of the closed landfill, it can be inferred that the production rate of landfill gas has peaked (probably in the early to mid seventies) and has continued to decrease. It has been estimated that the methane gas generation rate is currently 50 standard cubic feet per minute (scfm).

Results of the Remedial Investigation: Landfill Gas

To investigate the potential for off-site landfill gas migration, two types of testing were performed during the time period of October 1991 through January 1993. The first involved the installation and sampling of landfill gas probes along the perimeter of the YCLF. The second involved air monitoring in basements of buildings adjacent to the YCLF. Seventeen landfill gas probes were installed and sampled. The gas analysis consisted of measurements with three field instruments: a combustible gas indicator (CGI), a flame ionization detector (FID), and a photoionization detector (PID).

The CGI data (expressed as a percentage of the lower explosive limit) are most relevant for a fire or explosion risk assessment. Six of the seventeen probes tested at 100% of the lower explosive limit (LEL): LFG-202, LFG-203, LFG-217, LFG-218, LFG-222 and LFG-223. Two of the remaining probes had elevated CGI readings (from 5% to 48%), and the remaining probes had

negligible readings (less than 2%). Most probes had been sampled three times (June and September 1992 and January 1993). Five of the probes which tested at 100% LEL were along the northeastern boundary of the YCLF, and one was on the western boundary. Gas sampling has confirmed that the primary flammable constituent in the landfill gas is methane.

Twenty-seven buildings were selected for basement air monitoring due to their proximity to the landfill gas probes with high CGI levels. Seven of these buildings were eliminated because they did not have basements or crawlspaces. The monitoring was conducted with a CGI, FID and PID. Most of the measurements were conducted in October 1992. When monitoring revealed evidence of landfill gas emissions in the 1401-1451 West Golf Road basements, an additional four buildings adjacent to the subject address were monitored. Of all 24 buildings monitored, only the subject basements revealed evidence of landfill gas emissions. These gas emission locations were in floor cracks, drains and sumps.

Description of the AEVS and the Basement Monitoring Program

The AEVS provides forced ventilation to each of the six subject basements. A single positive pressure blower provides fresh air to each basement via the PVC ductwork. A negative pressure exhaust fan is located in each basement to provide the exhaust air flow. The inflow and outflow rates are tuned periodically. The most recent performance tuning record is the Air Con letter dated January 28, 1998, which is included in the Appendix. Typically, the ventilation is adjusted to maintain an exchange rate of two room volumes per hour for each basement.

The AEVS operates continuously on a 24-hour basis. The system went into operation in June of 1994. The AEVS is inspected monthly and corrective actions are implemented as needed. These routine activities are documented monthly. An alarm system alerts the maintenance contractor if a mechanical malfunction develops. A record of such service calls is included in the monthly reports to USEPA.

A basement air monitoring program has been in place since August 1994. The monitoring has been based on two field measurement instruments, a CGI and an FID, for most of this program. However, since January 1998, additional field instrumentation has been used in this program for the analysis of methane, hydrogen sulfide, oxygen and carbon dioxide.

ENGINEERING ANALYSIS

The basement air monitoring data is the foundation for the assessment of risk due to fire or explosion. The large quantity of data available on this project makes the risk assessment a straightforward process. The analysis of this data set consisted of two tasks:

- Data quality assessment
- Evaluation of the AEVS effectiveness

The results of this analysis are the inputs to the risk assessment

Data Quality Assessment

The first step in the analysis is to assess the quality of the data which will form the basis for a risk management decision. The objective of the monitoring program is to obtain field observations on a regular basis which will indicate the absence or presence of a fire/explosion risk. The field observations which are relevant to assessing the risk to fire or explosion are the CGI measurements. The CGI is a recognized method for measuring flammable gas concentrations and has a sensitivity which enables it to detect flammable gas at levels as low as 1% LEL. Throughout the monitoring program, the CGI equipment used at YCLF has been routinely calibrated against both known standards and background. The CGI measurements have been obtained in a comparable manner using accepted practices. Thus, the CGI data set meets or exceeds the data quality objectives for this risk assessment.

The data set examined comes from 113 monitoring events starting August 18, 1994, and ending March 4, 1998, a period of 43 months. The frequency of monitoring events is as follows:

- Events 1-45: weekly monitoring (8/18/94 to 6/23/95)
- Events 46-73: monthly monitoring (7/14/95 to 1/14/98)
- Events 74-113: daily monitoring (1/19/98 to 3/4/98)

There are 6,515 CGI measurements in this data set. Two types of measurements have been taken. One set consists of measurements taken near known or suspected emission locations, and the other set consists of measurements taken in the breathing zone. The specific number of monitoring locations in each basement has evolved over the monitoring program. Typically, the number of monitoring locations has ranged from 51 to 67, or approximately 8 to 11 locations per basement. The distribution of monitoring data by location is:

- Source measurements = 2,938
- Breathing zone measurements = 2,899
- Background measurements = 678

For the purposes of fire and explosion safety, a significant CGI measurement at known or suspected emission locations is defined as 100% LEL. This is because an emission of less than LEL is incapable of supporting combustion. The history of detections at any given location is highly variable and appears to be more dependent on changing weather conditions than AEVS operation. There have been 102 significant detections compared to 2,938 source measurements (approximately 3.5%). Two basements, #1425 and #1451, are responsible for 85% of these detections. The occurrence of these significant detections is almost randomly distributed throughout the monitoring period.

For the purposes of fire and explosion safety, a significant CGI measurement in the breathing zone is 25% LEL or greater. The criterion of 25% LEL represents the safe upper limit of the flammable gas concentration. This criterion is based on A Standard for Explosion Protection, 1992 Edition (NFPA 69), published by the National Fire Protection Association (NFPA). A copy of this standard is included in the Appendix.

During the 3½ year monitoring period, there have been zero exceedances of the 25% LEL criterion out of 2,899 breathing zone measurements. There have been only 74 detections in the breathing zone (approximately 2.6% of the 2,899 measurements) and all of these have been below the safe upper limit of 25% LEL. The highest breathing zone measurement obtained thus far was 8% LEL on January 31, 1995, in #1425. This is significantly below the safe upper limit of 25% LEL. The basement air monitoring program has demonstrated that the risk of a fire or explosion is not imminent.

Evaluation of the AEVS Effectiveness

In the Operation and Maintenance Plan, it is stated that the AEVS was designed to satisfy two objectives:

- Provide for continuous purging of landfill gas emissions into the basements
- Maintain a positive pressure differential to limit landfill gas emissions entering the basements

The first objective has been satisfied. With the most recent performance tuning, each basement is ventilated with 1.95 to 3.65 exchanges per hour. The flow rate of pure methane required to achieve LEL in a typical basement with two air exchanges per hour is 26.3 standard cubic feet per minute (scfm). The calculations are included in the Appendix. This flow rate is 53% of the total methane gas production rate from the YCLF. This means that at least 53% of the total methane produced by YCLF would have to find its way into a single basement to create an explosive atmosphere. This worst case scenario is an extremely unlikely event. Thus with the AEVS operating, the risk of an explosion is extremely improbable because the LEL cannot be attained.

The second objective has not been consistently satisfied in all basements. This inference is based on the assumption that the results of the smoke gun tests are truly indicative of pressurization. From the perspective of fire and explosion safety, the positive pressure differential objective is a superfluous requirement which probably cannot be attained. The intent of the positive pressure requirement was to reduce (or eliminate) the flow rate of landfill gas emissions. This was to be accomplished by forcing ventilation air through the emission locations (floor cracks, drains and sumps). A flowing fluid, however, takes the path of least resistance. With the benefit of 3½ years operating experience with the AEVS, it has been learned that the emission locations have a greater hydraulic resistance than other openings in the basements such as flues, exhaust pipes and other unsealed openings. Thus, the ventilation air escapes through the openings which offer the least resistance instead of the emission locations.

Another strategy to limit emissions has been to block off the flow path. Although cracks can be sealed and drains can be plugged, it is likely that the gas pressure in the soil would build up to the point that a new point of entry into the basement would be found. Since the AEVS can easily ventilate the basements and keep the landfill gas below LEL, there is a strong argument for monitoring the known source locations without altering them and possibly creating new ones.

RISK ASSESSMENT OF A FIRE OR EXPLOSION

There is an important distinction between hazard and risk. In the context of safety engineering, hazard is defined as the potential to cause death, injury or property damage. For example, a mixture of methane and air in the flammable concentration range is a hazard. Risk is defined as a measure of both the hazard of a condition and its likelihood. In the subject basements, the fundamental question is to determine the likelihood of forming a flammable mixture. Since the primary flammable constituent in landfill gas is methane, the discussion below specifically relates to methane.

Following the AIChE guidance on risk analysis for fires and explosions, the entire range of possible accident scenarios for a flammable gas can be represented by a diagram called an event tree (see the figure in the Appendix). There are ten scenarios considered in this diagram, but only two of them apply to a release of methane. Both scenarios assume a continuous release of methane (as opposed to an instantaneous release). The primary distinction between the two scenarios is based on the ignition timing, either immediate or delayed.

For the case of immediate ignition, a jet flame forms at the point of gas emission into the room. Based on the monitoring results, it is concluded that a jet flame cannot form at any of the observed source locations because the emission flow rate is too small. The evidence for this is the following observation: sources which measure 100% LEL at the surface will typically measure 0% LEL three inches above the surface. This indicates extremely low flow rates.

For the case of delayed ignition, a potentially flammable gas cloud forms in the room. Ignition of a flammable gas cloud would result in an explosion and flash fire. Mixing calculations show that if the AEVS is operating, the LEL can only be achieved if at least 53% of the entire landfill gas production from YCLF is directed into a single basement. This is an extremely improbable worst case scenario.

The basement monitoring data indicate that flammable gas concentration has never attained 25% LEL, which is the safe upper limit recommended by NFPA 69. The reasonableness of this safe upper limit is demonstrated by the fact that a similar limit, 20% LEL, is suggested by another standard, the Standard for Gas Transmission and Distribution Piping Systems (B31.8), 1995 Edition published by the American Society of Mechanical Engineers (ASME). The subject

basements have not exceeded either of these safe limits in 3 ½ years. Out of 2,899 CGI measurements, there have been only 74 detections and all of these have been below 20% LEL. In fact, the highest CGI measurement ever recorded during the monitoring program was 8% LEL. Thus the monitoring data support the conclusion that the risk of a fire or explosion is essentially zero with the AEVS in operation.

CONCLUSIONS

The principal hazard of landfill gas migration into the subject basements is a fire or explosion. As an interim action the Yeoman Creek Technical and Steering Committees implemented both an administrative control, the basement air monitoring program, and an engineering control, the AEVS. During the 3½ years of monitoring and AEVS operation, there has never been a CGI measurement which has exceeded 25% LEL in the breathing zone, the safe upper limit specified by NFPA 69. In other words, there have been zero exceedances of the safe upper limit out of 2,899 measurements taken during 113 monitoring events. Packer Engineering concludes that there is no imminent threat of fire or explosion in the subject basements provided that a monitoring program continues and the AEVS remains in operation.

PACKER ENGINEERING, INC.

Report prepared by:

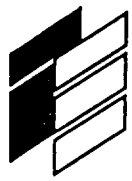
Russell A. Ogle

Russell A. Ogle, Ph.D., P.E.
Director of Chemical Engineering

Reviewed by:

John L. Schumacher

John L. Schumacher, P.E.
Staff Chemical Engineer

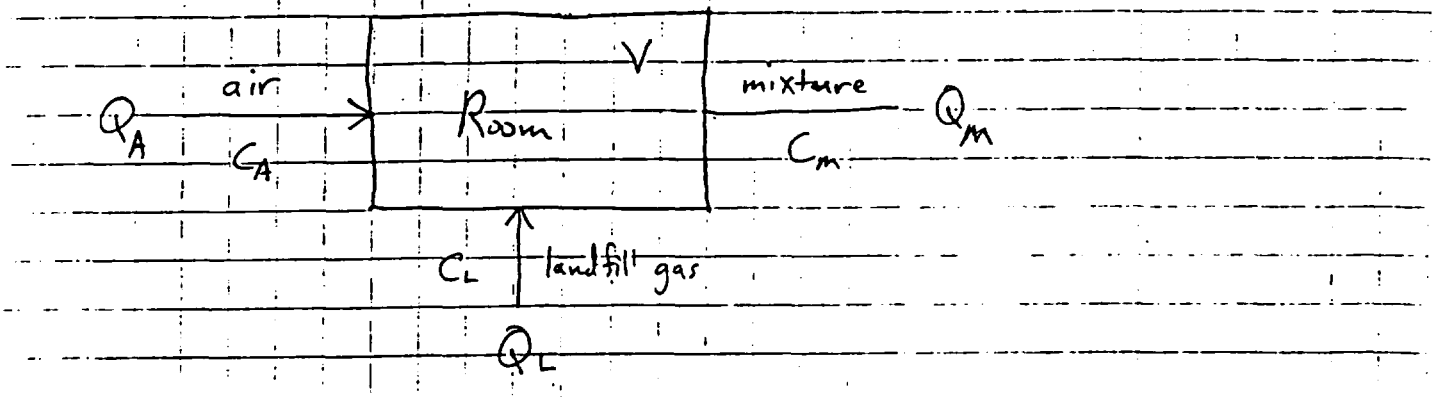


APPENDIX

PACKER ENGINEERING INC

File No. Yeoman Creek LF By RAO
Title Steady State Mixing Checked By JCS
Date 3/16/98 Page 1 of 2

① Problem: All LFG leaks into one room. Find final fuel concentration, C_m.



Mass Balances (volume basis, standard conditions, steady state)

Total: $Q_A + Q_L = Q_m$ (Q_i = volume flow rate) (1)

Methane: $C_A Q_A + C_L Q_L = C_m Q_m$ (C_i = mol fraction) (2)

Assume $C_A = 0$; Then (2) yields $C_L Q_L = C_m Q_m$

Solving for C_m: $\boxed{C_m = C_L (Q_L / Q_m)}$ (3)

Substitute (1) for Q_m into (3):

$$\boxed{C_m = C_L \left(\frac{Q_L}{Q_A + Q_L} \right)} \quad (4)$$

Note that the mixture concentration is a function of both the leak flow rate and the fresh air flow rate.

PACKER ENGINEERING, INC

File No. _____ By RAD

Title _____ Checked By JLS

Date _____ Page 2 of 2

(2) Find the LFG flow rate required to achieve C_M = LEL

Assume Q_A = 5001 scfm, C_L = 100% methane (worst case)

Write Q_L as a fraction of Q_A: $Q_L = \alpha Q_A$

$$C_M = C_L\left(\frac{Q_L}{Q_A+Q_L}\right) = (1)\left(\frac{\alpha Q_A}{Q_A+\alpha Q_A}\right) = \frac{\alpha}{1+\alpha}$$

$C_M(1+\alpha) = \alpha$, $C_M + \alpha C_M = \alpha$, $C_M = (1-C_M)\alpha$

$$\alpha = \frac{C_M}{1-C_M} \quad (5)$$

For C_M = 0.05 (LEL methane), α = 0.0526

$$\alpha = \frac{0.05}{1-0.05} = 0.0526$$

If the LFG is pure methane, the LFG flow rate must equal 5.26% of the fresh air flow rate in order to achieve LEL in the room.

(3) Compare the LFG flow rate to YCLF methane production (50 scfm):

For Q_A = 500 scfm, Q_L = 0.0526 Q_A = 26.3 scfm,

AIR CONDITIONING • VENTILATION • HEATING • PROCESS PIPING • REFRIGERATION

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WAUKEGAN, ILLINOIS 60085-6599

January 28, 1998

DeMaximis, Inc.
4155 El Camino Way
Palo Alto, CA 94306

Attn: Robin Robinson

Re: Yeoman Creek/Edward Field Landfill

Per your request, in addition to the routine maintenance for January 1998 we have also performed additional performance tuning to verify air quantities are within design requirements. The following is a schedule indicating our results.

Location	Area	Specified CFM	Actual CFM	Air Changes Per Hour	Notes
1401	1830 Sq. Ft.	OA 900	928	3.65	
		EXH 400	405	1.59	
1407/1413	1830 Sq. Ft.	OA 500	508	2.00	
		EXH 400	405	1.59	
1415/1419	1740 /Sq. Ft.	OA 500	496	2.05	
		EXH 400	415	1.71	
1423/1425	1830 Sq. Ft.	OA 500	496	1.95	
		EXH 400	400	1.57	
1431	1830 Sq. Ft.	OA 500	514	2.02	
		EXH 400	392	1.54	
1451	2990 Sq. Ft.	OA Max	1358	3.27	
		EXH 400	405	0.97	

As you can see from above air measurements, the AEVS system is providing more supply (outdoor air) to each basement than it is exhausting. Existing building systems such as boiler flues, domestic heater flues, dryer exhaust, kitchen exhaust, toilet exhaust, air handlers and unsealed openings provide additional ventilation affecting space pressurization.

If you have any questions, please call.

Keith Larsen

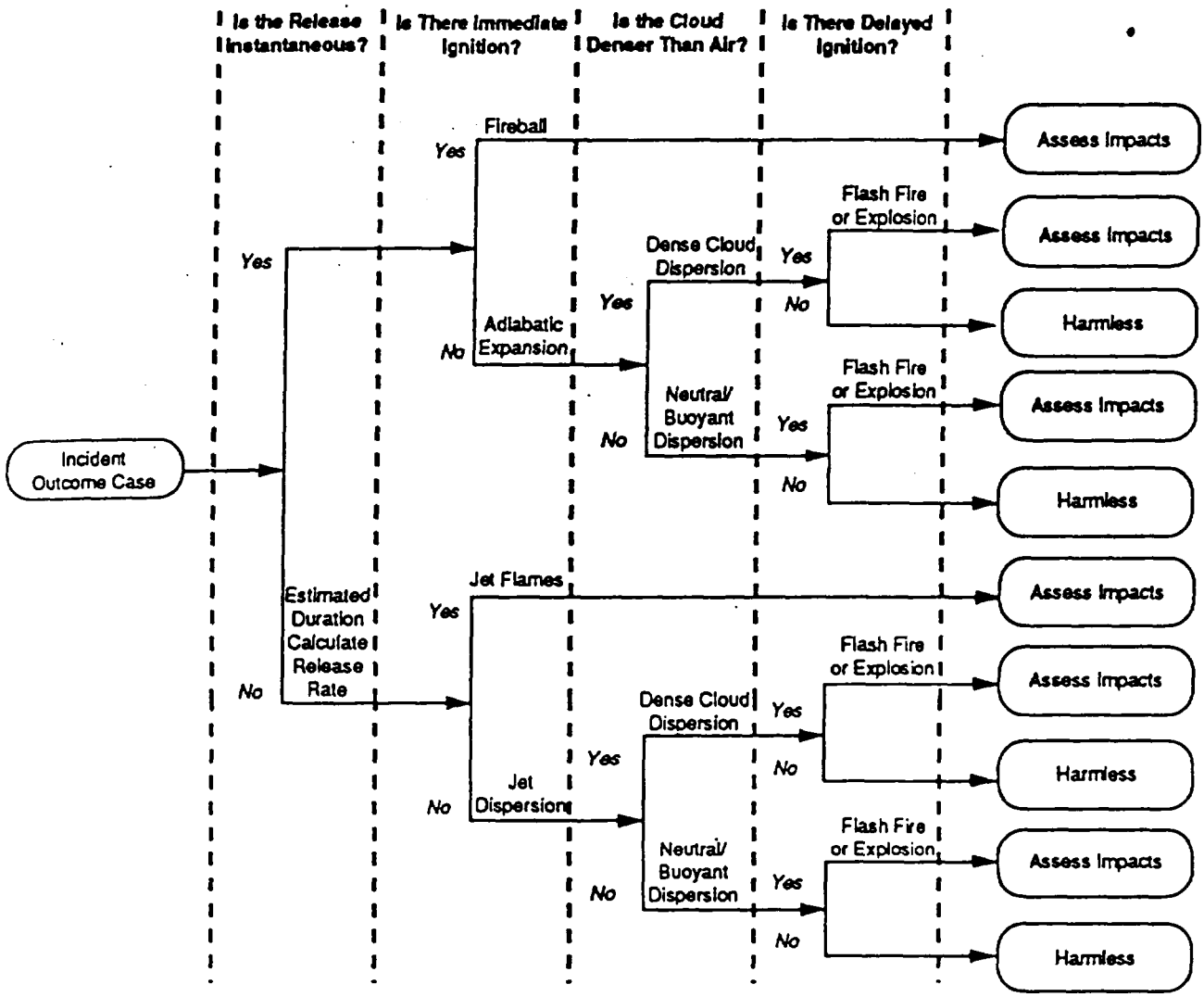

Figure 1.11. Spill event tree for a flammable gas release.

concentrations selected rather than developing complete cloud profiles, and a directional incident outcome assumed rather than study an omnidirectional incident. Each decision removes a multiplier from the number of cases to be studied.

It is the analyst's responsibility to ensure that sufficient definition results from the number of incident outcome cases specified to achieve study objectives. Decisions made concerning parameter selection and the range of values to be studied within each parameter need to be challenged through peer review and documented. Likewise the perceived importance of such parameters and their values can and should be checked through sensitivity studies following the

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NFPA 69

Standard on

Explosion Prevention Systems

1992 Edition

This edition of NFPA 69, *Standard on Explosion Prevention Systems*, was prepared by the Technical Committee on Explosion Protection Systems and acted on by the National Fire Protection Association, Inc. at its Fall Meeting held November 18-20, 1991 in Montréal, Québec, Canada. It was issued by the Standards Council on January 17, 1992, with an effective date of February 10, 1992, and supersedes all previous editions.

The 1992 edition of this document has been approved by the American National Standards Institute.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

Origin and Development of NFPA 69

In 1965, an NFPA Committee was appointed to develop standards for explosion protection systems. These standards would include information on inerting to prevent explosions and venting to minimize damage from an explosion.

A tentative draft on explosion prevention systems was presented at the NFPA Annual Meeting in New York City in May 1969. This tentative document was officially adopted in May 1970. NFPA 69 was revised in 1973 and reconfirmed in 1978.

In 1982, the Committee on Explosion Protection Systems began a thorough review of NFPA 69, including the development of a chapter on the technique of deflagration pressure containment. The results of that effort became the 1986 edition.

This 1992 edition of NFPA 69 incorporates a new chapter on deflagration isolation systems including such techniques as flame arresters, fast-acting valves, and liquid seals. Partial amendments were made to several sections of the standard including: refining certain essential definitions; improving the description of oxidant concentration reduction technique and its instrumentation requirement; fine-tuning the deflagration suppression technique; and fine-tuning the deflagration pressure containment technique.

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NOTE: Membership on a Committee shall not in and of itself constitute an endorsement of the Association or any document developed by the Committee on which the member serves.

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NFPA 69

Standard on

Explosion Prevention Systems

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates explanatory material on that paragraph in Appendix A.

Information on referenced publications can be found in Chapter 8 and Appendix E.

Chapter 1 General

1-1 Scope.

1-1.1 This standard shall apply to the design, construction, operation, maintenance, and testing of systems for the prevention of deflagration explosions by means of the following methods:

(a) Control of oxidant concentration;

(b) Control of combustible concentration;

(c) Explosion suppression;

(d) Deflagration pressure containment;

(e) Spark extinguishing systems.

1-1.2 This standard shall not apply to devices or systems designed to protect against overpressure due to phenomena other than internal deflagrations.

1-1.3* This standard shall not apply to the design, construction, and installation of deflagration vents.

1-1.4 This standard shall not apply to:

(a) The preparation of tanks, piping, or other enclosures for hot work, such as cutting and welding (*see NFPA 327, Standard Procedures for Cleaning or Safeguarding Small Tanks and Containers*);

(b) The general use of inert gas for fire extinguishment;

(c) Rock dusting of coal mines, as covered by Title 30, *Code of Federal Regulations*, Part 75;

(d) Unconfined deflagrations, such as open-air or vapor cloud explosions.

1-1.5 This standard shall not apply to ovens or furnaces handling flammable or combustible atmospheres, as covered by NFPA 86, *Standard for Ovens and Furnaces*; NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*; and NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*.

1-1.6 Nothing in this standard is intended to preclude the use of new technologies that meet the intent of this standard and provide reliable service.

1-2 Purpose. This standard outlines the minimum requirements for installing systems for the prevention of explosions of enclosures that contain flammable concentrations of combustible gases, vapors, mists, dusts, or hybrid mixtures. Basic information is provided for design engineers, operating personnel, and authorities having jurisdiction.

1-3* Techniques. Five techniques are recognized in this standard and they are grouped into two classes. One class is based on preventing combustion; the other is based on preventing or limiting damage after combustion occurs.

1-3.1 Methods Based on Preventing Combustion:

(a) Oxidant concentration reduction;

(b) Combustible concentration reduction.

1-3.2 Methods Based on Limiting or Preventing Damage:

(a) Explosion suppression;

(b) Deflagration pressure containment;

(c) Spark extinguishing systems.

1-4 Limitations. The limitations specific to each method are addressed in the chapter on that method.

1-5 Factors to Be Considered. The following factors shall be considered in the selection of one of the methods and the design of the system:

(a) Effectiveness of each method;

(b) Reliability of the system;

(c) Personnel hazards inherent in each method.

1-5.1 The reliability of the system chosen shall be assessed on the system's design basis; the possibility of electrical and mechanical malfunction; dependence on sophisticated activating systems; and the need for special installation, training, operating, and maintenance procedures.

1-5.2 In general, explosion prevention systems are used to protect processing, storage, and materials handling equipment. When explosion prevention techniques are applied to rooms, buildings, or other enclosures where personnel may be present, consideration shall be given to the safety of the personnel.

1-6 Plans.

1-6.1 Plans and system specifications shall be reviewed by the authority having jurisdiction.

1-6.2 Plans shall contain sufficient detail to enable the authority having jurisdiction to evaluate the explosion hazard and the effectiveness of the system. Details shall include pertinent chemical and physical characteristics of the materials involved, location of hazards, the enclosures or limits and isolation of the hazards, and exposures to the hazards.

1-7 Approval of Installations. The complete system shall be tested in accordance with the requirements of the authority having jurisdiction.

1-8* Inspection and Maintenance.

1-8.1 All systems shall be thoroughly inspected for proper operation. A suitable inspection and preventive maintenance schedule shall be established.

1-8.2 Analyzers and other system instrumentation can require more frequent periodic inspection than that required for other components of the system. Such tests shall be made according to manufacturer's recommendations or as required by operating conditions.

1-9 Definitions. For the purpose of this standard, the following terms shall have the meanings given below.

Approved.* Acceptable to the "authority having jurisdiction."

Authority Having Jurisdiction.* The "authority having jurisdiction" is the organization, office or individual responsible for "approving" equipment, an installation or a procedure.

Blanketing (or Padding). The technique of maintaining an atmosphere that is either inert or fuel-enriched in the vapor space of a container or vessel.

Combustible. Capable of undergoing combustion.

Combustible Concentration Reduction. The technique of maintaining the concentration of combustible material in a closed space below the lower flammable limit.

Combustible Dust. Any finely divided solid material, 420 microns or less in diameter (i.e., material passing through a U.S. No. 40 standard sieve), that presents a fire or explosion hazard when dispersed and ignited in air or other gaseous oxidizer.

Combustion. A chemical process of oxidation that occurs at a rate fast enough to produce heat and usually light, in the form of either a glow or flames.

Deflagration. Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium.

Deflagration Pressure Containment. The technique of designing a vessel and its auxiliary equipment so that it can withstand the pressures resulting from a deflagration originating within the vessel.

Detonation. Propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium.

Explosion. The bursting or rupture of an enclosure or a container due to the development of internal pressure from a deflagration.

Explosion Suppression. The technique of detecting and arresting combustion in a confined space while the combustion is still in its incipient stage, thus preventing the development of pressures that could result in an explosion.

Flammable Limits. The minimum and maximum concentrations of a combustible material in a homogeneous mixture with a gaseous oxidizer that will propagate a flame. (*See NFPA 325M, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*)

Flammable Range. The range of concentrations between the lower and upper flammable limits.

Gas. The state of matter characterized by complete molecular mobility and unlimited expansion. Used synonymously with the term "vapor."

Hybrid Mixture. A mixture of a combustible gas with either a combustible dust or combustible mist.

Inert Gas. A noncombustible, nonreactive gas that renders the combustible material in a system incapable of supporting combustion.

Inerting. A technique by which a combustible mixture is rendered nonignitable by addition of an inert gas. (*See also Blanketing.*)

Labeled. Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Limiting Oxidant Concentration (LOC). The concentration of oxidant below which a deflagration cannot occur. Materials other than oxygen can act as oxidants.

Listed.* Equipment or materials included in a list published by an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

Mist. A dispersion of fine liquid droplets in a gaseous medium.

Oxidant. Any gaseous material that can react with a fuel (either gas, dust, or mist) to produce combustion. Oxygen in air is the most common oxidant.

Oxidant Concentration Reduction. The technique of maintaining the concentration of the oxidant in a closed space below the concentration required for ignition to occur.

Padding. (*See Blanketing.*)

Purge Gas. A gas that is continuously or intermittently added to a system to render the atmosphere nonignitable. The purge gas may be inert or combustible. (*See Chapter 2.*)

Shall. Indicates a mandatory requirement.

Should. Indicates a recommendation or that which is advised but not required.

Spark Extinguishing System. A technique by which the radiant energy of a spark or an ember is detected and the spark or ember is quenched.

Suppressant. The chemical agent used in an explosion suppression system to extinguish the incipient explosion.

Vapor. *(See Gas.)*

Ventilation. The process of supplying or removing an atmosphere to or from any space by natural or mechanical means.

Chapter 2 Oxidant Concentration Reduction

2-1 Application.

2-1.1* The technique for oxidant concentration reduction for deflagration prevention can be considered for application to any system where a mixture of oxidant and combustible material is confined to an enclosure within which the oxidant concentration can be controlled. The system shall be maintained at an oxidant concentration low enough to prevent a deflagration. [*See Appendix B for a discussion of the control of combustible gas mixtures. Also, see Appendix C for limiting oxidant concentrations (LOC).*]

2-1.2 Oxidant concentration reduction can be applied to rooms or buildings. However, since oxygen-deficient atmospheres cannot sustain life, operations in such areas shall be remotely controlled or operating personnel shall be provided with breathing apparatus, as well as other safeguards.

2-2 Design and Operating Requirements.

2-2.1* The following factors shall be considered in the design of a system to reduce the oxidant concentration:

(a) Required reduction in oxidant concentration;

(b) Variations in the process, process temperature and pressure, and materials being processed;

(c) Gas supply source and equipment installation;

(d) Compatibility of the purge gas with the process;

(e) Operating controls;

(f) Maintenance, inspection, and testing;

(g) Leakage of purge gas to surrounding areas;

(h) Need for breathing apparatus by personnel.

2-2.2 Appendix C lists limiting oxidant concentrations to prevent deflagration of combustible gases or suspensions of combustible dusts for several materials where oxygen is the only oxidant. The values were obtained during tests conducted at atmospheric pressure and room temperatures, using spark or pilot ignition sources. Higher energy ignition sources, higher temperatures, or higher pressures can reduce the LOC values shown. The extent of oxygen reduction shall be determined by testing where conditions vary significantly from standard conditions.

2-2.3 Where a purge gas system is used for lines collecting ignitible gas or vapor mixtures and where the collection system terminates at a flare or incinerator, an additional backflash prevention or protection system shall be installed. Hard piped vapor control systems do not generally require flame arresters at each source connection to the system, provided the system is designed to operate outside the flammable range. Systems requiring hook-ups prior to vapor transfer, such as vapor collection from mobile vehicles, shall be purged to a safe level below the LOC prior to transfer, or backflash protection shall be provided near the point of connection. Caution shall be exercised for those inerted systems that might form pyrophoric iron sulfide when allowing air to enter such systems.

2-3 Purge Gas Sources.

2-3.1 The purge gas shall be obtained from a reliable source that is capable of continuously supplying the required amount of purge gas to maintain the necessary degree of oxidant deficiency. Possible sources include, but are not limited to, the following:

(a) Commercially available inert gas, such as nitrogen, carbon dioxide, argon, or helium, supplied from high pressure tanks or cylinders or from air separation plants;

(b) Inert gas supplied from a gas generator that burns or catalytically oxidizes a hydrocarbon to produce an oxygen-deficient purge gas;

(c) The products of combustion from process furnaces or boiler furnaces; purification or cooling can be necessary to avoid contamination;

(d) Steam, if it can be supplied at a rate sufficient to raise and maintain the protected vessel or system at a high enough temperature to prevent condensation of the steam;

(e) High purity nitrogen supplied by air oxidation of ammonia;

(f) Inert gas supplied by removal of oxygen from air by absorption, adsorption, chemical reaction, or membrane permeation;

(g) Fuel gases such as methane or natural gas.

2-3.2 The purge gas supply shall have the capacity to meet total projected system requirements.

2-3.3 Electrical power and fuel supplies for purge gas generating systems shall be designed to minimize outages.

2-4 Gas Conditioning.

2-4.1 Purge gas shall be conditioned to minimize contaminants that might be harmful to the gas distribution system or to the product or material being protected.

2-4.1.1 Where flue gas is used as a purge gas, entrained dust, soot, or other foreign particles shall be removed if they can interfere with the operation of the system.

2-4.1.2 Before introduction, the purge gas shall be at a temperature compatible with the process being protected. This will minimize the chance of thermal ignition or condensation.

2-4.1.3 Purge gas that is distributed in a system subject to freezing temperatures shall have a dew point such that water will not condense out at the minimum ambient temperature to which the system will be exposed.

2-5 Piping Systems.

2-5.1 Purge gas distribution systems shall be designed and installed in accordance with recognized engineering practices. Where purge gas pressure exceeds 15 psig (103 kPa gage), the piping system shall be designed according to ANSI/ASME B31.3, *Chemical Plant and Petroleum Refinery Piping Code*.

2-5.2 Where necessary, piping systems shall be provided with filters, screens, or other means of preventing foreign material from entering critical parts of the system, such as pressure regulators, valves, and instrumentation.

2-5.3 Where necessary, moisture traps shall be provided and lines shall drain toward the traps. Adequate blowdown connections shall be provided. Moisture traps shall be protected from freezing.

2-5.4 When flue gas or combustion gas is used, suitable means shall be provided to prevent propagation of flame into the system being protected.

2-5.5* Manual shutoff valves shall be provided at each major division point in the distribution system.

2-5.6 The inert gas distribution system shall be designed to prevent contamination by hazardous process materials.

2-5.6.1 Where necessary, check valves or other design features shall be incorporated to prevent the potential for contamination either because of loss of purge gas supply or because of excessive pressure in the process unit being protected.

2-5.6.2 A single check valve shall not be considered a positive backflow connection.

2-5.7* Cross connections between the purge gas distribution system and any other system shall be prohibited unless positive measures are taken to prevent backflow from the other system into the purge gas system.

Exception: Cross connections to backup purge gas systems shall be permitted without backflow prevention unless backflow could create a hazard.

2-5.8 The entire distribution system shall be cleaned and functionally tested prior to being placed in service.

2-5.9 The gases from an enclosure or vessel being purged shall be vented to a safe location.

2-6* Application of Purge Gas at Points of Use.

2-6.1 Purge gas shall be introduced and exhausted so that effective distribution is ensured and the desired oxidant concentration reduction is maintained throughout the system being protected. Multiple inlets and outlets shall be permitted.

2-6.2 Connections between the purge gas distribution piping and the protected enclosure or system shall be designed for maximum purge gas pressure.

2-7 Instrumentation.

2-7.1 Suitable instrumentation shall be provided to monitor the purge gas being supplied to the distribution system.

2-7.2 Instrumentation shall be installed at as many points as necessary to ensure the desired oxidant concentration reduction within the protected system. A safety margin shall be maintained between the LOC and the normal working concentration in the system. The safety margin shall take into account the fluctuations occurring in the system, the sensitivity and reliability of monitoring and control equipment, and the probability and consequences of an explosion.

2-7.2.1 Where the oxygen concentration is continuously monitored, a safety margin of at least 2 volume percent below the LOC shall be maintained unless the LOC is less than 5 percent, in which case the equipment shall be operated at no more than 60 percent of the LOC.

Exception: This requirement does not apply to partial oxidation processes.

2-7.2.2 Where the oxygen concentration is not continuously monitored, the oxygen concentration shall be designed to operate at no more than 60 percent of the LOC, or 40 percent of the LOC if the LOC is below 5 percent. If the oxygen concentration is not continuously monitored, the oxygen concentration shall be checked on a regularly scheduled basis.

Exception: Low pressure field storage tanks that have inert padding do not generally require checking of the oxygen concentration of the vapor space.

2-7.3 Instrumentation shall be properly calibrated at scheduled intervals.

2-7.4 When conditions being measured are critical to safety of personnel, suitable alarms shall be provided to indicate abnormal operation of the system.

Chapter 3 Combustible Concentration Reduction

3-1 Application. The technique of combustible concentration reduction can be considered for application to any system where a mixture of a combustible material and an oxidant is confined to an enclosure and where the concentration of the combustible can be maintained below the lower flammable limit. (*See Appendix B for a discussion of the control of combustible gas mixtures. Also, see Appendix D for information on calculating the time required for ventilation.*)

3-2 Basic Design Considerations. The following factors shall be considered in the design of a system to reduce the combustible concentration below the lower flammable limit:

(a) Required reduction in combustible concentration;

(b) Variations in the process, process temperature and pressure, and materials being processed;

(c) Operating controls;

(d) Maintenance, inspection, and testing.

3-2.1 The lower flammable limits of the combustible components shall be determined at all operating conditions, including startup and shutdown. (*See NFPA 325M, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*)

3-3 Design and Operating Requirements.

3-3.1 The combustible concentration shall be maintained at or below 25 percent of the lower flammable limit.

Exception: When automatic instrumentation with safety interlocks is provided, the combustible concentration shall be permitted to be maintained at or below 60 percent of the lower flammable limit.

3-3.2* When catalytic oxidation is used for combustible concentration reduction, flame arresters shall be provided in all inlets to the catalytic oxidation unit. These flame arresters shall be periodically inspected and properly maintained.

3-3.3 Ventilation or Air Dilution.

3-3.3.1 If ventilation is used, the outlets from the protected equipment shall be located so that hazardous concentrations of the exhausted air cannot enter or be drawn into fresh air intakes of environmental air handling systems.

3-3.3.2 Air intakes shall be located so that combustible material cannot enter the system even in the event of spills or leaks.

3-3.3.3 Filters, driers, or precipitators in the air intakes shall be located so that they are accessible for cleaning and maintenance.

3-4 Instrumentation.

3-4.1 Suitable instrumentation shall be provided to monitor the control of the concentration of combustible components.

3-4.2 At scheduled intervals instrumentation shall be properly calibrated.

3-4.3 Where the system being protected presents a personnel hazard, alarms shall be provided to indicate abnormal operation of the system.

Chapter 4 Deflagration Suppression

4-1 Application.

4-1.1 The technique of deflagration suppression shall be permitted to be considered for any enclosure in which combustible gases, mists, or dusts are subject to deflagration in a gas phase oxidant.

4-1.2 Equipment that shall be permitted to be protected by a deflagration suppression system includes but is not limited to:

(a) Processing equipment, such as reactor vessels, mixers, blenders, pulverizers, mills, driers, ovens, filters, screens, and dust collectors;

(b) Storage equipment, such as atmospheric or low pressure tanks, pressure tanks, and mobile facilities;

(c) Material handling equipment, such as pneumatic and screw conveyors, and bucket elevators;

(d) Laboratory and pilot plant equipment, including hoods, glove boxes, test cells, and other equipment.

4-2 Limitations.

4-2.1 Deflagration suppression will be successful only where the suppressant can be effectively distributed.

4-2.2 Deflagration suppression is limited by the physical and chemical properties of the reactants in the system.

4-2.3 Deflagration suppression is applicable only to systems involving deflagrations that take place in a gas phase oxidant.

4-3 Personnel Safety.

4-3.1 The deflagration suppression system shall be disarmed prior to performing any maintenance operations on the protected equipment. Operation of the protected equipment shall be interlocked through the suppression system control panel so that operation cannot be resumed until the suppression system is rearmed.

4-3.2 Personnel shall be trained with regard to safety procedures to be carried out prior to and during maintenance.

4-4 Basic Design Considerations. The design of a deflagration suppression system shall include but shall not necessarily be limited to:

(a) Deflagration characteristics of the combustible material;

(b) Equipment to be protected;

(c) Detection technique;

(d) Suppressant;

(e) Installation, operation, and test procedures.

4-4.1 A thorough analysis of the hazard shall be conducted to determine the type and degree of deflagration hazard inherent in the process. Such factors as type of combustible, combustible-to-oxidant ratio, total volume to be protected, operating conditions, etc., shall be reviewed in detail. Possible malfunctions that can affect the extent of the deflagration hazard shall also be determined.

4-4.2 Discharge of the deflagration suppression system shall be permitted to also actuate other devices or systems, such as high speed isolation valves, rapid pneumatic conveying system shutdowns, or deflagration vents.

4-5 Detectors.

4-5.1 The deflagration shall be detected by sensing either the pressure increase or the radiant energy from the combustion process.

4-5.2 Detectors that respond to radiant energy shall be used for systems open to the atmosphere.

4-5.3 Provisions shall be made to prevent obscuration of radiant energy detectors.

4-5.4 Detectors shall be protected from the accumulation of foreign material that would prevent functioning.

4-5.5 Detection circuits shall be continuously supervised. The supervisory system shall produce an alarm in the event of failure of the detection circuits.

4-6 Electrically Fired Initiators.

4-6.1 Electrically fired initiators shall be used to release the suppressant.

4-6.2 Initiators shall be mounted so that their maximum temperature rating is not exceeded.

4-6.3* The wiring circuits for the initiators shall be continuously supervised. The supervisory system shall produce an alarm in the event of loss of circuit continuity.

4-6.4 A reliable source of electrical energy shall be used so that the firing characteristics of the initiators do not deviate from the manufacturer's specifications.

4-7 Power Units.

4-7.1 A power unit with standby battery power backup shall be provided in each suppression system. It shall be capable of supplying sufficient energy to:

(a) Actuate all initiators;

(b) Energize visual and audible alarms.

4-7.2 The power unit shall meet applicable requirements of NFPA 70, *National Electrical Code*.®

4-7.3 Supervisory circuits shall be provided to detect open circuits or other faults. The supervisory circuits shall be interlocked with a visual trouble signal.

4-8* Suppressant.

4-8.1 The suppressant shall be compatible with the combustible material in the protected enclosure.

4-8.2 The suppressant shall operate at the expected extremes of temperature encountered in the protected enclosure.

4-9 Installation.

4-9.1 All components of the system shall be mounted in the location and in the manner specified by the system designer.

4-9.2 Detectors and suppressant discharge nozzles shall be mounted so that environmental- or vibration-induced malfunctions are minimized.

4-9.3 Suppressant discharge nozzles shall be mounted in such a way as to prevent damage or failure to any appurtenances or fixtures in the enclosure protected.

4-9.4 Suitable means shall be used to protect detectors and suppressant discharge devices from accumulating foreign material that would prevent functioning.

4-9.5 Terminals and mechanical parts shall be protected from moisture and other contaminants.

4-9.6 Mounting locations shall be chosen so as not to exceed maximum operating temperatures of system components.

4-10 Electrical.

4-10.1 All wiring to the suppression system and between components of the system shall be grounded and shall be isolated and shielded from all other wiring to prevent possible induced currents.

4-10.2 When environmental conditions warrant, conduits shall be sealed to prevent entrance of moisture and other contaminants.

4-10.3 When a conduit is used for wiring multiple installations, the wiring for each suppression system shall be run in separate conduits. Alternatively, each system shall be permitted to be wired with shielded cables run in common conduits.

4-11 Inspection and Maintenance.

4-11.1 Suppression systems shall be thoroughly inspected and tested at 3-month intervals by personnel trained by the system's manufacturer. Containers of suppressant shall be checked for leakage and the quantity of agent, and the container pressure of refillable containers shall be confirmed.

4-11.2 Any container shown to have suffered a net weight loss exceeding 5 percent or net pressure loss (adjusted for temperature) exceeding 10 percent shall be refilled or replaced.

4-11.3 In the event of system operation, all components shall be inspected, replacement parts installed if necessary, and the system tested prior to restoration to full operating condition.

Chapter 5 Deflagration Pressure Containment

5-1 General.

5-1.1 Deflagration pressure containment is a technique for specifying the design pressure of a vessel and its appurtenances so they are capable of withstanding the pressures resulting from an internal deflagration.

5-1.2 This chapter is limited to determining the vessel design pressure required to withstand the pressures resulting from an internal deflagration. This chapter is also limited to systems in which the oxidant is air.

5-1.3 The design pressure specified by this chapter shall be based on the most severe set of system conditions that can occur.

5-1.4 When deflagration pressure containment is applied to a vessel with attached equipment, the pressure loads imposed on the attached equipment can be equal to or greater than the pressure loads experienced by the protected vessel. Therefore, measures shall be taken to protect this attached equipment. Techniques such as isolation or venting shall be considered.

5-2 Design Limitations.

5-2.1* Deflagration pressure containment techniques shall not be applied to systems for the purpose of containing a detonation.

5-2.2* Deflagration pressure containment shall not be applied to vessels having a length-to-diameter (L/D) ratio greater than 5 unless appropriate test data are available.

5-2.3* Deflagration pressure containment shall not be applied to systems where two or more vessels are connected by large-diameter pipes or ducts, unless appropriate test data are available.

5-2.4* Deflagration pressure containment shall not be applied to any system where the initial pressure exceeds 30 psig (206.7 kPa gage) unless appropriate test data are available.

5-3 Design Bases.

5-3.1 Vessels designed for deflagration pressure containment shall be designed and constructed according to the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, which takes into consideration sources of overpressure other than deflagration.

5-3.2 The design pressure of the vessel, as calculated in 5-3.3, shall be based either on preventing rupture of the vessel (i.e., on the ultimate strength of the vessel) or on preventing permanent deformation of the vessel (i.e., on the yield strength of the vessel) from internal positive overpressure. Due to the vacuum that can follow a deflagration, all vessels whose deflagration pressure containment design is based on preventing deformation shall also be designed to withstand full vacuum.

5-3.3 The design pressure shall be calculated according to the following equations:

$$P_r = \frac{1.5\,[R(P_i + 14.7) - 14.7]}{F_u}$$

$$P_d = \frac{1.5\,[R(P_i + 14.7) - 14.7]}{F_y}$$

Where: P_r = the design pressure to prevent rupture due to internal deflagration, psig;
P_d = the design pressure to prevent deformation due to internal deflagration, psig;
P_i = the maximum initial pressure at which the combustible atmosphere exists, psig;
R = the ratio of the maximum deflagration pressure to the maximum initial pressure, as described in 5-3.3.1;
F_u = the ratio of the ultimate stress of the vessel to the allowable stress of the vessel;
F_y = the ratio of the yield stress of the vessel to the allowable stress of the vessel.

NOTE: 1 psi = 6.89 kPa.

5-3.3.1* The dimensionless ratio R is the ratio of the maximum deflagration pressure, in absolute pressure units, to the maximum initial pressure, in consistent absolute pressure units. As a practical design basis (since optimum conditions seldom exist in industrial equipment) for most gas/air mixtures, R shall be taken as 9; for organic dust/air mixtures, R shall be taken as 10. For St-3 dust/air mixtures, R shall be taken as 13.

Exception: A different value of R shall be permitted to be used if appropriate test data or calculations are available to confirm its suitability.

5-3.3.2 For operating temperatures below 25°C (77°F), the value of R shall be adjusted according to the following formula:

$$R' = R \times \left(\frac{298}{273 + Ti} \right)$$

where R is either 9.0 or 10.0 and Ti is the operating temperature in °C.

5-3.3.3 For vessels fabricated of low carbon steel and low alloy stainless steel $F_u = 4.0$ and $F_y = 2.0$.

5-3.4 The presence of any pressure relief device on the system shall not cause the design pressure calculated by 5-3.3 to be reduced.

5-3.5* For positive pressure systems handling gases and liquids, the maximum initial pressure, P_i, shall be the maximum pressure at which a combustible mixture can exist, but not higher than the setting of the pressure relief device plus its accumulation. For positive pressure systems handling dusts, this maximum initial pressure shall be the maximum possible discharge pressure of the compressor or blower that is suspending or transporting the material or the setting of the pressure relief device on the vessel being protected plus its accumulation, whichever is greater. For gravity discharge of dusts, the maximum initial pressure shall be taken as 0.0 psig (0.0 kPa gage).

5-3.6 For systems operating under vacuum, the maximum initial pressure shall be taken as no less than atmospheric pressure (0.0 psig or 0.0 kPa gage).

5-3.7 The vessel design pressure shall be based on the wall thickness of the vessel, neglecting any allowance for corrosion or erosion.

5-3.8 The design must take into consideration the minimum operating temperature at which a deflagration may occur. This minimum temperature must be compared with the temperature characteristics of the material of construction of the vessel to ensure that brittle fracture will not result from a deflagration.

5-3.9 Auxiliary equipment such as vent systems, manways, fittings, and other openings into the vessel shall be designed and inspected periodically to ensure integrity of the total system.

5-4 Maintenance. Relief devices shall be inspected periodically to ensure that they are not plugged, frozen, or corroded.

5-5 Vessel Appurtenances. Threaded fasteners on vessel appurtenances shall be inspected to ensure that design pressure ratings are maintained.

5-6 Inspection After a Deflagration. Any vessel designed to contain a deflagration that experiences a deflagration shall be thoroughly inspected to verify that the vessel is still serviceable for its intended use.

Chapter 6 Spark Extinguishing Systems

6-1 Application.

6-1.1 Spark extinguishing systems are for the detection and extinguishment of sparks or embers as they pass through ducts that transport combustible dusts or solids.

6-1.2 The system operates by means of detectors that sense the radiation of a hot or glowing particle and actuate a special extinguishing system that quenches the particle. Because the detection is by means of radiation, the spark detection systems shall not be used in duct systems that have places through which incident light can affect the detectors.

Exception: Such systems shall be permitted to be used in duct systems that have openings, if the detectors are designed to be insensitive to visible light.

6-2 Limitations.

6-2.1 Spark extinguishing systems shall not be used for ducts that transport combustible gases.

6-2.2 Spark extinguishing systems shall not be used where the extinguishing agent may create a hazard.

6-3 System Design.

6-3.1 Detectors.

6-3.1.1 Spacing between a detector and the extinguishing agent injection point shall be based on the linear velocity of the material in the duct and the response time of the detector and the actuator circuitry.

6-3.1.2 The number of detectors shall be sufficient to detect a glowing particle at any location in the cross-sectional area of the duct.

6-3.1.3 All detector circuits shall be supervised and shall sound a manual reset alarm upon circuit failure.

6-3.2 Power Supply.

6-3.2.1 The primary power supply shall be supervised and upon failure shall cause automatic engagement of the emergency power supply.

6-3.2.2 Each spark extinguishing system shall have a connected emergency power supply meeting the requirements of *National Electrical Code* Article 700 and be capable of operating the system for 24 hours.

6-3.2.3 A manual reset alarm shall sound upon loss of the primary power supply, or the protected system shall be interlocked to shut down upon loss of power to the spark extinguishing system.

6-3.3 Extinguishing System.

6-3.3.1 Discharge nozzles shall be located and arranged so that solid particles will not obstruct the nozzle.

6-3.3.2 The electric circuit for the automatic injection valve shall be supervised and shall sound a manual reset alarm upon loss of power.

6-3.3.3 If water is used as the extinguishing agent, the water supply system shall be equipped with an in-line strainer.

6-3.3.4 The extinguishing agent supply system shall be capable of supplying all discharge nozzles at the rated volume and pressure.

6-3.3.5 The system shall contain enough extinguishing agent to provide for at least 100 operations of the system.

6-3.3.6 A manual reset alarm shall sound when the pressure of the extinguishing agent falls below 50 percent of the system's operating design pressure.

6-3.3.7 Auxiliary heating systems for extinguishing agent storage shall be provided when necessary. When such heating systems are provided, the temperature of the extinguishing agent shall be supervised and a manual reset alarm shall sound at both the low and high temperature limits.

6-4 Testing. The spark extinguishing system shall be tested weekly.

Exception: For systems that have a permanently installed test light that automatically tests the detection system, regular testing shall be permitted to be done monthly instead of weekly.

Chapter 7 Deflagration Isolation Systems

7-1 Application.

7-1.1 The technique of deflagration isolation shall be permitted for gaseous or combustible dust systems.

7-1.2 Isolation systems, where used, shall be designed, manufactured, installed, operated, and maintained to prevent passage of, arrest, divert, or extinguish the deflagration.

7-1.3 Deflagration isolation system design shall be permitted to be based on various techniques that include but are not limited to the following types of hardware systems:

(a) Rotary valve;

(b) Flame arrester;

(c) Automatic fast acting closing valve;

(d) Flame front diverter;

(e) Flame front extinguishing system;

(f) Liquid seals.

7-2* Rotary Valve.

7-2.1 Rotary valves shall be used only for systems handling dust.

7-2.2 Rotary valves shall be designed with clearance between the rotor and the valve housing small enough to prevent the passage of a flame. At least two vanes on each side of the valve housing shall be in a position of minimum clearance at all times.

7-2.3 Rotary valves shall be designed to withstand the maximum anticipated deflagration pressure.

7-2.4* Rotary valves shall have metal bodies and vanes unless it is shown by test data that a plastic or composite material will prevent flame passage.

7-2.5 An internal inspection of rotary valves shall be conducted periodically, based on facility experience, to determine that the clearance conforms to the requirements of 7-2.2

7-3 Flame Arresters.

7-3.1* Definition.

Flame Arrester. A device that prevents the transmission of a flame through a flammable gas/air mixture by quenching the flame on the surfaces of an array of small passages through which the flame must pass. The emerging gases are sufficiently cooled to prevent ignition on the protected side.

7-3.2* Flame arresters shall be placed in the potential flame path between the source of ignition and the system to be protected.

7-3.3 This section shall not apply to:

(a) Devices that utilize a liquid seal to prevent the passage of flame;

(b) Devices that rely on gas flow velocity to prevent upstream propagation of flame;

(c) Systems handling dusts.

7-3.4 Flame arresters shall be installed in accordance with the manufacturers' instructions.

7-3.5* Flame arresters for in-line use shall be tested for that application.

7-3.6* If an in-line arrester can experience continued burning for an interval of time exceeding that for which it was tested, some means of detecting such burning shall be provided on both sides of the arrester along with an alarm or automatic device to interrupt flow prior to failure. If thermocouples are used, they shall not be placed in thermowells.

7-3.7* Arresters shall be inspected periodically, based on facility experience, and after each incident in which they have been called upon to function. The inspection shall determine whether any damage has occurred that could affect the performance of the device. Damaged components shall be replaced.

7-4* Automatic Fast Acting Valve Systems.

7-4.1 Automatic fast acting valve systems shall be designed to detect a deflagration and prevent flame propagation beyond the fast acting valves by providing a positive mechanical seal.

7-4.2* Fast acting valves and deflagration detectors shall be capable of withstanding expected deflagration pressures.

7-4.3* Fast acting valve systems shall be tested to verify their performance.

7-4.4 Where failure of the pipe leading to the fast acting valve can create a hazard, the pipe shall be capable of withstanding maximum pressure.

7-4.5 Automatic fast acting valve systems shall be disarmed prior to performing any maintenance operations on the protected equipment. Measures shall be provided to prevent resumption of operations until the system is rearmed.

7-4.6 Personnel shall be trained in safety procedures to be carried out prior to, during, and after maintenance.

7-4.7 Detection.

7-4.7.1 Deflagration shall be detected by sensing either the pressure increase or the radiant energy from the combustion process.

7-4.7.2* Provision shall be made to prevent obscuration of radiant energy detectors.

7-4.7.3 Detectors shall be protected from the accumulation of foreign material that would prevent functioning.

7-4.7.4 Detection circuits shall be continuously supervised. The supervisory system shall produce an alarm in the event of failure of the detection circuits.

7-4.8 Valve Actuators.

7-4.8.1 Valve actuators shall be mounted so that their maximum temperature rating is not exceeded.

7-4.8.2 Wiring circuits for the actuators shall be continuously supervised and produce an alarm in the event of loss of circuit continuity or circuit grounding.

7-4.8.3 The source of electrical energy shall meet the actuator manufacturer's specifications.

7-4.9 Electrical Power.

7-4.9.1 Electrical power systems shall meet applicable requirements of NFPA 70, *National Electrical Code*.

7-4.9.2 All automatic fast acting valve system wiring shall be isolated and shielded from all other wiring to prevent possible operation interference by induced currents.

7-4.9.3 High and low voltage circuits shall be in separate conduits.

7-4.9.4 Wiring for a system shall be run in separate conduits. If multiple systems are installed using shielded cables, wiring shall be permitted to be run in common conduits.

7-4.9.5 Supervisory circuits shall be provided to detect open circuits or other faults. Supervisory circuits shall be interlocked with a suitable alarm.

7-4.9.6 A standby power supply designed in accordance with Article 700 of NFPA 70, *National Electrical Code*, shall be provided for fast acting automatic valve systems.

7-4.10 Installation.

7-4.10.1 All components of the system shall be mounted in the location and in the manner specified by the system designer.

7-4.10.2 Detectors and fast acting valves shall be mounted so that vibration-induced malfunctions are minimized.

7-4.10.3 Terminals and mechanical parts shall be protected from moisture and other contaminants.

7-4.10.4 Mounting locations shall be chosen so as not to exceed maximum operating temperatures of system components.

7-4.11 Inspection and Maintenance.

7-4.11.1 Automatic fast acting valve systems shall be inspected and tested periodically based on facility experience by trained personnel.

7-4.11.2 In the event of system operation, all components shall be inspected, replacement parts installed if necessary, and the system tested prior to restoration.

7-5* Flame Front Diverters. Flame front diverters shall be permitted to be used as a deflagration loss control measure.

7-5.1 **Flame Front Diverter.** This is a device comprised of a body and a closure device. The pressure wave that precedes the flame front opens the closure and the body diverts the flame front to atmosphere. Some flame front diverters are equipped with an internal closure flap that, upon activation, creates a physical barrier to downstream flame propagation.

7-5.2* Design. Flame front diverters have demonstrated, in some cases, the ability to divert deflagrations by directing the deflagrations to atmosphere. However, tests have indicated that some diverters have been ineffective in completely diverting a deflagration; but, where this has occurred, the deflagration severity in the system has been greatly reduced.

7-5.3* Flame front diverters shall be tested for the application.

7-6 Flame Front Extinguishing Systems.

7-6.1* Flame front extinguishing systems shall be permitted to be used to isolate a deflagration and shall comply with the requirements of Chapter 4.

7-7 Liquid Seals.

7-7.1* A liquid seal is a device for preventing the passage of flame by passing the gas through a liquid. The liquid seal devices shall be designed for the gases being handled at the flow velocities range in the system and to withstand the maximum anticipated deflagration pressure. The liquid seals shall be designed in accordance with other recognized practices.

7-7.2* Means for providing and maintaining an adequate liquid level shall be provided as well as an alarm to detect malfunction.

Chapter 8 Referenced Publications

8-1 The following documents or portions thereof are referenced within this standard and shall be considered part of the requirements of this document. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

8-1.1 **NFPA Publications.** National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 70, *National Electrical Code*, 1990 edition

NFPA 86, *Standard for Ovens and Furnaces*, 1990 edition

NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*, 1991 edition

NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*, 1990 edition

NFPA 327, *Standard Procedures for Cleaning or Safeguarding Small Tanks and Containers*, 1987 edition.

8-1.2 **ASME Publications.** American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, or American National Standards Institute, 1430 Broadway, New York, NY 10018.

ASME Boiler and Pressure Vessel Code, Section VIII, Division 1

ASME Chemical Plant and Petroleum Refinery Piping Code, B31.3, 1990.

8-1.3 Federal Publication. U.S. Government Printing Office, Washington, DC 20401.

Code of Federal Regulations, Part 75, Title 30.

Appendix A

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

A-1-1.3 See NFPA 68, *Guide for Venting of Deflagrations.*

A-1-3 It should be recognized that there are other methods for preventing combustion. These include changing the process to eliminate combustible material either used or generated in the process. (Deflagration venting is not addressed in this standard; see NFPA 68, *Guide for Venting of Deflagrations.*)

A-1-8 Inspection, maintenance, and operator training are necessary requirements of any explosion prevention system. Reliability of the system and its instrumentation will only be as good as the inspection and periodic preventive maintenance they receive. Operator response and action to correct adverse conditions, as indicated by instrumentation or other means, will only be as good as the frequency and thoroughness of training provided.

A-1-9 Approved. The National Fire Protection Association does not approve, inspect or certify any installations, procedures, equipment, or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

A-1-9 Authority Having Jurisdiction. The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner since jurisdictions and "approval" agencies vary as do their responsibilities. Where public safety is primary, the "authority having jurisdiction" may be a federal, state, local or other regional department or individual such as a fire chief, fire marshal, chief of a fire prevention bureau, labor department, health department, building official, electrical inspector, or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the "authority having jurisdiction." In many circumstances the property owner or his designated agent assumes the role of the "authority having jurisdiction"; at government installations, the commanding officer or departmental official may be the "authority having jurisdiction."

A-1-9 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The "authority having jurisdiction" should utilize the system employed by the listing organization to identify a listed product.

A-2-1.1 Operation of a system with an oxidant concentration low enough to prevent a deflagration does not mean that incipient fires are prevented. Smoldering may occur in fibrous materials or dust layers at very low oxidant concentrations, later to result in a fire or explosion when exposed to higher oxidant concentrations. Caution should be exercised when opening such systems to the air.

A-2-2.1 Purge gases generated by any of the acceptable methods described in this standard may not necessarily be suitable for all applications. In general, the physical and chemical properties of the combustible materials involved will govern the type and required purity of the purge gas needed. Chlorinated and fluorinated hydrocarbons are sometimes used. Although these gases are more costly than carbon dioxide or nitrogen, the allowable oxygen concentration may be higher. The user is cautioned, however, that some halogenated hydrocarbons, carbon dioxide, and even nitrogen at elevated temperatures may react violently with certain dusts. Also, these gases may not be effective in providing explosion protection for certain combustible metal dusts, such as aluminum, magnesium, titanium, zirconium, thorium, and uranium. Argon, helium, and other rare gases may have to be used for inerting certain systems.

In general, personnel should not enter enclosures where the atmosphere is oxygen deficient. If it is necessary to enter such an enclosure, personnel must use self-contained breathing apparatus, preferably the positive pressure type. Canister-type gas masks must not be used; they do not supply oxygen and do not offer any protection. The toxicity of certain purge gases must be recognized. The potential for accidental release of purge gases into normally occupied areas must be recognized and necessary precautions taken.

A-2-5.5 This requirement is intended to provide for a sufficient number of isolation points to facilitate maintenance, while holding the number of isolation valves to a manageable number so that accidental shutoff is minimized.

A-2-5.7 Consideration should be given to providing positive means of preventing backflow of purge gas into other systems when such flow would present a hazard.

A-2-6 Methods of Application. Any of several methods may be used to ensure the formation and maintenance of a noncombustible atmosphere in an enclosure to be protected. These include "batch" methods applicable to "one-time" or occasional use, as in purging equipment during shutdown, and "continuous" methods intended to ensure safe conditions during normal operations.

Batch Purging Methods. Include syphon, vacuum, pressure, and venting to atmosphere.

Continuous Purging Methods. Include fixed rate application and variable rate or demand application.

Siphon Purging. Equipment may be purged by filling with liquid and introducing purge gas into the vapor space to replace the liquid as it is drained from the enclosure.

The volume of purge gas required will be equal to the volume of the vessel, and the rate of application can be made to correspond to the rate of draining.

Vacuum Purging. Equipment that normally operates at reduced pressure, or in which it is practical to develop reduced pressure, may be purged during shutdown by breaking the vacuum with purge gas. If the initial pressure is not low enough to ensure the desired low oxidant concentration it may be necessary to re-evacuate and repeat the process. The amount of purge gas required will be determined by the number of applications required to develop the desired oxidant concentration. Where two or more containers or tanks are joined by a manifold and must be purged as a group, the vapor content of each container or tank should be checked to determine that complete purging has been accomplished.

Pressure Purging. Enclosures may be purged by increasing the pressure within the enclosure by introducing purge gas under pressure and, after the gas has diffused, venting the enclosure to the atmosphere. More than one pressure cycle may be necessary to reduce the oxidant content to the desired percentage. Where two or more containers or tanks are joined by a manifold and should be purged as a group, the vapor content of each container or tank should be checked to determine that desired purging has been accomplished. Where a container filled with combustible material is to be emptied and then purged, purge gas may be applied to the vapor space at a pressure consistent with equipment design limitations, thus accomplishing both the emptying of the vessel and the purging of the vapor space in the same process.

Sweep-Through Purging. This process involves introducing a purge gas into the equipment at one opening, and letting the enclosure content escape to the atmosphere through another opening, thus sweeping out residual vapor. The quantity of purge gas required will depend on the physical arrangement. A pipeline can be effectively purged with only a little more than one volume of purge gas if the gas can be introduced at one end and the mixture released at the other. However, vessels will require quantities of purge gas much in excess of their volume.

If the system is complex, involving side branches through which circulation cannot be established, the sweep-through purging method may be impractical, and pressure or vacuum purging might be more appropriate.

The relationship between the number of volumes of purge gas circulated and the reduction in concentration of the critical component in original tank contents, assuming complete mixing, is shown on the graph, Figure A-2-6(a).

It will be noted that:

(a) The total quantity required may be less than that for a series of steps of pressure purging.

(b) From four to five volumes of purge gas will suffice to almost completely displace the original mixture, assuming complete mixing.

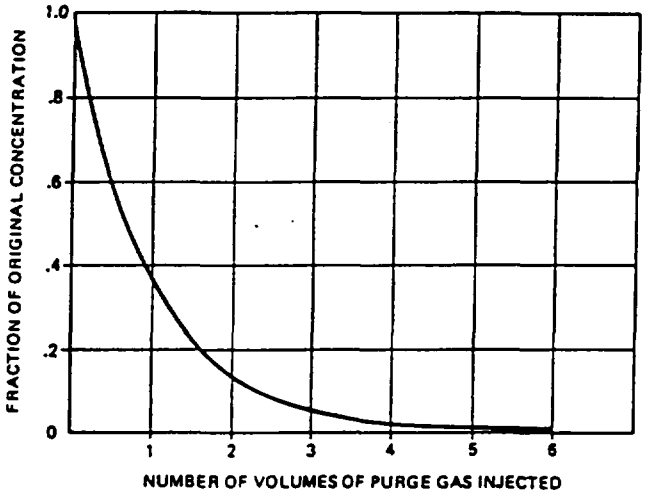

Figure A-2-6(a) Dilution ratio — purging at atmospheric pressure. (Complete mixing assumed.)

Fixed Rate Application. This method involves the continuous introduction of purge gas into the enclosure at a constant rate, which must be sufficient to supply the peak requirement in order that complete protection may be provided, and a corresponding release of purge gas and whatever gas, mist, or dust has been picked up in the equipment.

(a) Advantages are simplicity, lack of dependence on devices such as pressure regulators, and possible reduced maintenance.

(b) Disadvantages are:

1. A continuous loss of product where the space contains a volatile liquid, due to constant "sweeping" of the vapor space by the purge gas;

2. Increased total quantity of purge gas, because it is supplied whether needed or not;

3. Possible disposal problems (toxic and other effects) for the mixture continuously released.

(c) Figure A-2-6(b) shows a method of flow control that can be used with fixed rate application.

Variable Rate or Demand Application. This method involves the introduction of purge gas into an enclosure at a variable rate dependent on demand, based usually on maintaining within the protected enclosure an arbitrarily selected pressure slightly above that of the surrounding atmosphere. Peak supply rate must be computed as described in subsection (c) below.

(a) Advantages are that purge gas is supplied only when actually needed, and that it is possible, when desirable, to completely prevent influx of air.

(b) A disadvantage is that operation depends on the functioning of pressure control valves operating at sometimes very low pressure differentials, which are sometimes difficult to maintain.

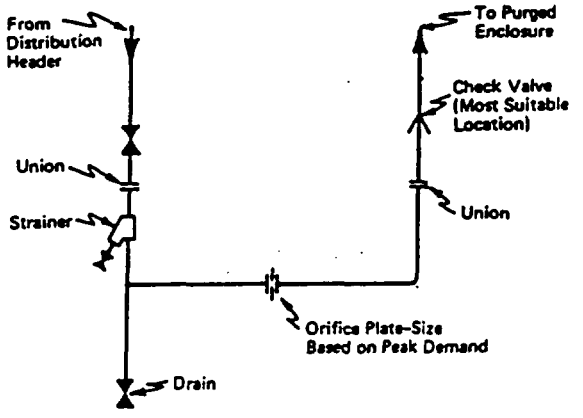

Figure A-2-6(b). Schematic sketch showing method of flow control that may be used with fixed rate application.

(c) Figure A-2-6(c) shows a method of flow control that can be used with variable rate application. Figure A-2-6(d) shows an alternate method applicable where the purge gas requirement during out pumping is a large part of the peak demand.

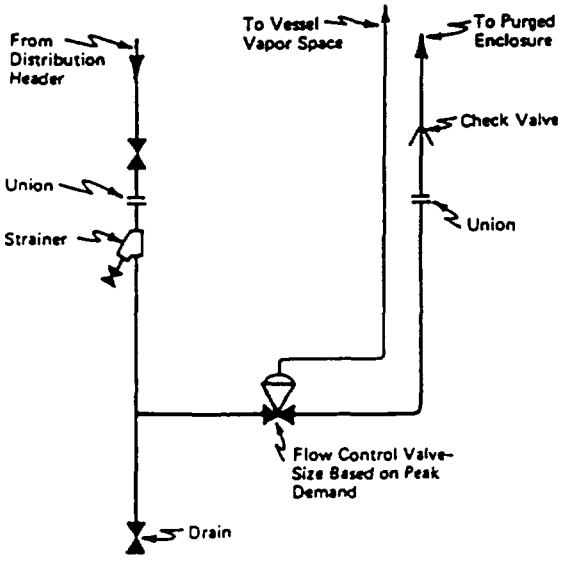

Figure A-2-6(c). Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure A-2-6(d).

Calculation of Peak Purge Gas Rates. Peak demand is defined in Chapter 2 as the total projected system requirements.

For any one element of the system, the peak demand is controlled by such factors as:

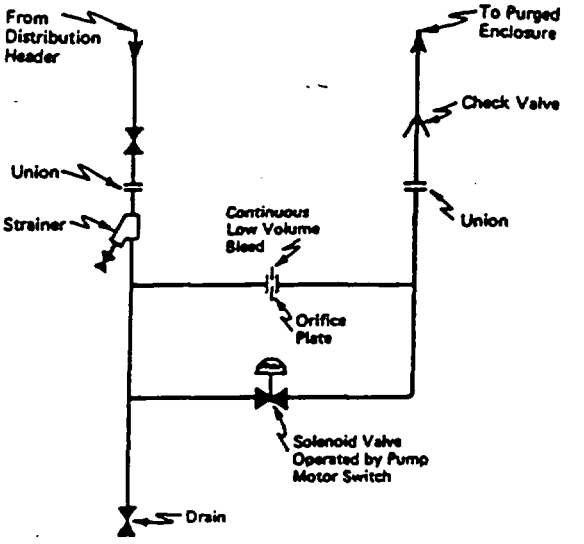

Figure A-2-6(d). Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure A-2-6(c).

(a) Maximum withdrawal rate;

(b) Temperature change;

(c) Leaks;

(d) Rapid atmospheric pressure changes.

Cooling of the contents of a vessel containing a vapor or hot liquid presents a special and frequent case of vacuum purging. Condensation of vapor to a liquid or reduction in pressure of the gas phase can rapidly produce partial vacuum, which may impose excessive stresses on equipment or even collapse of the vessel; may suck in air from joints that may not leak under internal pressure; and may require high supply rates of inert gas. Each situation must be treated individually.

The peak supply rate must be computed for each case with consideration being given to cooling rate, vessel size, and configuration, which determine the rate of condensation.

If neither the reducing valve nor the source gas can be sufficiently reliable to supply the amount of inert gas required to prevent reduction of pressure below atmospheric, the vessel may have to be designed for full vacuum.

For a vessel containing a liquid, the purge gas demand from liquid withdrawal, change of liquid composition from mixing, or increasing solubility of purge gas in the liquid will be the volume equivalent of the capacity of the largest pump that can withdraw liquid, or the maximum possible gravity outflow rate, whichever is greater. Where two tanks are manifolded together, so that one can flow by gravity into the other, a vapor space interconnection is sometimes used to reduce the required purge gas supply from outside sources.

For outdoor tanks operating at or near atmospheric pressure, the maximum demand from temperature change will occur in outdoor tanks operating at near atmospheric pressure, as a result of sudden cooling by a summer thun-

derstorm. The rate of purge gas supply necessary to prevent vessel pressure falling significantly below atmospheric pressure can be calculated as follows:

(a) For tanks over 800,000 gal (3.028 million L) capacity, 2 cu ft (0.056 cu m) of purge gas per hour for each square foot of total shell and roof area.

(b) For smaller tanks, 1 cu ft (0.028 cu m) purge gas per hour for each 40 gal (151 L) of tank capacity, or the rate corresponding to a mean rate of the change of the vapor space temperature of 100°F (37.8°C) per hour. (*See API Standard 2000, Venting Atmospheric and Low-Pressure Storage Tanks, for further information.*)

The rates for temperature change and liquid withdrawal must be added unless there is some special circumstance that will prevent them from occurring simultaneously.

In some equipment, such as pulverizers, the rate of purge gas supply necessary to exclude air may be dominated by leakage, and temperature change can be ignored.

A-3-3.2 The combustible concentration can be reduced by recirculating the atmosphere containing it through a catalytic oxidation unit where the combustible material and oxidant undergo catalytic oxidation at concentrations below the lower flammable limit.

A-4-6.3 The explosive device and the firing circuit should be continuously supervised.

A-4-8 Halogenated hydrocarbons, such as bromochloromethane and bromotrifluoromethane, or dry chemical agents may be used with most combustibles. Suitability of the suppressant should be determined if elevated temperatures or pressures are anticipated or if the oxidant is a material other than air.

Water may also be used as a suppressant if it can be demonstrated to be effective. If ambient temperatures below 0°C (32°F) are expected, a suitable antifreeze must be used.

A-5-2.1 Deflagration pressure containment is not adequate for detonable systems because the maximum pressure rise will be much greater than the factors established in 5-3.3.1 and 5-3.3.2. It should be recognized that some systems may be capable of deflagration or detonation. For example, systems containing a substantial proportion of hydrogen are prone to detonation, as are systems containing acetylene or acetylenic compounds. Saturated organic compounds such as propane, ethane, and alcohols generally will not detonate in vessels, but may do so in pipework.

A-5-2.2 The intent of this requirement is to prevent the application of deflagration pressure containment to any vessel that may be susceptible to pressure piling. Vessels with a higher L/D ratio may be designed for deflagration pressure containment using other techniques for estimating the required design pressure.

A-5-2.3 When two vessels connected by a large-diameter pipe both contain a combustible mixture, a deflagration in one vessel can precompress the unburned mixture in the other vessel. The maximum deflagration pressure that can be developed in the second vessel may be substantially greater than would normally happen in a single vessel (See Bartknecht, W.; *Explosions: Course, Prevention, Protection*; pp 18-23).

A-5-2.4 Only limited information is available for deflagration containment of systems with initial pressures exceeding 30 psig (206.7 kPa gage). Increased initial pressure may increase the potential for detonation. For this reason it is recommended that, for systems that may operate at an initial pressure of 30 psig (206.7 kPa gage) or higher, deflagration pressure containment be used only where appropriate test data are available. The testing must be carefully designed because the detonation potential of a system is affected by vessel dimensions.

A-5-3.3.1 The maximum deflagration pressures for several dusts can be found in Appendix D of NFPA 68.

A-5-3.5 The maximum initial pressure will depend on the origin of the pressure. In some cases, this pressure will be determined by the setting of a relief device on the system. In these cases, the maximum initial pressure is the sum of the relief device set pressure and the relief device accumulation pressure. Overpressure due to boiling of the vessel contents (as, for example, from external fire exposure) may raise the concentration of fuel in the vapor phase above its upper flammable limit and would not constitute a deflagration hazard.

A-7-2 The acceptance of a rotary valve for use as a deflagration isolation device should consider the minimum ignition energy and the ignition temperature of the dust. Additionally, the width and the length of the gap should be related to these factors. Information about the testing techniques and the relationship of the factors may be found in a paper by G. Schuber.

The passage of a flame front through the rotary valve is not the only mechanism by which ignition can occur downstream of a rotary valve. The passage of smoldering embers through the valve may be a source of ignition on the downstream side of the valve.

A-7-2.4 The use of plastics, elastomers, or other synthetic material either for the full vane or as wear strips may allow the flame front to pass through the valve. This may be because of a lack of mass and low specific heat which is not sufficient to cool the flame during its passage.

A-7-3.1 Flame arresters are manufactured in several mechanical configurations, which include but are not limited to the following:

(a) Banks of closely spaced parallel plates;

(b) Banks of small diameter tubes;

(c) Wire screens;

(d) Elements consisting of alternating flat and crimped plates that are spirally wound together to produce the equivalent of small diameter tubes;

(e) Porous or sintered metal elements.

A-7-3.2 The ignition source may be outside the protected system as in the case of a flame arrester on a tank vent. Alternatively, the ignition source may be within the system

as in the case of a flame arrester installed in a pipe that connects two or more tank vents.

A-7-3.5 Flame arresters are reliable only when installed within parameters for which they have been tested. These conditions include:

(a) The fuel mixture used in the test should be the same as, or have flame propagation characteristics similar to, those encountered in the application.

(b) The length of pipe between the arrester and the likely ignition source should be less than or equal to the maximum length for which it was successfully tested.

(c) The smallest and largest size of a particular type of arrester should be tested.

(d) The arrester should be tested in the same configuration in which it will be installed, including the arresting element, the case in which it is contained, the hardware for mounting the element in its case, any gaskets or seals required, the flange or other connector used to attach the arrester to the system, and materials of construction.

(e) The maximum temperature and pressure likely to exist at the arrester at the moment of ignition should be used.

(f) Where appropriate for the specific application, testing with ignition both upstream and downstream (relative to the gas flow direction) should be done.

(g) The device should be tested over the range of flow velocities that could be encountered.

(h) If continuous burning can occur at the arrester, the test procedure should include a continuous burn test.

A-7-3.6 The functionality of a flame arrester can be destroyed if it is heated to an excessively high temperature by the combustion gases reaching it or by exposure to an external source of heat such as a flame.

The functionality-limiting temperature is dependent upon the design, mass, and material of construction of the flame arrester and is unique to the design. It must be determined by test and is usually below the autoignition temperature.

A-7-3.7 If the arrester is used in a service where freezing or plugging may occur, some means of detecting the onset of plugging, such as a differential pressure switch, should be provided.

A-7-4 See Figure A-7-4.

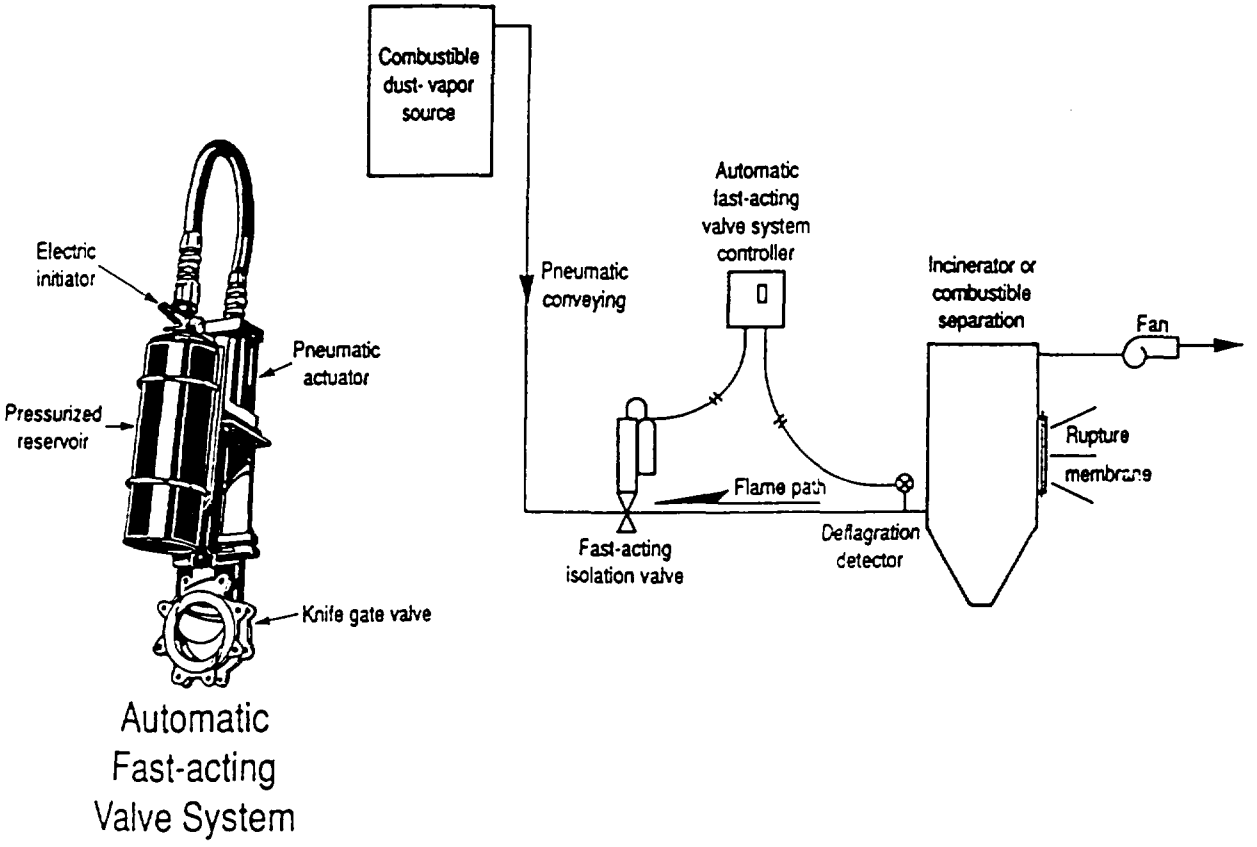

Figure A-7-4 Typical application and design of fast-acting, automatic closing valve assembly.

A-7-4.2 The following factors affect the performance of fast acting automatic closing valves and must be considered in design and applications. These factors include but are not limited to:

(a) Deflagration characteristics of the combustible material;

(b) Volume, configuration, and operating characteristics of the vessel;

(c) Type of deflagration protection used on the vessel and piping;

(d) Volume, length, cross-sectional area, configuration and strength of the piping;

(e) Velocity of combustible-air mixture in pipe;

(f) Location of system components;

(g) Closure time of the valve including control and detection components;

(h) Detection technique.

A-7-4.3 Fast acting valve systems are reliable only when designed and installed within the parameters for which they have been tested. These parameters include but are not limited to:

(a) The flame propagation characteristics used in the placement design should be representative of the fuel mixture giving the highest flame speed and the maximum conveying velocities to be encountered in the application.

(b) The response time of the fast acting valve system shall be established by testing. This response time will be used in the placement design to calculate the required length of pipe between the fast acting valve and the detector.

A-7-4.7.2 Detectors that respond to radiant energy may be used provided that the application environment will not inhibit their proper operation. Airborne dust particles, dust coating of the detector viewing window, certain gases, and the distance to the ignition source may inhibit sufficiently rapid response to the hazard.

A-7-5 See Figure A-7-5.

A-7-5.2 Flame front diverter system design considerations should include but not be limited to:

(a) Deflagration characteristics of the combustible material;

(b) Volume, configuration, and operating characteristics of the equipment to be protected and conveying system;

(c) Type of deflagration protection used on the vessel;

(d) Length, cross-sectional area, configuration, and strength of the piping;

(e) Velocity of combustible-air mixture in pipe;

(f) Location of flame front diverter and its associated piping;

(g) Turbulence generating features in the piping such as fittings, valves, elbows, and wall roughness;

(h) Location of probable ignition sources.

(i) The body design should divert the flame front to atmosphere and away from the downstream piping.

(j) The body should be capable of withstanding expected deflagration pressure.

(k) The closure device should be either a rupture disc or cover plate.

(l) Where the closure device could be a missile hazard, it should be either tethered or contained in a cage.

(m) The hazard of flame discharge from the flame front diverter should be considered when designing the placement of the device. The flame front diverter should discharge to a safe, unrestricted, outdoor location.

A-7-5.3 The testing of flame front diverters should include but not be limited to the following items:

(a) The test fuel mixture should be the same as, or have flame propagation characteristics similar to, those encountered.

(b) The length of pipe between the installed flame front diverter and the ignition source should be less than or equal to the maximum length for which the diverter was tested.

(c) Ignition source location (upstream, downstream, or both locations) should be tested in the same configuration as the protection application.

(d) For upstream ignition, the diverter should be tested over the range of flow velocities that could be encountered at the time of ignition or that may develop as a result of ignition.

(e) Installation and maintenance.

1. Flame front diverters should be installed and maintained according to manufacturer's instructions.

2. Flame front diverters should be inspected periodically, based on facility experience, and after each operation. Inspection should determine whether any damage that could affect the performance of the device has occurred. Damaged components should be repaired or replaced.

A-7-6.1 System design and test considerations should include:

(a) Deflagration characteristics of the combustible material;

(b) Volume, configuration, and operating characteristics of the equipment involved;

(c) Type of deflagration protection used on the equipment;

(d) Length, cross-sectional area, configuration, and strength of the pipe;

(e) Velocity of combustible-air mixture in pipe;

(f) Location of system components.

A-7-7.1 For most system, the *API Recommended Practice 521* should be used when designing liquid seals. For systems where the oxidant/flammable gas may approach a stoichiometric mixture, tests should be performed to determine the design of liquid seals.

A-7-7.2 Where the inlet gas is a combustible mixture, additional precautions should be taken to prevent overheating of inlet piping within the liquid seal device by a continuous fire in the seal enclosure.

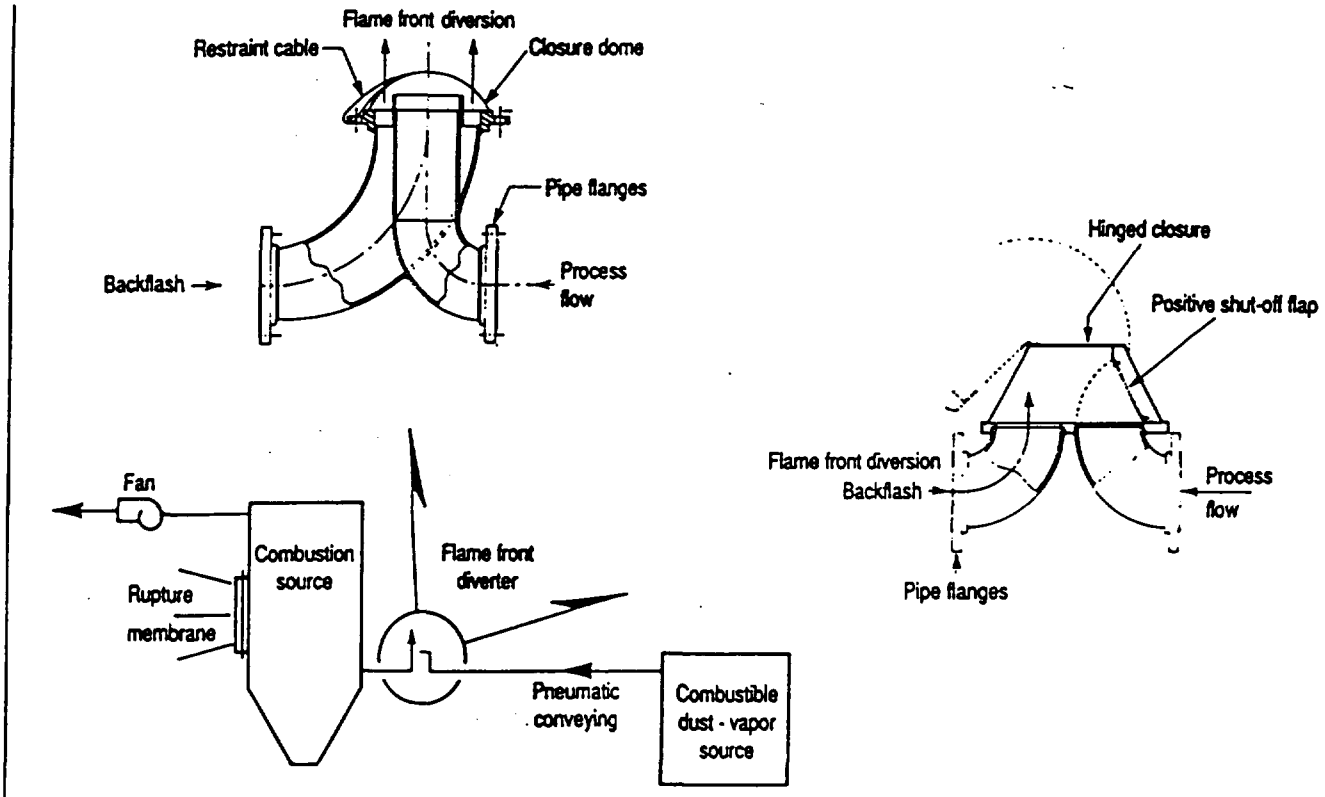

Figure A-7-5 Typical application and design of flame front diverters.

Appendix B Control of Combustible Gas Mixtures by Oxidant Concentration Reduction and Combustible Concentration Reduction

B-1 General. As covered in chapters 2 and 3, a combustible gas/oxidant mixture may be controlled by reducing the concentration of oxidant or by adding an inert constituent to the mixture. Both processes can be explained most easily by referring to a "flammability diagram." Figure B-1 shows a typical flammability diagram that represents a mixture of a combustible gas, an inert gas, nitrogen, and an oxidant, oxygen, at a given temperature and pressure.

A mixture of air (79 percent N_2 and 21 percent O_2, by volume) and combustible gas is represented by the line DABE. A given mixture of the combustible gas and air, whether ignitible or not, is specified by some point on this line. Point A indicates the upper flammable limit of this mixture, while Point B represents its lower flammable limit.

Any point within the area bounded by FBCAG is in the flammable range and can be ignited. Any point outside this area represents a mixture that cannot be ignited. Point C represents the limiting oxidant concentration to prevent ignition; any mixture containing less oxygen cannot be ignited. (*See Appendix C.*)

Any mixture of oxygen and combustible gas alone, i.e., without any nitrogen, is represented by the left-hand side of the triangle. Any mixture of nitrogen and combustible gas alone, i.e., no oxygen present, is represented by the right-hand side of the triangle.

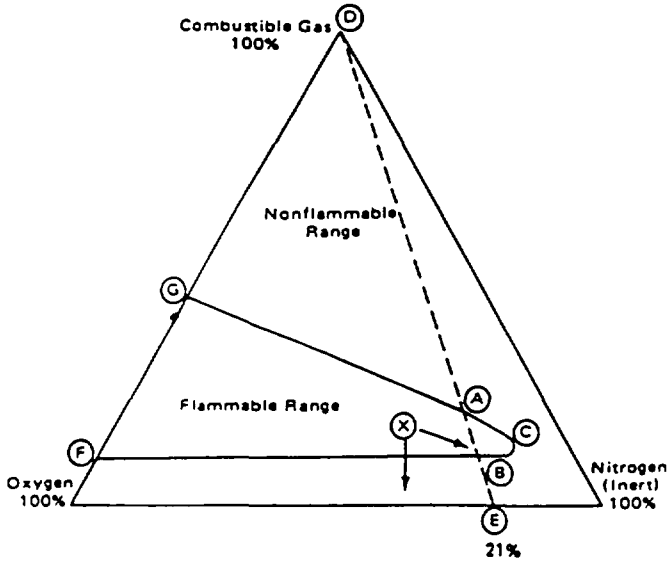

Figure B-1 Typical flammability diagram.

B-2 Effect of Pressure and Temperature. As shown in Figure B-2, pressure and temperature can have an effect on the flammability diagram. An increase in pressure results in an increase in the upper flammable limit and a decrease in the limiting oxidant concentration to prevent ignition, points C, C', and C". There is a slight effect on the lower flammable limit, a decrease, but the effect is not as pronounced as that of the upper limit.

An increase in temperature has a similar effect on the flammability diagram.

The exact effects on a system, produced by changes in pressure or temperature, must be determined for each system.

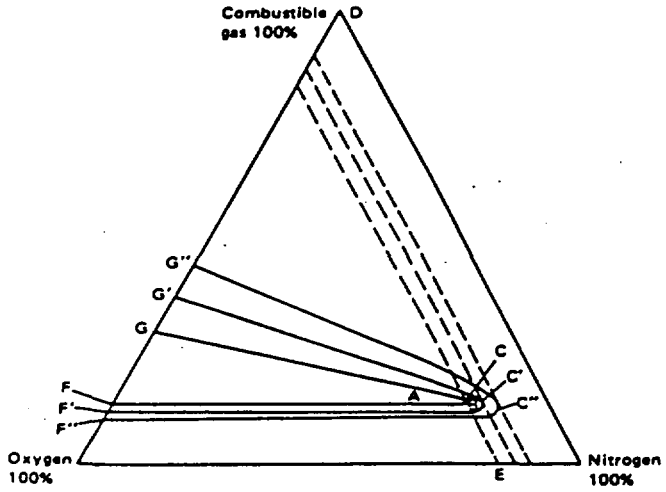

Figure B-2 Effect of pressure on flammability diagram.

B-3 Effect of Inert Diluents. The addition of an inert diluent to a mixture of combustible material and oxidant will affect the lower and upper flammable limits and the limiting oxidant concentration. Figure B-3 illustrates the effect of some typical diluents on the flammability limits of methane. This figure shows that nitrogen is more effective than helium and carbon dioxide is more effective than nitrogen.

B-4 Oxidant Concentration Reduction. Referring back to the flammability diagram in Figure B-1, the point "x" represents some arbitrary mixture of combustible gas, oxygen, and nitrogen that lies well within the flammable range. If it is desired to change the composition of the mixture so that it lies outside the flammable range, one way to do this is by reducing the concentration of oxidant. As the concentration of oxygen decreases, the concentration of nitrogen increases. Point "x," in effect, moves toward the inert gas apex.

B-5 Combustible Concentration Reduction. Again referring to Figure B-1, with "x" in the flammable range, the composition of the mixture may be altered by reducing the concentration of combustible gas. In simpler terms, point "x" moves away from the combustible gas apex and eventually drops below the lower flammability line FBC.

B-6 Mixtures of Gases. Where mixtures of two or more combustible gases are encountered, the limits of flammability of the mixture can often be reliably predicted by using the following formulas suggested by Le Chatelier:

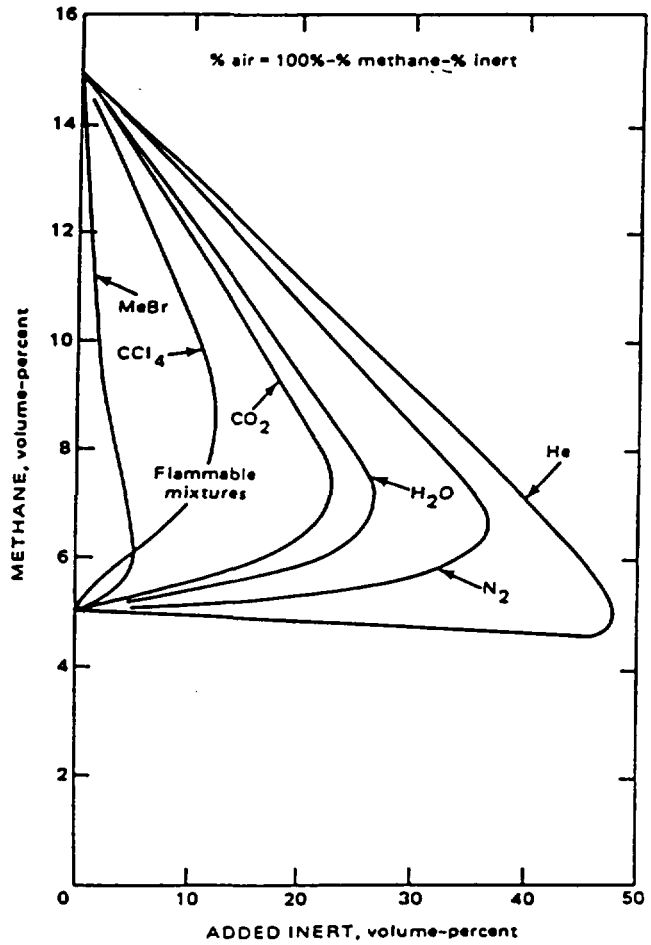

Figure B-3 Limits of flammability of methane-inert gas-air mixtures at 25°C (77°F) and atmospheric pressure.

Coward, H.F. and Jones G.W.; Limits of Flammability of Gases and Vapors; Bureau of Mines Bulletin 503, 1952, 155 p.

$$\text{Lower Flammable Limit} = \frac{P_1 + P_2 + P_3 + \ldots + P_n}{\frac{P_1}{LFL_1} + \frac{P_2}{LFL_2} + \ldots + \frac{P_n}{LFL_n}}$$

$$\text{Upper Flammable Limit} = \frac{P_1 + P_2 + P_3 + \ldots + P_n}{\frac{P_1}{UFL_1} + \frac{P_2}{UFL_2} + \ldots + \frac{P_n}{UFL_n}}$$

Where P_1, P_2, etc. are the volume fractions of components 1, 2, 3, etc. of the mixture; LFL_1, LFL_2, LFL_3, etc. are the lower flammable limits of components 1, 2, 3, etc., respectively; and UFL_1, UFL_2, UFL_3, etc., are the upper flammable limits at components 1, 2, 3, etc., respectively.

Appendix C Limiting Oxidant Concentrations

Table C-1 Limiting Oxidant Concentrations to Prevent Deflagrations of Combustible Gases Using Nitrogen or Carbon Dioxide as Diluents

Gas or Vapor	Limiting Oxidant Concentration N_2/Air: Volume % O_2 Above Which Deflagration Can Take Place	Limiting Oxidant Concentration CO_2/Air: Volume % O_2 Above Which Deflagration Can Take Place	Reference
Methane	12	14.5	1
Ethane	11	13.5	1
Propane	11.5	14.5	1
n-Butane	12	14.5	1
Isobutane	12	15	1
n-Pentane	12	14.5	1
Isopentane	12	14.5	2
n-Hexane	12	14.5	1
n-Heptane	11.5	14.5	2
Ethylene	10	11.5	1
Propylene	11.5	14	1
1-Butene	11.5	14	1
Isobutylene	12	15	4
Butadiene	10.5	13	1
3-Methyl-1-butene	11.5	14	4
Benzene	11.4	14	1, 7
Toluene	9.5	—	7
Styrene	9.0	—	7
Ethylbenzene	9.0	—	7
Vinyltoluene	9.0	—	7
Divinylbenzene	8.5	—	7
Diethylbenzene	8.5	—	7
Cyclopropane	11.5	14	1
Gasoline			
(73/100)	12	15	2
(100/130)	12	15	2
(115/145)	12	14.5	2
Kerosene	10 (150°C)	13 (150°C)	5
JP-1 fuel	10.5 (150°C)	14 (150°C)	2
JP-3 fuel	12	14.5	2
JP-4 fuel	11.5	14.5	2
Natural gas (Pittsburgh)	12	14.5	1
n-Butyl chloride	14	—	3
	12 (100°C)		3
Methylene chloride	19 (30°C)	—	3
	17 (100°C)		3
Ethylene dichloride	13	—	3
	11.5 (100°C)		3
1,1,1-trichloroethane	14	—	3
Trichloroethylene	9 (100°C)		3
Acetone	11.5	14	4
n-Butanol	NA	16.5(150°C)	4
Carbon disulfide	5	7.5	4
Carbon monoxide	5.5	5.5	4
Ethanol	10.5	13	4
2-Ethyl butanol	9.5 (150°C)	-	4
Ethyl ether	10.5	13	4
Hydrogen	5	5.2	4
Hydrogen sulfide	7.5	11.5	4
Isobutyl formate	12.5	15	4
Methanol	10	12	4
Methyl acetate	11	13.5	4
Propylene oxide	7.8	—	8
Methyl ether	10.5	13	4
Methyl formate	10	12.5	4
Methyl ethyl ketone	11	13.5	4
μDMH (dimethylhydrazine)	7	—	6
Vinyl chloride	13.4	—	7
Vinylidiene chloride	15	—	7

Table C-1 (continued)

NOTE 1: See 2-7.2 for the required oxygen level in equipment.
NOTE 2: Data were determined by laboratory experiment conducted at atmospheric temperature and pressure. Vapor-air-inert gas samples were placed in explosion tubes and ignited by electric spark or pilot flame.

References.

1. Coward, H. F., and G. W. Jones, *Limits of Flammability of Gases and Vapors*, BuMines Bulletin 503, 1952, 155 p.

2. Jones, G. W., M. G. Zabetakis, J. K. Richmond, G. S. Scott, and A. L. Furno, Research on the Flammability Characteristics of Aircraft Fuels, Wright Air Development Center, Tech. Report 52-35, Supplement I, 1954, 57 p.

3. *Jour. Chem. Eng. Data*, v. 13, July 1968, Kuchta, J. M., A. L. Furno, A. Bartkowiak, and G. H. Martindill, "Effect of Pressure and Temperature on Flammability Limits of Chlorinated Combustibles in Oxygen-Nitrogen and Nitrogen Tetroxide-Nitrogen Atmospheres," p. 421.

4. Zabetakis, M. G., Flammability Characteristics of Combustible Gases and Vapors. BuMines Bulletin 627, 1965, 121 p.

5. Zabetakis, M. G., B. H. Rosen. Considerations Involved in Handling Kerosine. *Proc. API*, v. 37, Sec. III, 1957, p. 296.

6. Unpublished data, U.S. Bureau of Mines.

7. Unpublished data, Dow Chemical Co.

8. U.S. Bureau of Mines

Table C-2 Limiting Oxidant Concentrations to Prevent Deflagrations of Suspensions of Combustible Dusts Using Nitrogen or Carbon Dioxide as Diluents

Dust	Limiting Oxidant Concentration N_2/Air Volume % O_2 Above Which Deflagration Can Take Place	Limiting Oxidant Concentration CO_2/Air Volume % O_2 Above Which Deflagration Can Take Place
Agricultural		
Coffee	15.8	17
Cornstarch	8	11
Dextrin	11.9	14
Soy Flour	13.2	15
Starch	9.3	12
Sucrose	11.9	14
Chemical		
Ethylene Diamine Tetra-Acetic Acid	10.6	13
Isatoic Anhydride	10.6	13
Methionine	13.2	15
Ortazol	18.4	19
Phenothiazine	15.8	17
Phosphorous Pentasulfide	9.3	12
Salicylic Acid	15.8	17
Sodium Lignosulfate	15.8	17
Stearic Acid & Metal Stearates	10.6	13
Carbonaceous		
Charcoal	15.8	17
Coal, Bituminous	15.8	17
Coal, Sub-bituminous	13.2	15
Lignite	13.2	15
Metal		
Aluminum	0	2
Antimony	14.5	16
Chromium	11.9	14
Iron	6.7	10
Magnesium	0	0
Manganese	11.9	14
Silicon	9.3	12
Thorium	0	0
Titanium	0	0
Uranium	0	0
Vanadium	11.9	14
Zinc	6.7	10
Zirconium	0	0
Miscellaneous		
Cellulose	10.6	13
Paper	10.6	13
Pitch	8	11
Sewage Sludge	11.0	14
Sulfur	9.3	12
Wood Flour	14.5	16
Plastics Ingredients		
Azelaic Acid	11.0	14
Bisphenol A	9.3	12
Casein, rennet	15.8	17
Hexamethylene tetramine	11.9	14
Isophthalic Acid	11.9	14
Paraformaldehyde	9.3	12
Pentaerythritol	11.9	14
Phthalic Anhydride	11.9	14
Terephthalic Acid	13.2	15

Table C-2 (continued)

Dust	Limiting Oxidant Concentration N_2/Air Volume % O_2 Above Which Deflagration Can Take Place	Limiting Oxidant Concentration CO_2/Air Volume % O_2 Above Which Deflagration Can Take Place
Plastics — Special Resins		
Coumarone-Indene Resin	11.9	14
Lignin	15.8	17
Phenol, Chlorinated	14.5	16
Pinewood Residue	10.6	13
Rosin, DK	11.9	14
Rubber, Hard	13.2	15
Shellac	11.9	14
Sodium Resinate	11.9	14
Plastics — Thermoplastic Resins		
Acetal	8	11
Acrylonitrile	10.6	13
Butadiene-Styrene	10.6	13
Carboxymethyl Cellulose	14.5	16
Cellulose Acetate	8	11
Cellulose Triacetate	9.3	12
Cellulose Acetate Butyrate	11.9	14
Ethyl Cellulose	8	11
Methyl Cellulose	10.6	13
Methyl Methacrylate	8	11
Nylon	10.6	13
Polycarbonate	13.2	15
Polyethylene	9.3	12
Polystyrene	11.9	14
Polyvinyl Acetate	15.8	17
Polyvinyl Butyrate	11.9	14
Plastics — Thermosetting Resins		
Allyl Alcohol	10.6	13
Dimethyl Isophthalate	10.6	13
Dimethyl Terephthalate	9.3	12
Epoxy	9.3	12
Melamine Formaldehyde	15.8	17
Polyethylene Terephthalate	10.6	13
Urea Formaldehyde	14.5	16

NOTE 1: Data in this table were obtained by laboratory tests conducted at room temperature and pressure, using a 24-watt continuous-spark ignition source and were reported in U.S. Bureau of Mines Report of Investigation 6543.

NOTE 2: Where nitrogen is used as the diluent, the values shown in Table C-2 were obtained according to the following equation:

$$O_n = 1.3\ O_c - 6.3$$

Where O_n = the maximum oxygen concentration for nitrogen dilution; and
O_c = the maximum oxygen concentration with CO_2 dilution.

NOTE 3: See A-2-7.2 for the required oxygen level in equipment.

NOTE 4: Data on the use of dry powders or water as inerting materials and on the effects of inerting on pressure development in a closed vessel are given in U.S. Bureau of Mines Reports of Investigations 6549, 6561, and 6811.

Appendix D Ventilation Calculations

D-1 Time Required for Ventilation. An estimate of the time required to reduce the concentration of a combustible gas to a safe limit by purging with fresh air can be calculated using the following method.

For an enclosed volume, V, the change in concentration, dC, over a given time period, dt, using a fixed flowrate of fresh air, Q, is given by:

$$VdC = QCdt \tag{1}$$

By rearranging:

$$\int_{Co}^{C} \frac{dC}{C} = \frac{Q}{V}\int_{0}^{t} dt \tag{2}$$

where Co = initial concentration of gas
t = time required to reach the desired concentration.

Integrating (2) yields:

$$\ln\left(\frac{C}{Co}\right) = \frac{-Q}{V}t. \tag{3}$$

Equation (3) assumes perfect mixing. Since this is not the case in actual practice, a correction factor, K, must be introduced:

$$\ln\left(\frac{C}{Co}\right) = \frac{-Q}{V}(K)t. \tag{4}$$

In perfect mixing K = 1.0. Table D-1 lists values of K for certain conditions.

Table D-1 Mixing Efficiency for Various Ventilation Arrangements

Method of Supplying	Efficiency (K) Values: Single Exhaust Opening	Efficiency (K) Values: Multiple Exhaust Openings
—No Positive Supply		
Infiltration through cracks,	0.2	0.3
open doors or windows	0.2	0.4
—Forced Air Supply		
Grills and registers	0.3	0.5
Diffusers	0.5	0.7
Perforated ceiling	0.8	0.9

Few data exist on defining the degree of mixing. Most authorities recommend a K value no greater than 0.25.

Consider the problem of reducing the gasoline vapor concentration of an enclosure of 1000 cu ft (28 cu m), by means of a 2000 cu ft/min (56 cu m/min) ventilation rate, from 20 volume percent to:

(a) the upper flammable limit, 7.6%
(b) the lower flammable limit, 1.4%
(c) 25% of lower flammable limit, 0.35%.

The difference between K = 1 (perfect mixing) and K = 0.2 in calculating the time needed to reduce the concentration to the levels specified may be shown.

Using Equation (3):

$$\text{(a) } \ln\left(\frac{7.6}{20.0} = \frac{-2000}{1000}\right)(K)(t)$$

$$\ln 0.38 = -2(K)(t)$$

$$t = \frac{\ln 0.38}{-2(K)} = \frac{-0.97}{-2(K)}$$

$$t = \frac{0.485}{(K)}$$

For K = 1, t = 0.49 min

For K = 0.2, t = 2.5 min.

$$\text{(b) } \ln\left(\frac{1.4}{20} = \frac{-2000}{1000}\right)(K)(t)$$

$$\ln 0.07 = -2(K)(t)$$

$$t = \frac{\ln 0.07}{-2(K)} = \frac{-2.66}{-2(K)}$$

$$t = \frac{1.33}{(K)}$$

For K = 1, t = 1.33 min

For K = 0.2, t = 6.65 min.

$$\text{(c) } \ln\left(\frac{0.35}{20} = \frac{-2000}{1000}\right)(K)(t)$$

$$\ln 0.018 = -2(K)(t)$$

$$t = \ln\frac{0.018}{-2(K)} = \frac{-4.02}{-2(K)}$$

$$t = \frac{2.01}{(K)}$$

For K = 1, t = 2 min

For K = 0.2, t = 10 min.

D-2 Number of Air Changes Required for Inerting. The calculation method described above provides a solution expressed directly in terms of time. To develop a solution in terms of required number of air changes, the equation is written as follows:

$$\left(\frac{C}{Co}\right) = e^{-KN} \tag{5}$$

Where N = required number of air changes.

Equation (5) can be rewritten:

$$\ln\left(\frac{C}{Co}\right) = -KN. \qquad (5)$$

Using the example in D-1, the number of air changes required to reach the upper flammable limit, 7.6%, at K = 0.2, is:

$$\ln\left(\frac{7.6}{20}\right) = -0.2\ N$$

$$N = \frac{\ln 0.38}{-0.2} = \frac{-0.97}{-0.2} = 4.8.$$

Since the airflow rate is 2000 cu ft/min (56 cu m/min) and the volume of the enclosure is 1000 cu ft (28 cu m), it turns out that a complete air change takes ½ min. Equation (6) indicates that 4.8 air changes are needed. This translates to a required time of 2.4 min, exactly what was calculated in D-1.

D-3 Buildup of Combustible Concentration in Enclosed Area. If a constant source of a combustible gas, such as a leak, is introduced into an enclosed volume, Equation (6) must be modified as follows:

$$C = \left(\frac{G}{Q}\right)(1 - e^{-KN}) \qquad (7)$$

C = Concentration
G = Combustible, cu ft/min
Q = air, cu ft/min
K = Mixing efficiency factor
N = Number of theoretical air changes.

As an example, consider a leak of 100 cu ft/min (2.8 cu m/min) of a 15 percent combustible gas/air mixture in a room of 1000 cu ft (28 cu m). How long would it take to reach a concentration of 5 percent throughout the enclosure, assuming a mixing coefficient, K, equal to 0.2? Thus:

C = 0.05
G = 15 ft³/min (100 × 0.15)
Q = 85 ft³/min (100 − 15)
K = 0.2.

Equation (7) can be rewritten into a more convenient logarithmic form:

$$\ln\left(1 - \frac{CQ}{G}\right) = -KN \qquad (8)$$

$$\ln\left[1 - \frac{0.05\ (85)}{15}\right] = -0.2N$$

$$\ln\ (0.71667) = -0.2N$$

$$-0.33314 = -0.2N$$

$$1.67 = N.$$

Since the volume is 1000 cu ft and the leak is at 100 cu ft/min,

$$\left(\frac{1000\ \text{ft}^3}{100\ \text{ft}^3/\text{min}}\right) \times (1.67) = 16.7\ \text{min}.$$

A concentration of 5 percent will be reached in 16.7 min.

Equations (5) and (7) can be plotted as shown in Figures D-1 and D-2.

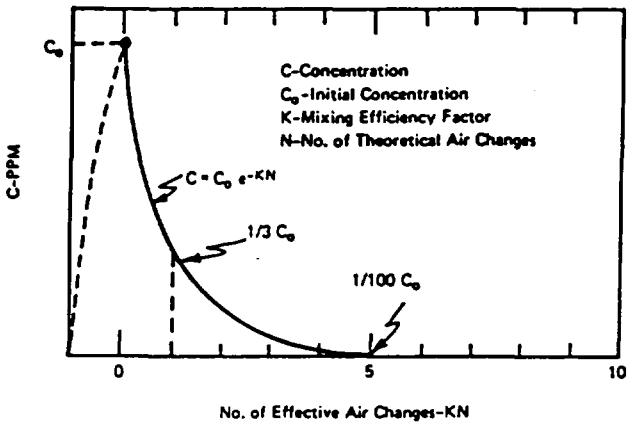

Figure D-1 Combustible decay curve. General ventilation: instantaneous release.

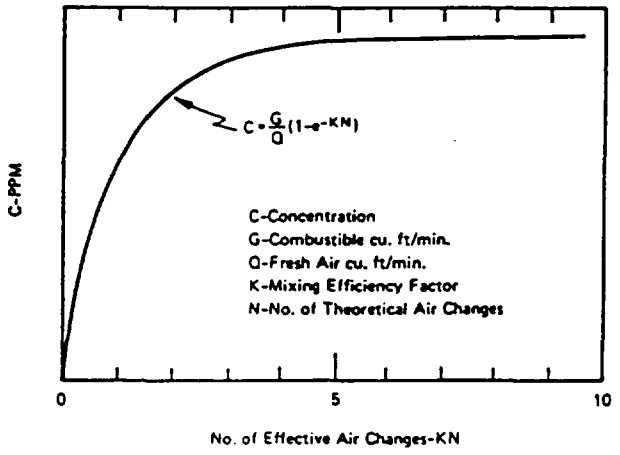

Figure D-2 Combustible buildup curve. General ventilation: continuous release.

With respect to Figure D-2, which illustrates a continuous release in an enclosed volume, once a continuous release begins, the combustible concentration increases rapidly until 3 air changes occur. After three air changes, the bracketed term in Equation (7) approaches unity and concentration does not change much. Thus, steady-state concentration is independent of air-change rate and really depends on the volumetric flow of fresh air. For design purposes it is best to specify in terms of cubic feet per minute and avoid using the approach of specifying in terms of air changes per hour.

Although general ventilation is helpful in removing airborne combustibles, better control can be achieved in many cases by supplementing general ventilation with local ventilation.

Local ventilation can be used when the source of emission can be predicted. For example, local ventilation rather than general ventilation is recommended when:

(a) The operator or ignition sources must be very close to the point of combustible release;

(b) The combustible escape rate is uncertain;

(c) Controlling combustible dusts.

Local exhaust ventilation captures the combustible at its source, and a properly designed system achieves almost 100 percent effectiveness provided that the local exhaust pickup can be placed close to the point of release.

Appendix E Referenced Publications

E-1 The following documents or portions thereof are referenced within this standard for informational purposes only and thus should not be considered part of the requirements of this document. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

E-1.1 NFPA Publication. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 68, *Guide for Venting of Deflagrations*, 1988 edition.

NFPA 325M, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*, 1991 edition.

E-1.2 Bureau of Mines Publications. The following publications are available from the U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Center, 4800 Forbes Avenue, Pittsburgh, PA 15213.

Nagy, J.; Dorsett, H.G., Jr.; Jacobson, M: *Preventing Ignition of Dust Dispersions by Inerting*; Report of Investigations 6543; 1964.

Nagy, J.; Cooper, A.R.; Stupar, J.M.: *Pressure Development in Laboratory Dust Explosions*; Report of Investigations 6561; 1964.

Nagy, J; and Surincik, D.J.: *Thermal Phenomena During Ignition of a Heated Dust Dispersion*; Report of Investigation 6811; 1966.

E-1.3 API Publications. The following publications are available from the American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005.

API RP 521-90, *Guide for Pressure-Relieving and Depressuring Systems*

API STD 2000-82, *Venting Atmospheric and Low-Pressure Storage Tanks (Nonrefrigerated and Refrigerated)*, Third Edition (R-1987).

E-2 Bibliography. This part of the Appendix lists other publications pertinent to the subject of this NFPA document and which may or may not be referenced.

Bartknecht, W.; *Explosions: Course, Prevention, Protection*; Springer-Verlag; Heidelberg; 1981.

Coward, J.F. and Jones, G. W.; *Limits of Flammability of Gases and Vapors*; Bulletin 503; U.S. Bureau of Mines; Pittsburgh, PA; 1952.

Jones, G. W., M. G. Zabetakis, J. K. Richmond, G. S. Scott, and A. L. Furno. Research on the Flammability Characteristics of Aircraft Fuels. Wright Air Development Center, Tech. Report 52-35, Supplement I, 1954, 57 p.

Kuchta, J. M., A. L. Furno, A. Bartkowiak, and G. H. Martindill. Effect of Pressure and Temperature on Flammability Limits of Chlorinated Combustibles in Oxygen-Nitrogen and Nitrogen Tetroxide-Nitrogen Atmospheres. *Jour. Chem. Eng. Data*, v. 13, July 1968, p. 421.

Noronha, J. A.; Merry, J. T.; and Reid, W.C.; *Deflagration Pressure Containment for Vessel Safety Design, Plant/Operations Progress*, Vol. 1, No. 1; American Institute of Chemical Engineers; New York, NY; Jan., 1982.

Schuber, G.; *Rotary Valves for Explosion Isolation: Approval Without Testing*; European Information Centre for Explosion Protection-International Symposuim, Antwerp, Belgium, September, 1989.

Zabetakis, M.G.; *Flammability Characteristics of Combustible Gases and Vapors*; Bulletin 627; U.S. Bureau of Mines, Pittsburgh, PA; 1965.

Zabetakis, M.G.; *Gasfreeing of Cargo Tanks*; Information Circular 7994; U.S. Bureau of Mines; Pittsburg, PA; 1961.

Zabetakis, M. G., B. H. Rosen. Considerations Involved in Handling Kerosine. *Proc. API*, v. 37, Sec. III, 1957, p. 296.

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APPENDIX M
GAS LEAKAGE CONTROL CRITERIA

See para. 852.2.

M1 SCOPE

This Appendix provides criteria for detection, grading, and control of gas leakage.

M2 DEFINITIONS (APPLICABLE TO THIS APPENDIX ONLY)

Bar hole is a hole that is made in the soil or paving for the specific purpose of testing the subsurface atmosphere with a CGI.

Building is any structure which is normally or occasionally entered by humans for business, residential, or other purposes, and in which gas could accumulate.

Combustible gas indicator (CGI) is a device capable of detecting and measuring gas concentrations of the gas being transported in the atmosphere.

Confined space is any subsurface structure, such as vaults, catch basins, or manholes, of sufficient size to accommodate a person, and in which gas could accumulate.

Followup inspection is an inspection performed after a repair has been completed to determine the effectiveness of the repair.

Gas associated substructure is a device or facility utilized by a gas company such as a valve box, vault, test box, or vented casing pipe, which is not intended for storing, transmitting, or distributing gas.

LEL is the lower explosive limit of the gas being transported.

Prompt action shall consist of dispatching qualified personnel without delay for the purpose of evaluating and, where necessary, abating the existing or probable hazard.

Reading is a repeatable deviation on a CGI or equivalent instrument, expressed in LEL. Where the reading is in an unvented confined space, consideration should be given to the rate of dissipation when the space is ventilated and the rate of accumulation when the space is resealed.

Small substructures (other than gas associated substructures) are any subsurface structures that are of insufficient size to accommodate a person, such as telephone and electrical ducts and conduit or nongas-associated valve and meter boxes, and in which gas could accumulate or migrate.

Tunnel is a subsurface passageway large enough for a man to enter and in which gas could accumulate.

M3 LEAKAGE SURVEY AND TEST METHODS

The following gas leakage surveys and test methods may be employed, as applicable, singly or in combination, in accordance with written procedures.

Surface gas detection survey
Subsurface gas detector survey (including bar hole surveys)
Vegetation survey
Pressure drop test
Bubble leakage test
Ultrasonic leakage test

Other survey and test methods may be employed if they are deemed appropriate and are conducted in accordance with procedures which have been tested and proven to be at least equal to the methods listed in this section.

(a) Surface Gas Detection Survey

(1) Definition. A continuous sampling of the atmosphere at or near ground level for buried gas facilities and adjacent to above-ground gas facilities with a gas detector system capable of detecting a concentration of 50 ppm of gas in air at any sampling point.

(2) Procedure. Equipment used to perform these surveys may be portable or mobile. For buried piping, sampling of the atmosphere should take place, where

practical, at no more than 2 in. above the ground surface. In areas where the piping is under pavement, pipings should also be at curb line(s), available *ground surface openings (such as manholes, catch basins*, sewer, power, and telephone duct openings, fire traffic signal boxes, or cracks in the pavement or sidewalk), or other interfaces where the venting of gas is likely to occur. Sampling should be adjacent to the buried piping.

(3) Utilization. The use of this survey method may be limited by adverse conditions (such as excessive wind, excessive soil moisture, or surface sealing by ice or water).

The survey should be conducted at speeds slow enough to allow an adequate sample to be continuously obtained by placement of equipment intakes over the most logical venting locations, giving consideration to the location of gas facilities and any adverse conditions which might exist.

(b) Subsurface Gas Detection Survey

(1) Definition. The sampling of the subsurface atmosphere with a combustible gas indicator (CGI) or other device capable of detecting 0.5% gas in air at the sample point.

(2) Procedure. The survey should be conducted by performing tests with a CGI in a series of available openings (confined spaces and small substructures) or bar holes over, or adjacent to, the gas facility. The location of the gas facility and its proximity to buildings and other structures should be considered in the spacing of the sample points. Sampling points should be as close as possible to the main or pipeline, and not further than 15 ft laterally from the facility. Along the route of the main or pipeline, sampling points should be spaced at twice the distance between the pipeline and the nearest building wall, or at 30 ft, whichever is greater, but, in no case need the spacing be less than 10 ft. The sampling pattern should include sample points adjacent to service taps, street intersections, and known branch connections as well as sampling points over or adjacent to buried service lines at the building wall.

(3) Utilization

(a) Good judgment should be used to determine when available openings (such as manholes, vaults, or valve boxes) are sufficient to provide an adequate survey. When necessary, additional sample points (bar holes) should be made.

(b) Sampling points should be of sufficient depth to sample directly within the subsurface or subsurface atmosphere.

(c) Vegetation Survey

(1) Definition. Visual observations made to detect abnormal or unusual indications in vegetation.

(2) Procedure. All visual indications should be evaluated using a combustible gas indicator (CGI). Personnel performing these surveys should have good allround visibility of the area being surveyed and their speed of travel should be determined by taking into consideration the following:

(a) system layout

(b) amount and type of vegetation

(c) visibility conditions (such as lighting, reflected light, distortions, terrain, or obstructions)

(3) Utilization

(a) This survey method should be limited to areas where adequate vegetation growth is firmly established.

(b) This survey should not be conducted under the following conditions:

(1) soil moisture content abnormally high

(2) vegetation dormant

(3) vegetation in an accelerated growth period, such as in early spring

(c) Other acceptable survey methods should be used for locations within a vegetation survey area where vegetation is not adequate to indicate the presence of leakage.

(d) Pressure Drop Test

(1) Definition. A test to determine if an isolated segment of pipeline loses pressure due to leakage.

(2) Procedure. Facilities selected for pressure drop tests should first be isolated and then tested. The following criteria should be considered in determining test parameters.

(a) Test Pressure. A test conducted on existing facilities solely for the purpose of detecting leakage should be performed at a pressure at least equal to the operating pressure.

(b) Test Medium. The test medium used must comply with the requirements of para. 841.3.

(c) Test Duration. The duration of the test should be of sufficient length to detect leakage. The following should be considered in the determination of the duration:

(1) volume under test

(2) time required for the test medium to become temperature stabilized

(3) sensitivity of the test instrument

(3) Utilization. Pressure drop tests should be used only to establish the presence or absence of a leak on a specifically isolated segment of a pipeline. Normally, this type of test will not provide a leak location. Therefore, facilities on which leakage is indicated may require further evaluation by another detection method in order that the leak may be located, evaluated, and graded.

(e) Bubble Leakage Test

(1) Definition. The application of a soap water or other bubble-forming solutions on exposed piping to determine the existence of a leak.

(2) Procedure. The exposed piping systems should be reasonably cleaned and completely coated with the solution. Leaks are indicated by the presence of bubbles. The bubble-forming solution should not be used on piping unless it has been determined by investigation or test that the piping is adequately resistant to direct contact with the solution.

(3) Utilization. This test method may be used for the following:

(a) testing exposed aboveground portions of a system (such as meter set assemblies or exposed piping or bridge crossings);

(b) testing a tie-in joint or leak repair which is not included in a pressure test.

(f) Ultrasonic Leakage Test

(1) Definition. The testing of exposed piping facilities with an instrument capable of detecting the ultrasonic energy generated by escaping gas. The instrument used should be suitable for the pressure involved.

(2) Procedure. In the testing of a gas facility by this method, the following should be considered.

(a) Line Pressure. As the line pressure increases, the magnitude of the ultrasonic energy generated by a leak increases.

(b) Location of Facility. Objects near or surrounding a facility being tested may reflect or attenuate the ultrasonic energy generated, making it difficult to detect or pinpoint the leak.

(c) Leak Frequency. A number of leaks in a given area can create a high ultrasonic background level which may reduce the detection capabilities of this type test.

(d) Type of Facility. Pneumatic and gas-operated equipment generate ultrasonic energy. The location and amount of this type of equipment should be known to determine if the ultrasonic background is too high.

Personnel conducting this test should scan the entire area to eliminate the tracking of reflected indications.

Ultrasonic indications of leakage should be verified or pinpointed, or both, by one of the other acceptable survey or test methods.

(3) Utilization. The ultrasonic test may be used for the testing of exposed piping facilities. However, if the ultrasonic background level produces a full scale meter reading when the gain is set at midrange, the facility should be tested by some other survey method.

M4 TYPICALLY AVAILABLE INSTRUMENTS FOR THE DETECTION OF GAS

(a) Type and General Usage. A listing of typical available instruments and their type of usage is shown in Table M4.

(b) Maintenance of Instruments. Each instrument utilized for leak detection and evaluation shall be operated in accordance with the manufacturer's recommended operating instructions and:

(1) should be periodically "checked" while in use to insure that the recommended voltage requirements are available;

(2) should be tested daily or prior to use to insure proper operation, to insure that the sampling system is free of leakage, and to insure that the filters are not obstructing the sample flow;

(3) hydrogen flame ionization (HFI) systems should be tested at each startup and periodically during a survey.

(c) Calibration of Instruments. Each instrument utilized for leak detection and evaluation shall be calibrated in accordance with the manufacturer's recommended calibration instructions:

(1) after any repair or replacement of parts;

(2) on a regular schedule, giving consideration to the type and usage of the instrument involved. HFI systems and CGI instruments should be checked for calibration at least once each month while in use.

(3) at any time it is suspected that the instrument's calibration has changed.

M5 LEAKAGE CLASSIFICATION AND ACTION CRITERIA

M5.1 General

The following establishes a procedure by which leakage indications of flammable gas can be graded and controlled. When evaluating any gas leak indication, the preliminary step is to determine the perimeter of the leak area. When this perimeter extends to a building wall, the investigation should continue into the building.

M5.2 Leak Grades

Based on an evaluation of the location or magnitude of a leak, or both, one of the following leak grades shall be assigned, thereby establishing the leak repair priority:

(a) Grade 1 is a leak that represents an existing or

probable hazard to persons or property, and requires immediate repair or continuous action until the conditions are no longer hazardous.

(b) Grade 2 is a leak that is recognized as being nonhazardous at the time of detection, but requires scheduled repair based on probable future hazard.

(c) Grade 3 is a leak that is nonhazardous at the time of detection and can be reasonably expected to remain nonhazardous.

M5.3 Leak Classification and Action Criteria

Criteria for leak classification and leakage control are provided in Tables M5.3A, M5.3B, and M5.3C. The examples of leak conditions provided in the Tables are presented as guidelines and are not exclusive. The judgment of the company personnel at the scene is of primary importance in determining the grade assigned to a leak.

M5.4 Reevaluation of a Leak

When a leak is to be reevaluated (see Action Criteria in Tables M5.3B and M5.3C), it should be classified using the same criteria as when the leak was first discovered.

M6 PINPOINTING

M6.1 Scope

Pinpointing is a systematic process of tracing a detected gas leak to its source. Use of the following procedures as appropriate should prevent unnecessary excavation, which is more time consuming than pinpointing a leak.

M6.2 Procedure

(a) Determine the migration of gas by establishing the outer boundaries of the indications. This will define the area in which the leak will normally be located. These tests should be made with a CGI without expending excessive effort providing sample points.

(b) Locate all gas lines to narrow the area of search, giving particular attention to the location of valves, fittings, tees, and stubs. Connections have a relatively high probability of leakage. Caution should be exercised to prevent damage to other underground structures during barring or excavating.

(c) Identify foreign facilities in the area of search. Look for evidence of recent construction activities which could have contributed to the leakage. Gas may also migrate and vent along a trench provided for other facilities.

(d) Place evenly spaced bar or test holes over the suspected leaking gas line and trace the gas to its source by identifying the test holes with the highest readings. All bar holes should be of equal depth and diameter and down to the pipe depth where necessary in order to obtain consistent and worthwhile readings. All CGI readings should be taken at an equal depth. Only the highest sustained readings should be utilized.

(e) High readings are found frequently in more than one adjacent bar hole and additional techniques are necessary to determine which reading is closest to the probable source. Many of the bar hole readings will normally decline over a period of time, but it may be desirable to dissipate excess gas from the underground locations to hasten this process. Evaluation methods should be used with caution to avoid the distorting of the venting patterns.

(f) Once the underground leakage has been identified, additional holes and deeper holes should be probed to bracket the area more closely. For example, test holes may be spaced 6 ft apart initially. The 6 ft spacing between the two highest test holes might then be probed with additional test holes with spacing as close as 12 in.

(g) Additional tests include taking CGI readings at the top of a bar hole or using a manometer or bubble forming solution to determine which bar hole has the greatest positive flow. Other indications are: dust particles blowing from the bar holes, the sound of gas coming from the bar hole, or the feel of gas flow on a sensitive skin surface. On occasion, sunlight defraction can be observed as the gas vents to the atmosphere.

(h) When gas is found in an underground conduit, tests at available openings may be used to isolate the source in addition to the techniques previously mentioned. Many times the leak is found at the intersection of the foreign conduit and a gas line, and particular attention should be given to these locations.

(i) When the pattern of the CGI readings has stabilized, the bar hole with the highest reading will usually pinpoint the gas leak.

(j) When and where piping has been exposed, test with bubble-forming solution particularly to locate smaller leaks.

M6.3 Precautions

(a) Unusual situations, which are unlikely but possible, may complicate these techniques on some occa-

sions. For example, multiple leakage, which gives confusing data, can occur. To eliminate this potential complication, the area should be rechecked after repairs are completed. Gas may form pockets occasionally and give a strong indication until the cavity in which the pocket has formed has been vented. Foreign gases, such as gas from decomposed material, occasionally may be encountered. This presence is characterized by fairly constant CGI readings between 15% and 30% of gas in air throughout an area. Landfill areas could, thus, give substantially higher readings. Gas detected in sewer systems should be considered as migrating gas leakage until proven otherwise by test and/or analysis.

(b) When pinpointing leakage where the gas is heavier than air (LP gas) the gas will normally stay low near the pipe level, but may flow downhill. LP gases usually do not diffuse rapidly or migrate widely in the soil so the leak is generally close to the indication. If the gas is venting into a duct or sewer system, it can travel considerable distances.

TABLE M4
TYPE AND GENERAL USAGE[1]

Instrument Type		Lower Sensitivity Level			Upper Sensitivity Level			Sampling Method	Sample Flow Rate
Surface Survey	Subsurface Survey	PPM[2]	% LEL	% Gas	PPM	% LEL	% Gas		
...	Catalytic type (hotwire % LEL)	5,000	10	5	50,000	100	5[3]	Hand aspirated	...
...	Thermal conductivity (% Gas)	25,000	50	2.5	...	...	100	Hand aspirated	...
Amplified thermal conductivity	...	50	1	...	...	...	25[3]	Pump	3 liters/min
nfrared detector	...	5	...	...	1,000	2	0.1	Pump	2–5 liters/min
Hydrogen flame[4] ionization detector	...	1	...	...	10,000 to 50,000	20 to 100	1 to 5	Pump	2–5 liters/min

IOTES:

The PPM, percent LEL, and percent gas values shown are for methane concentrations. Where other gases (such as liquefied petroleum gas or manufactured gas) are involved, appropriate adjustment should be made to be commensurate with the criteria of these procedures.

(2) PPM: parts per million.

(3) When the maximum concentration detectable is exceeded, the needle of the instrument meter will drop to zero or below.

4) Upper sensitivity level varies with different models.

TABLE M5.3A
LEAK CLASSIFICATION AND ACTION CRITERIA — GRADE 1

Grade	Definition	Action Criteria	Examples
1	A leak that represents an existing or probable hazard to persons or property, and requires immediate repair or continuous action until the conditions are no longer hazardous.	Requires *prompt action*[1] to protect life and property, and continuous action until the conditions are no longer hazardous.	(1) Any leak which, in the judgment of operating personnel at the scene, is regarded as an immediate hazard. (2) Escaping gas that has ignited. (3) Any indication of gas which has migrated into or under a building or into a tunnel. (4) Any reading at the outside wall of a building, or where gas would likely migrate to an outside wall of a building. (5) Any reading of 80% LEL, or greater in a confined space. (6) Any reading of 80% LEL, or greater in small substructures (other than gas associated substructures) from which gas would likely migrate to the outside wall of a building. (7) Any leak that can be seen, heard, or felt, and which is in a location that may endanger the general public or property.

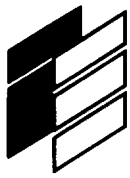
NOTE:
(1) The prompt action in some instances may require one or more of the following:
- (a) implementation of company emergency plan (see para. 850.4);
- (b) evacuating premises;
- (c) blocking off an area;
- (d) rerouting traffic;
- (e) eliminating sources of ignition;
- (f) venting the area;
- (g) stopping the flow of gas by closing valves or other means;
- (h) notifying police and fire departments.

TABLE M5.3B
LEAK CLASSIFICATION AND ACTION CRITERIA — GRADE 2

Grade	Definition	Action Criteria	Examples
	A leak that is recognized as being nonhazardous at the time of detection, but justifies scheduled repair based on probable future hazard.	Leaks should be repaired or cleared within 1 calendar year, but no later than 15 months from the date the leak was reported. In determining the repair priority, criteria such as the following should be considered: (1) amount and migration of gas; (2) proximity of gas to buildings and subsurface structures; (3) extent of pavement; (4) soil type, and soil conditions (such as frost cap, moisture, and natural venting). Grade 2 leaks should be reevaluated at least once every 6 months until cleared. The frequency of reevaluation should be determined by the location and magnitude of the leakage condition. Grade 2 leaks may vary greatly in degree of potential hazard. Some Grade 2 leaks, when evaluated by the above criteria, may justify scheduled repair within the next 5 working days. Others will justify repair within 30 days. During the working day on which the leak is discovered, these situations should be brought to the attention of the individual responsible for scheduling leak repair. On the other hand, many Grade 2 leaks, because of their location and magnitude, can be scheduled for repair on a normal routine basis with periodic reinspection as necessary.	(1) *Leaks Requiring Action Ahead of Ground Freezing or Other Adverse Changes in Venting Conditions.* Any leak which under frozen or other adverse soil conditions would likely migrate to the outside wall of a building. (2) *Leaks Requiring Action Within 6 Months.* (a) any reading of 40% LEL, or greater, under a sidewalk in a wall-to-wall paved area that does not qualify as a Grade 1 leak; (b) any reading of 100% LEL, or greater, under a street in a wall-to-wall paved area that has significant gas migration and does not qualify as a Grade 1 leak; (c) any reading less than 80% LEL in small substructures (other than gas associated substructures) from which gas would likely migrate creating a probable future hazard; (d) any reading between 20% LEL and 80% LEL in a confined space; (e) any reading on a pipeline operating at 30% SMYS, or greater, in a Class 3 or 4 location, which does not qualify as a Grade 1 leak; (f) any reading of 80% LEL, or greater, in gas associated substructures; (g) any leak which, in the judgment of operating personnel at the scene, is of sufficient magnitude to justify scheduled repair.

TABLE M5.3C
LEAK CLASSIFICATION AND ACTION CRITERIA — GRADE 3

Grade	Definition	Action Criteria	Examples
3	A leak that is nonhazardous at the time of detection and can be reasonably expected to remain nonhazardous.	These leaks should be reevaluated during the next scheduled survey or within 15 months of the date reported, whichever occurs first, until the leak is regarded or no longer results in a reading.	*Leaks Requiring Reevaluation at Periodic Intervals* (1) Any reading of less than 80% LEL in small gas associated substructures; (2) any reading under a street in areas without wall-to-wall paving where it is unlikely the gas could migrate to the outside wall of a building; (3) any reading of less than 20% LEL in a confined space.



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