

NFPA 69 Explosion Prevention Systems 1992 Edition



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The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

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Tentative Interim Amendment

NFPA 69

Explosion Prevention Systems

1992 Edition

**Reference: Table C-2
TIA 92-1 (NFPA 69)**

Pursuant to Section 4 of the NFPA Regulations Governing Committee Projects, the National Fire Protection Association has issued the following Tentative Interim Amendment to NFPA 69, *Standard on Explosion Prevention Systems*, 1992 edition. The TIA was processed by the Technical Committee on Explosion Protection Systems and was issued by the Standards Council on January 12, 1995 with an effective date of February 1, 1995.

A Tentative Interim Amendment is tentative because it has not been processed through the entire standards-making procedures. It is interim because it is effective only between editions of the standard. A TIA automatically becomes a proposal of the proponent for the next edition of the standard; as such, it then is subject to all of the procedures of the standards-making process.

1. *Change the title of Table C-2 to read as follows:*

Table C-2 Limiting Oxidant Concentrations When Using Nitrogen or Carbon Dioxide as Diluents.

2. *Change the L.O.C. value for aluminum when using nitrogen from "0" to "5*".*
3. *Add a footnote to read as follows:*

NOTE 5*: Determined by Test. See R. Eckhoff's book, *Dust Explosions in the Process Industries*, p. 586, Butterworth-Heinemann, Oxford, 1991.

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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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NFPA 69
Standard on
Explosion Prevention Systems

1992 Edition

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 ignitable 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:

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

where R is either 9.0 or 10.0 and T_i 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.

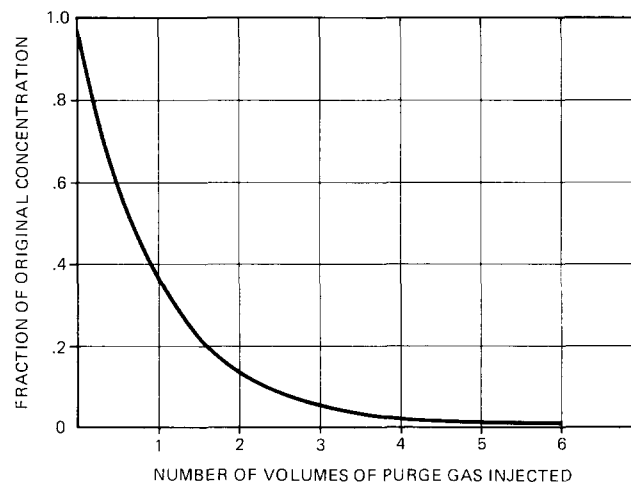


Figure A-2-6(a) Dilution ratio — purging at atmospheric pressure. (Complete mixing assumed.)

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.

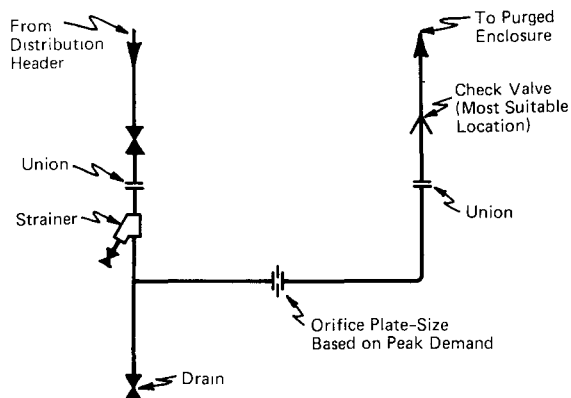


Figure A-2-6(b). Schematic sketch showing method of flow control that may be used with fixed rate application.

(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.

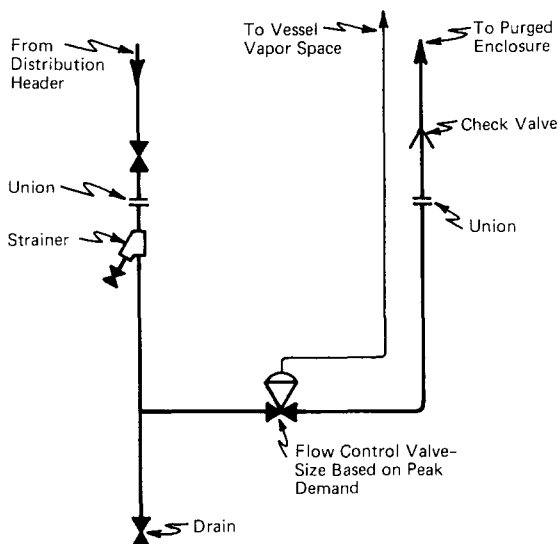


Figure A-2-6(c). Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure A-2-6(d).

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:

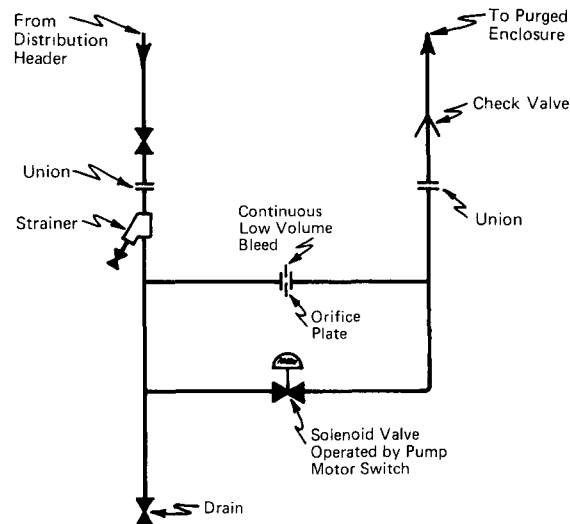


Figure A-2-6(d). Schematic sketch showing a method of flow control that can be used with variable rate application. See also Figure A-2-6(c).

- (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. Schubert.

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.

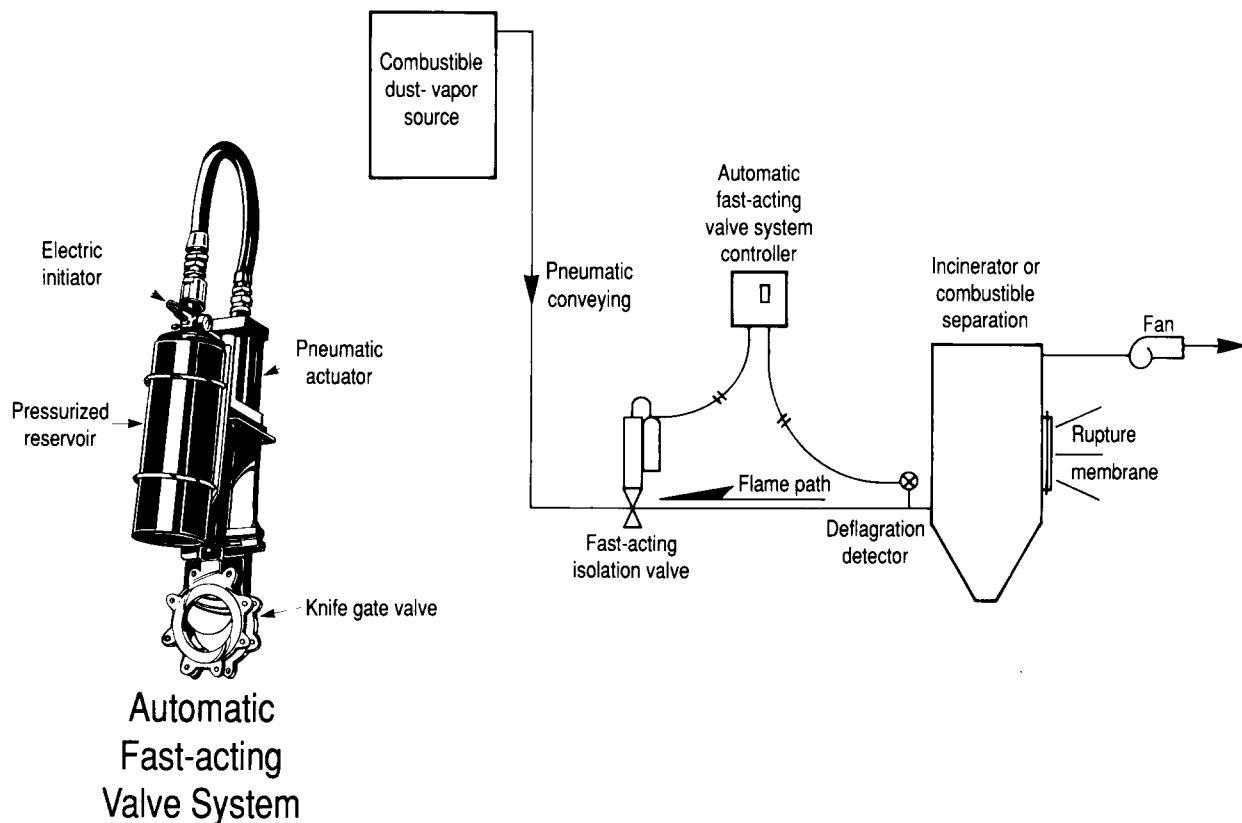


Figure A-7-4 Typical application and design of fast-acting, automatic closing valve assembly.

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.

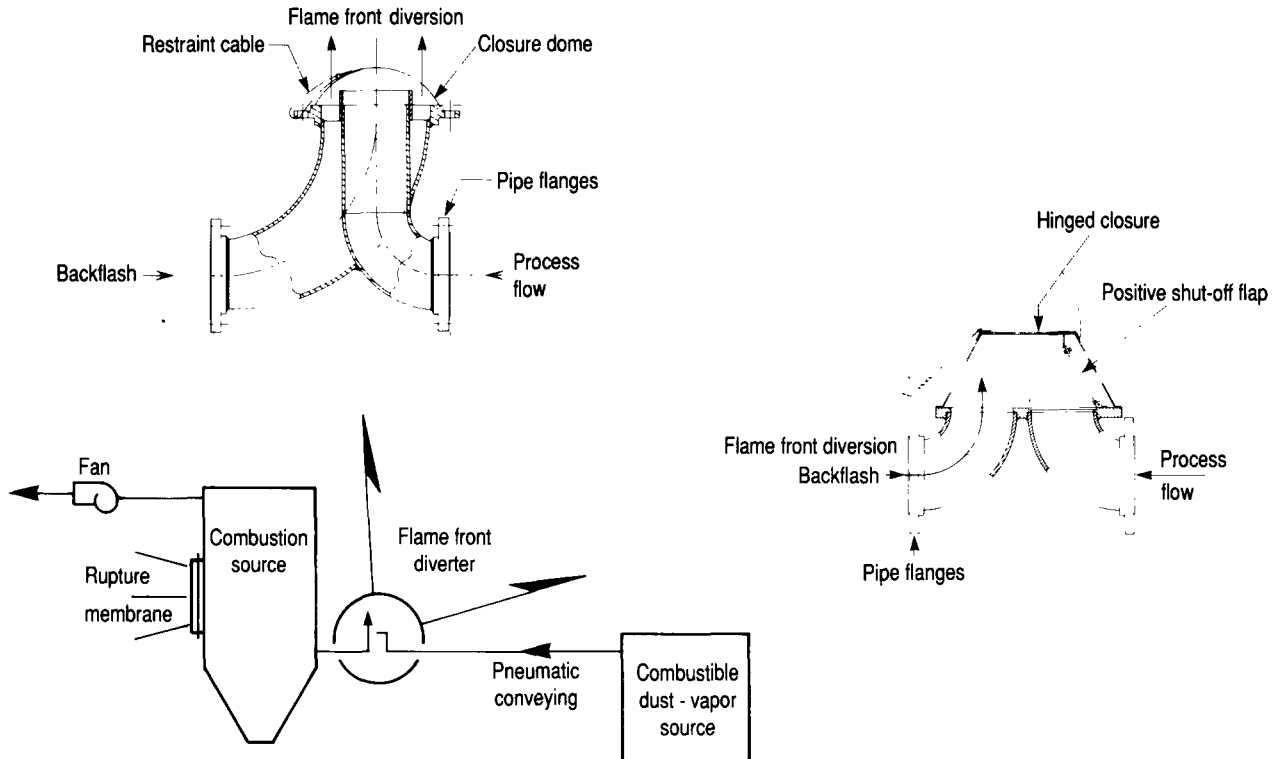


Figure A-7-5 Typical application and design of flame front diverters.

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 ignitable 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.

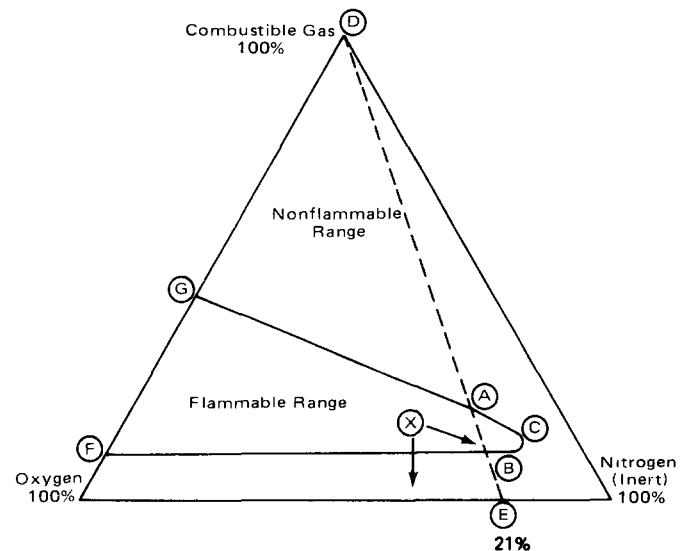


Figure B-1 Typical flammability diagram.

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.

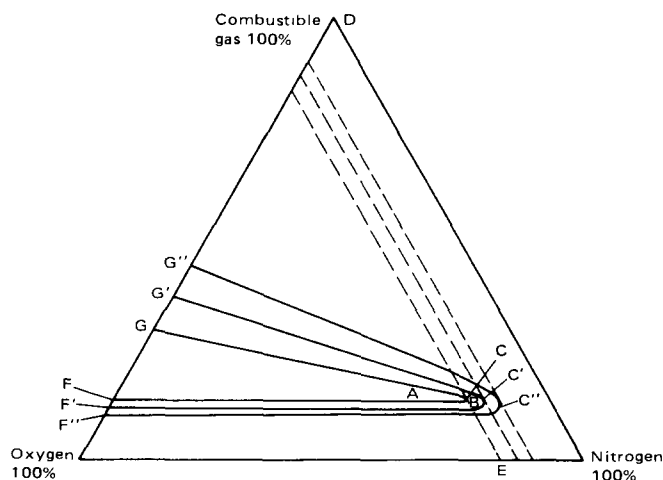


Figure B-2 Effect of pressure on flammability diagram.

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:

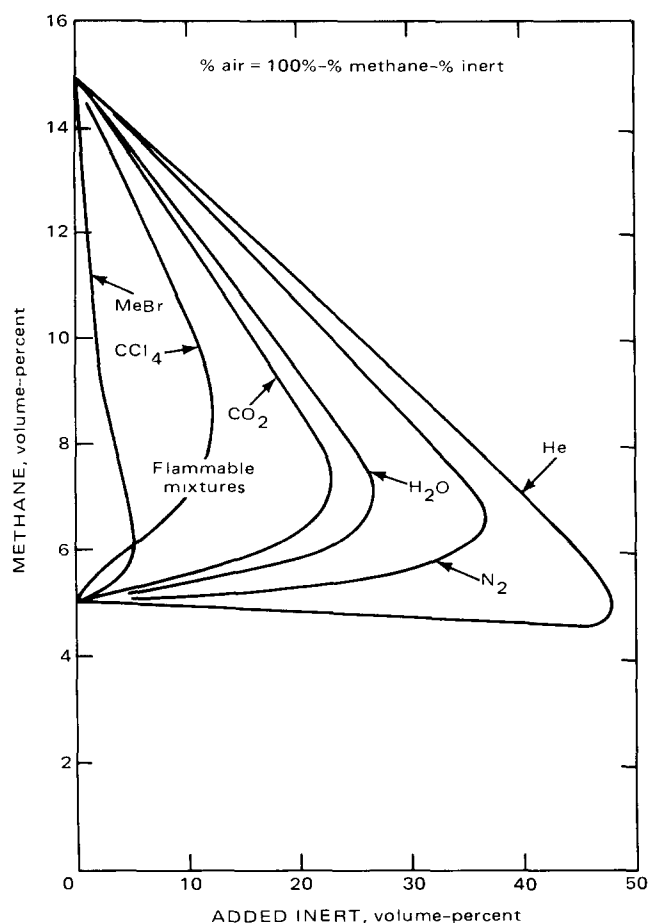


Figure B-3 Limits of flammability of methane-inert gas-air mixtures at 25°C (77°F) and atmospheric pressure.

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

$$\text{Lower Flammable Limit} = \frac{P_1 + P_2 + P_3 + \dots + P_n}{\frac{P_1}{\text{LFL}_1} + \frac{P_2}{\text{LFL}_2} + \dots + \frac{P_n}{\text{LFL}_n}}$$

$$\text{Upper Flammable Limit} = \frac{P_1 + P_2 + P_3 + \dots + P_n}{\frac{P_1}{\text{UFL}_1} + \frac{P_2}{\text{UFL}_2} + \dots + \frac{P_n}{\text{UFL}_n}}$$

Where P_1, P_2 , etc. are the volume fractions of components 1, 2, 3, etc. of the mixture; $\text{LFL}_1, \text{LFL}_2, \text{LFL}_3$, etc. are the lower flammable limits of components 1, 2, 3, etc., respectively; and $\text{UFL}_1, \text{UFL}_2, \text{UFL}_3$, 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

Table C-1 (continued)

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
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
Vinylidene chloride	15	—	7

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 CO₂ 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:

$$VdC = QCdt \quad (1)$$

By rearranging:

$$\int_{C_o}^C \frac{dC}{C} = \frac{Q}{V} \int dt \quad (2)$$

where C_o = initial concentration of gas

t = time required to reach the desired concentration.

Integrating (2) yields:

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

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

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

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	Multiple Exhaust Openings
—No Positive Supply		
Infiltration through cracks, open doors or windows	0.2	0.3
—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):

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

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

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

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

For $K = 1$, $t = 0.49$ min

For $K = 0.2$, $t = 2.5$ min.

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

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

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

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

For $K = 1$, $t = 1.33$ min

For $K = 0.2$, $t = 6.65$ min.

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

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

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

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

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:

$$\left(\frac{C}{C_o} \right) = e^{-K\lambda} \quad (5)$$

Where N = required number of air changes.

Equation (5) can be rewritten:

$$\ln \left(\frac{C}{C_0} \right) = -KN. \quad (5)$$

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 $\frac{1}{2}$ 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:

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

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:

$$C = 0.05$$

$$G = 15 \text{ ft}^3/\text{min} (100 \times 0.15)$$

$$Q = 85 \text{ ft}^3/\text{min} (100 - 15)$$

$$K = 0.2.$$

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

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

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

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

$$-0.33314 = -0.2N$$

$$1.67 = N.$$

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.

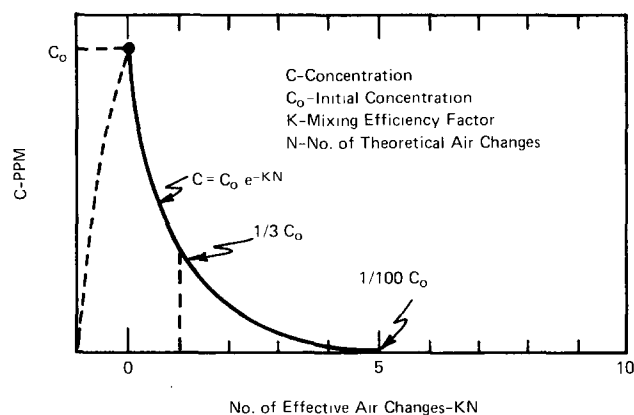


Figure D-1 Combustible decay curve. General ventilation: instantaneous release.

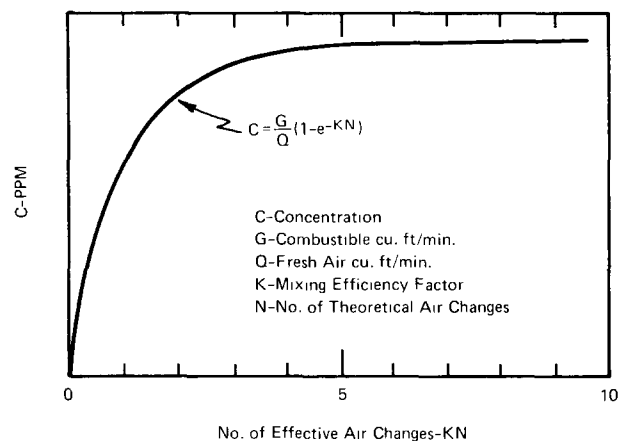


Figure D-2 Combustible buildup curve. General ventilation: continuous release.

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: