

NFPA 69

Standard on Explosion Prevention Systems

2002 Edition



NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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NFPA 69
Standard on
Explosion Prevention Systems
2002 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 NFPA at its May Association Technical Meeting held May 19–23, 2002, in Minneapolis, MN. It was issued by the Standards Council on July 19, 2002, with an effective date of August 8, 2002, and supersedes all previous editions.

This edition of NFPA 69 was approved as an American National Standard on July 19, 2002.

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 on 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.

The 1992 edition of NFPA 69 incorporated a new chapter, on deflagration isolation systems. Partial amendments were made to refine definitions, improve descriptions of oxidant concentration reduction techniques, improve material on deflagration suppression, and fine-tune deflagration pressure containment material.

The 1997 edition of this standard included some reorganization and updating of the technical material to improve its usability. New material was added on enrichment to operate above the upper flammable limit as a means of explosion protection with minimum oxidant concentrations for preventing explosions. Material was added for provisions on reliability of explosion protection control systems and deflagration suppression systems for consistency with other NFPA standards.

The 2002 edition of NFPA 69 includes new information on spark detection and extinguishment system design. A reorganization of the protection methods now reflects a hierarchy based upon the degree of explosion prevention. The LOC values for gases and vapors in Annex C have been updated based upon recent research. The standard has been revised to reflect NFPA *Manual of Style* requirements.

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This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

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

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

A reference in brackets [] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, Annex F lists the complete title and edition of the source documents for both mandatory and nonmandatory extracts. Editorial changes to extracted material consist of revising references to an appropriate division in this document or the inclusion of the document number with the division number when the reference is to the original document. Requests for interpretations or revisions of extracted text shall be sent to the appropriate technical committee.

Information on referenced publications can be found in Chapter 2 and Annex F.

Chapter 1 Administration

1.1 Scope. (Reserved)

1.2 Purpose.

1.2.1 This standard shall cover the minimum requirements for installing systems for the prevention of explosions in enclosures that contain flammable concentrations of flammable gases, vapors, mists, dusts, or hybrid mixtures.

1.2.2 This standard shall provide basic information for design engineers, operating personnel, and authorities having jurisdiction.

1.3 Application.

1.3.1 This standard shall apply to systems and equipment used for the prevention of explosions by the prevention or control of deflagrations.

1.3.2 This standard shall not apply to following:

- (1) Devices or systems designed to protect against detonations
- (2)*Design, construction, and installation of deflagration vents
- (3) Protection against overpressure due to phenomena other than internal deflagrations
- (4) Chemical reactions other than combustion processes
- (5) Unconfined deflagrations, such as open-air or vapor cloud explosions
- (6) Rock dusting of coal mines, as covered by 30 CFR 75
- (7) General use of inert gas for fire extinguishment
- (8)*Preparation of tanks, piping, or other enclosures for hot work, such as cutting and welding
- (9) Ovens or furnaces handling flammable or combustible atmospheres, as covered by the following:
 - (a) NFPA 86, *Standard for Ovens and Furnaces*
 - (b) NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*

(c) NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*

- (10) Marine vapor control systems regulated by 33 CFR 154
- (11) Marine vessel tanks regulated by 46 CFR 30, 32, 35, and 39

1.4 Retroactivity. The provisions of this standard reflect a consensus of what is necessary to provide an acceptable degree of protection from the hazards addressed in this standard at the time the standard was issued.

1.4.1 Unless otherwise specified, the provisions of this standard shall not apply to facilities, equipment, structures, or installations that existed or were approved for construction or installation prior to the effective date of the standard. Where specified, the provisions of this standard shall be retroactive.

1.4.2 In those cases where the authority having jurisdiction determines that the existing situation presents an unacceptable degree of risk, the authority having jurisdiction shall be permitted to apply retroactively any portions of this standard deemed appropriate.

1.4.3 The retroactive requirements of this standard shall be permitted to be modified if their application clearly would be impractical in the judgment of the authority having jurisdiction, and only where it is clearly evident that a reasonable degree of safety is provided.

1.5 Equivalency. Nothing in the standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard.

1.5.1 Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency.

1.5.2 The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

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

NFPA 70, *National Electrical Code*[®], 2001 edition.

NFPA 72[®], *National Fire Alarm Code*[®], 1999 edition.

NFPA 86, *Standard for Ovens and Furnaces*, 1999 edition.

NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*, 1999 edition.

NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*, 1999 edition.

NFPA 651, *Standard for the Machining and Finishing of Aluminum and the Production and Handling of Aluminum Powders*, 1998 edition.

2.3 Other Publications.

2.3.1 ASME Publications. American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5900.

ASME *Boiler and Pressure Vessel Code*, Section VIII, 1998.

ASME B31.3, *Process Piping*, 1999.

2.3.2 ASTM Publication. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 2079, *Standard Test Method for Limiting Oxygen (Oxidant) Concentration for Gases and Vapors*, 2000.

2.3.3 U.S. Government Publications. U.S. Government Printing Office, Washington, DC 20402.

Title 30, *Code of Federal Regulations*, Part 75.

Title 33, *Code of Federal Regulations*, Part 154, "Waterfront Facilities."

Title 46, *Code of Federal Regulations*, Part 30.

Title 46, *Code of Federal Regulations*, Part 32, "Shipping."

Title 46, *Code of Federal Regulations*, Part 35.

Title 46, *Code of Federal Regulations*, Part 39.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not included, common usage of the terms shall apply.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

3.2.3 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is 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.

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

3.2.5 Shall. Indicates a mandatory requirement.

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

3.2.7 Standard. A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix or annex, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

3.3 General Definitions.

3.3.1 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.

3.3.2 Burning Velocity.

3.3.2.1 Flame Burning Velocity. The burning velocity of a laminar flame under specified conditions of composition, temperature, and pressure for unburned gas.

3.3.2.2 Fundamental Burning Velocity. The burning velocity of a laminar flame under stated conditions of composition, temperature, and pressure of the unburned gas. [68:3.3]

3.3.3 Combustible. Capable of undergoing combustion.

3.3.4 Combustible Dust. Any finely divided solid material, 420 microns or smaller in diameter (material passing a U.S. No. 40 standard sieve), that presents a fire or deflagration hazard. [654:1.5]

3.3.5* Combustible Particulate Solid. A combustible solid material comprised of distinct particles or pieces, regardless of size, shape, or chemical composition, that is capable of being pneumatically conveyed.

3.3.6 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 flame.

3.3.7 Concentration Reduction.

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

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

3.3.8 Deflagration. Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium. [68:3.3]

3.3.9 Deflagration Pressure Containment. The technique of specifying the design pressure of a vessel and its appurtenances so they are capable of withstanding the maximum pressures resulting from an internal deflagration.

3.3.10 Deflagration 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.

3.3.11 Detonation. Propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium. [68:3.3]

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

3.3.13 Fast-Acting Valve. A valve that closes a path of deflagration propagation in a pipe or duct in response to upstream detection of a deflagration.

3.3.14* 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.

3.3.15 Flame Front Diverter. A device that opens in response to the pressure wave preceding the flame front of the deflagration, thereby venting the pressure wave and flame front.

3.3.16 Flame Speed. The speed of a flame front relative to a fixed reference point. Flame speed is dependent on turbu-

lence, the equipment geometry, and the fundamental burning velocity. [68:3.3]

3.3.17* Flammable Limits. The minimum and maximum concentrations of a combustible material in a homogeneous mixture with a gaseous oxidizer that will propagate a flame.

3.3.17.1 Lower Flammable Limit (LFL). The lower flammable limit is the lowest concentration of a combustible substance in an oxidizing medium that will propagate a flame.

3.3.17.2 Upper Flammable Limit (UFL). The upper flammable limit is the highest concentration of a combustible substance in an oxidizing medium that will propagate a flame.

3.3.18 Flammable Range. The range of concentrations between the lower and upper flammable limits. [68:3.3]

3.3.19 Gas. The state of matter characterized by complete molecular mobility and unlimited expansion; used synonymously with the term *vapor*. [68:3.3]

3.3.19.1 Inert Gas. A gas that is noncombustible and nonreactive.

3.3.19.2 Purge Gas. An inert or a combustible gas that is continuously or intermittently added to a system to render the atmosphere nonignitable.

3.3.20 Hybrid Mixture. A mixture of a flammable gas with either a combustible dust or combustible mist. [68:3.3]

3.3.21 Inerting. A technique by which a combustible mixture is rendered nonignitable by adding an inert gas or a noncombustible dust. (*See also Blanketing.*)

3.3.22* Isolation. A means of preventing certain stream properties from being conveyed past a predefined point.

3.3.22.1 Chemical Isolation. A means of preventing flame front and ignition from being conveyed past a predetermined point by injection of a chemical suppressant.

3.3.22.2 Deflagration Isolation. A method employing equipment and procedures that interrupts the propagation of a deflagration flame front past a predetermined point.

3.3.22.3 Flow Isolation. A method employing equipment and procedures that interrupts flow and prevents pressure rise beyond a predetermined point.

3.3.22.4 Ignition Source Isolation. A method employing equipment and procedures that interrupts the propagation of an igniting medium past a predetermined point.

3.3.23* Limiting Oxidant Concentration (LOC). The concentration of oxidant below which a deflagration cannot occur. Materials other than oxygen can act as the oxidants. [86:2.2]

3.3.24 Liquid Seal. A device that prevents the passage of flame by passing the gas mixture through a noncombustible liquid.

3.3.25 Maximum Pressure (P_{max}). The maximum pressure developed in a contained deflagration for an optimum mixture. [68:3.3]

3.3.26 Mist. A dispersion of fine liquid droplets in a gaseous medium. [68:3.3]

3.3.27 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. [68:3.3]

3.3.28 Padding. See 3.3.1.

3.3.29 Pressure Piling. A condition during deflagration in which pressure increases in the unreacted medium ahead of the propagating combustion zone.

3.3.30 Spark Extinguishing System. An extinguishing system in which the radiant energy of a spark or an ember is detected and the spark or ember is quenched.

3.3.31 Suppressant. The chemical agent used in a deflagration suppression system to extinguish the deflagration.

3.3.32 Vapor. See 3.3.19.

3.3.33 Ventilation. The changing of an atmosphere of any space by natural or mechanical means.

Chapter 4 General Requirements

4.1* Methods. The methods recognized in this standard shall be grouped based on the prevention of combustion or on the prevention or limitation of damage after combustion occurs.

4.1.1 Methods Based on the Prevention of Combustion. The following shall be considered methods based on preventing combustion:

- (1) Oxidant concentration reduction
- (2) Combustible concentration reduction

4.1.2 Methods Based on the Prevention or Limitation of Damage. The following shall be considered methods based on preventing or limiting damage:

- (1) Spark extinguishing systems
- (2) Deflagration suppression
- (3) Isolation methods
- (4) Deflagration pressure containment

4.2 Limitations. The limitations specific to each method shall be considered and are specified in the corresponding chapter for each method.

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

- (1) Effectiveness of each method
- (2) Reliability of the system
- (3) Personnel hazards inherent in each method

4.3.1 The reliability of the system chosen shall be assessed using the following factors:

- (1) System design basis
- (2) Possibility of electrical and mechanical malfunction
- (3) Dependence on sophisticated activating systems
- (4) Need for special installation, training, operating, testing, and maintenance procedures
- (5) Further limitations as presented in each chapter

4.3.2 In general, explosion prevention systems shall be used to protect processing, storage, and materials handling equipment.

4.3.3 When explosion prevention techniques are applied to rooms, buildings, or other enclosures where personnel are present, consideration shall be given to the safety of the personnel.

4.4 Plans.

4.4.1 Plans, system specifications, and manufacturer's recommendations for testing and maintenance shall contain

information that enables the authority having jurisdiction to evaluate the explosion hazard and the effectiveness of the system.

4.4.2 Details of the plans shall include the following:

- (1) Pertinent chemical and physical characteristics of the materials involved
- (2) Location of hazards
- (3) Enclosures or limits and isolation of the hazards
- (4) Exposures to the hazards

4.5 Acceptance Test. All new system installations and modifications shall be tested or otherwise evaluated to confirm the operational integrity of the system.

4.5.1 Tests shall be in accordance with the manufacturer's recommendations.

4.5.2 A written report of the tests shall be provided to the users.

4.6* Inspection and Maintenance.

4.6.1* All systems shall be inspected for operability in accordance with the manufacturer's recommendations.

4.6.2 An inspection and preventive maintenance schedule shall be established in accordance with the manufacturer's recommendations.

Chapter 5 Deflagration Prevention by Oxidant Concentration Reduction

5.1 Application. The technique for oxidant concentration reduction for deflagration prevention shall be permitted to be considered where a mixture of oxidant and flammable material is confined to an enclosure within which the oxidant concentration can be controlled.

5.1.1* The system shall be maintained at an oxidant concentration that is low enough to prevent a deflagration.

5.1.2 Oxidant concentration reduction shall be permitted to be applied to rooms or buildings, but one of the following shall apply, since oxygen-deficient atmospheres cannot sustain life:

- (1) Operations in such areas shall be remotely controlled.
- (2) Operating personnel shall be provided with breathing apparatus, as well as other safeguards.

5.2 Design and Operating Requirements.

5.2.1* Design Considerations. The following factors shall be considered in the design of a system intended to reduce the oxidant concentration:

- (1) Required reduction in oxidant concentration
- (2) Variations in the process, process temperature and pressure, and materials being processed
- (3) Source purge gas supply and equipment installation
- (4) Compatibility of the purge gas with the process
- (5) Operating controls
- (6) Maintenance, inspection, and testing
- (7) Leakage of purge gas to surrounding areas
- (8) Need for breathing apparatus by personnel

5.2.2 Limiting Oxidant Concentrations (LOC).

5.2.2.1* Table C.1(a), Table C.1(b), and Table C.1(c) shall be permitted to be used as a basis for determining limiting ox-

idant concentrations of flammable gases or suspensions of combustible dusts.

5.2.2.2 For fuel/inert/oxidant combinations not listed in Table C.1(a), Table C.1(b), and Table C.1(c) or for situations when the process conditions differ from the conditions under which the existing data were obtained, the test methods described in ASTM E 2079, *Standard Test Method for Limiting Oxygen (Oxidant) Concentration for Gases and Vapors*, shall be permitted to be used.

5.2.2.3 The extent of oxidant reduction shall be determined by testing where conditions vary significantly from the test conditions under which the data were obtained.

5.2.3 Use of Purge Gas Systems.

5.2.3.1 An additional backflash prevention or protection system shall be installed if a purge gas system is used for lines collecting flammable mixtures and the collection system terminates at a flare or incinerator.

5.2.3.2 Hard-piped vapor control systems shall not require flame arresters at each source connection to the system, provided that the system is designed to operate outside the flammable range.

5.2.3.3 Systems requiring hookups prior to vapor transfer, such as vapor collection from mobile vehicles, shall be purged to a level below the LOC prior to transfer, or backflash protection shall be provided near the point of connection.

5.2.3.4* Where oxygen-deficient atmospheres are maintained in equipment operating under conditions that might form pyrophoric iron sulfides or other pyrophoric materials, a procedure shall be developed to prevent uncontrolled oxidation of the sulfides or other pyrophoric materials.

5.3 Purge Gas Sources.

5.3.1 The purge gas shall be obtained from a source that is capable of continuously supplying the required amount of purge gas to maintain the necessary degree of oxidant deficiency.

5.3.2 Possible sources of purge gas shall include, but shall not be limited to, the following:

- (1) Commercially available inert gas, such as nitrogen, carbon dioxide, argon, or helium, supplied from high-pressure tanks or cylinders or from air separation plants
- (2) Inert gas supplied from a gas generator that burns or catalytically oxidizes a hydrocarbon to produce an oxygen-deficient purge gas
- (3) Products of combustion from process furnaces or boiler furnaces for which purification or cooling could be necessary to avoid contamination
- (4)*Steam, if it can be supplied at a rate that raises and maintains the protected vessel or system at a temperature high enough to prevent condensation of the steam
- (5) High-purity nitrogen supplied by air oxidation of ammonia
- (6) Inert gas supplied by removal of oxygen from air by absorption, adsorption, chemical reaction, or membrane permeation
- (7) Fuel gases such as methane or natural gas

5.4 Purge Gas Conditioning.

5.4.1 Purge gas shall be conditioned to minimize contaminants that might be harmful to the gas distribution system or that might interfere with the operation of the system.

5.4.2 Before introduction, the purge gas shall be at a temperature compatible with the process being protected to minimize the chance of thermal ignition or condensation.

5.4.3 Purge gas that is distributed in a system subject to freezing temperatures shall have a dew point such that water condensation cannot occur at the minimum ambient temperature to which the system will be exposed.

5.5 Piping Systems. Purge gas distribution systems shall be designed and installed in accordance with recognized engineering practices.

5.5.1 Where purge gas exceeds a gauge pressure of 15 psi (103 kPa), the piping system shall be designed in accordance with ANSI/ASME B31.3, *Process Piping*.

5.5.2 Where required, 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.

5.5.3 Where required, moisture traps shall be provided and lines shall drain toward the traps.

5.5.3.1 Blowdown connections for moisture traps shall be provided.

5.5.3.2 Moisture traps shall be protected from freezing.

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

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

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

5.5.6.1 Where required, check valves or other design features shall be incorporated to prevent the potential for contamination due to loss of purge gas supply or to excessive pressure in the process unit being protected.

5.5.6.2 A single check valve shall not be considered a positive backflow connection.

5.5.7* Cross-connections between the purge gas distribution system and any other system shall be prohibited unless one of the following criteria is met:

- (1) Positive measures shall be taken to prevent backflow from the other system into the purge gas system.
- (2) Cross-connections to backup purge gas systems shall be permitted without backflow prevention unless backflow could create a hazard.

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

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

5.6 Application of Purge Gas at Points of Use. Purge gas shall be introduced and exhausted so that distribution is ensured and the desired reduction in oxidant concentration is maintained throughout the system being protected.

5.6.1 Multiple inlets and outlets shall be permitted.

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

5.7 Instrumentation.

5.7.1* General. Instrumentation shall be provided to monitor the purge gas being supplied to the distribution system.

5.7.1.1 Instrumentation shall be calibrated at scheduled intervals.

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

5.7.2 Systems Operated Below the Limiting Oxidant Concentration (LOC).

5.7.2.1* Instrumentation shall be installed in as many points as necessary to ensure the desired oxidant concentration reduction within the protected system.

5.7.2.2 The determination of the LOC for the system shall be based on the worst credible case gas mixture yielding the smallest LOC.

5.7.2.3 A safety margin shall be maintained between the LOC and the normal working concentration in the system.

5.7.2.4* The safety margin shall take into account all of the following:

- (1) Fluctuations occurring in the system
- (2) Sensitivity and reliability of monitoring and control equipment
- (3) Probability and consequences of an explosion

5.7.2.5 One of the following requirements shall be met where the oxygen concentration is continually monitored:

- (1) A safety margin of at least 2 volume percent below the worst credible case LOC shall be maintained.
- (2) The LOC shall be less than 5 percent, in which case, the equipment shall be operated at no more than 60 percent of the LOC.

5.7.2.6 The requirement of 5.7.2.5 shall not apply to partial oxidation processes.

5.7.2.7 Where the oxygen concentration is not continuously monitored, all of the following requirements shall be met:

- (1) 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.
- (2) The oxygen concentration shall be checked on a regularly scheduled basis.

5.7.2.7.1* The vapor space in low-pressure field storage tanks that have padding shall not require checking of the oxygen concentration.

5.7.2.7.2 The procedure of pulling a partial vacuum and then breaking the vacuum with inert gas shall be permitted without measuring the oxygen concentration if all of the following apply:

- (1) The vacuum condition is held for a time to check for leakage.
- (2) The vacuum level is monitored.
- (3) The vacuum-creating medium is compatible with the process chemistry.
- (4) The residual oxygen partial pressure is calculated or demonstrated by test to be at least 40 percent below the LOC.

5.7.3 Systems Operated Above the Upper Flammable Limit (UFL).

5.7.3.1* Systems operating above the UFL shall be permitted to be used, and the UFL shall be determined at the conditions applicable to the system.

5.7.3.2 Vent headers operated near atmospheric pressure shall be permitted to be rendered nonflammable by the addition of at least 25 volume percent of natural gas or methane where both of the following criteria are met:

- (1) The vent headers shall not contain any vapor with a UFL greater than that of hydrogen in air (75 percent).
- (2) The vent headers shall not contain oxygen in concentrations greater than can be derived from ambient air.

5.7.3.3 Instrumentation to control methane flow shall be acceptable to the authority having jurisdiction.

Chapter 6 Deflagration Prevention by Combustible Concentration Reduction

6.1* Application. The technique for combustible concentration reduction shall be permitted to be considered 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 (LFL).

6.2 Basic Design Considerations.

6.2.1 All of the following factors shall be considered in the design of a system intended to reduce the combustible concentration below the lower flammable limit (LFL):

- (1) Required reduction in combustible concentration
- (2) Variations in the process, process temperature and pressure, and materials being processed
- (3) Operating controls
- (4) Maintenance, inspection, and testing

6.2.2* The lower flammable limits of the combustible components shall be determined at all operating conditions, including startup and shutdown.

6.3 Design and Operating Requirements.

6.3.1 Combustible Concentration Limit. The combustible concentration shall be maintained at or below 25 percent of the lower flammable limit (LFL), unless the following conditions apply:

- (1) Where 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.
- (2) Aluminum powder production systems designed and operated in accordance with NFPA 651, *Standard for the Machining and Finishing of Aluminum and the Production and Handling of Aluminum Powders*, shall be permitted to be maintained at or below 50 percent of the lower flammable limit.

6.3.2* Catalytic Oxidation. Where catalytic oxidation is used for combustible concentration reduction, flame arresters shall be provided and the following requirements shall apply:

- (1) Flame arresters shall be provided in all inlets to the catalytic oxidation unit.
- (2) Flame arresters shall be periodically inspected and maintained.

6.3.3 Ventilation or Air Dilution.

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

6.3.3.2 Air intakes shall meet one of the following requirements:

- (1) They shall be located so that combustible material cannot enter the air-handling system, even in the event of spills or leaks.
- (2) They shall be provided with gas detectors that automatically interlock to stop air intake.

6.3.3.3 Filters, dryers, or precipitators in the air intakes shall be located such that they are accessible for cleaning and maintenance.

6.4 Instrumentation.

6.4.1 Instrumentation shall be provided to monitor the control of the concentration of combustible components.

6.4.2 Instrumentation shall be calibrated at scheduled intervals.

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

Chapter 7 Deflagration Prevention by Hot Particle Detection and Intervention Systems

7.1 Application. Spark extinguishing systems shall be permitted to be considered for reducing the frequency of deflagrations in transport and receiving systems that handle combustible particulate solids.

7.1.1 Spark detection and extinguishing shall be used in conjunction with other explosion prevention or explosion protection measures, such as deflagration suppression or deflagration venting, for those systems posing a dust explosion hazard.

7.1.2 Spark extinguishing systems shall be used for the detection and extinguishment of sparks or embers as they pass through ducts that transport combustible dusts or solids.

7.1.3 The spark extinguishing system shall operate by means of detectors that sense the radiation from a hot or glowing particle and actuate a special extinguishing system that quenches the particle.

7.1.4 Because the detection is by means of radiation, spark detection systems shall not be used in duct systems that have openings through which incident light could affect the detectors, unless the detectors are designed to be insensitive to visible light.

7.2 Limitations.

7.2.1 Spark extinguishing systems shall not be used for ducts designed to transport flammable gases.

7.2.2 Spark extinguishing systems shall not be used where the extinguishing agent creates a hazard.

7.2.3* Spark detection and spark extinguishing systems shall be limited to the detection and extinguishment of sparks or embers traveling at the system transport velocity.

7.2.4 Spark detection and spark extinguishing systems shall not be used in extinguishing deflagration flame fronts or flow isolation.

7.3 Spark Detection and Spark Extinguishing System Design Considerations.

7.3.1* General. Spark detection and spark extinguishing systems shall be listed or approved.

7.3.2 Detectors.

7.3.2.1 Spacing between a detector and the extinguishing agent injection point shall be based on all of the following:

- (1) Linear velocity of the material in the duct
- (2) Response time of the detector
- (3) Actuator circuitry

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

7.3.2.3 Provisions shall be made to prevent obscuration of radiant energy detectors.

7.3.2.4 Detectors shall be protected from the accumulation of foreign material that would prevent functioning.

7.3.3 Power/Control Units.

7.3.3.1 A power/control unit with a minimum 24-hour standby battery backup shall be provided with each suppression system and shall supply energy to accomplish all of the following:

- (1) Power all detection devices
- (2) Energize all electrically actuated extinguishing systems
- (3) Energize visual and audible alarms
- (4) Transfer all auxiliary control and alarm contacts
- (5) Control system-disabling interlock and process shutdown circuits

7.3.3.2 The power/control unit shall meet the applicable requirements of 1.5.2 and Chapter 3 of *NFPA 72, National Fire Alarm Code*[®].

7.3.3.3 The power/control unit shall, as a minimum, fully and continuously supervise all of the following:

- (1) Wiring circuits for opens and other faults
- (2) AC power supply (primary)
- (3) Battery voltage, presence, and polarity
- (4) System safety interlock circuitry
- (5) System-disabling interlock circuitry
- (6) Releasing outputs
- (7) Electrical extinguishing actuators
- (8) Detectors
- (9) Visible and audible alarms
- (10) Circuit ground fault

7.3.3.4 In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

7.3.3.5 The supervisory signal circuits shall be provided with a visual and audible trouble signal.

7.3.4 Extinguishing System.

7.3.4.1 Discharge nozzles shall be located and arranged so that solid particles cannot obstruct the nozzles.

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

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

7.3.4.4 The system shall contain enough extinguishing agent to provide for no less than 100 operations of the system.

7.3.4.5 An alarm shall sound when the pressure of the extinguishing agent falls below the minimum supply pressure specified by the manufacturer.

7.3.4.6 Auxiliary heating systems for extinguishing agent storage shall be provided, when necessary, and shall comply with all of the following:

- (1) The temperature of the extinguishing agent shall be supervised.
- (2) An alarm shall sound at both the low and high temperature limits.

7.3.5 Other Intervention Systems. Other intervention systems, including the following, shall be permitted to be actuated by the optical detection system:

- (1) Water deluge
- (2) Carbon dioxide flooding
- (3) Automatic fast-acting valves
- (4) Diverting valves
- (5) Steam snuffing

7.4 Testing. A functional test of the extinguishing portion of the system shall be conducted in accordance with the manufacturer's specifications.

7.5 Spark Detection and Spark Extinguishing System Inspection and Maintenance. Spark extinguishing systems shall be inspected and maintained in accordance with the manufacturer's recommendations.

7.5.1 A written report on the most recent inspection shall be kept on file for review.

7.5.2 The report shall include test and calibration data on all system components.

Chapter 8 Deflagration Control by Suppression

8.1 Application.

8.1.1 The technique for deflagration suppression shall be permitted to be considered for most flammable gases, combustible mists, or combustible dusts that are subject to deflagration in a gas phase oxidant.

8.1.2 Enclosures that can be protected by a deflagration suppression system shall include, but shall not be limited to, the following:

- (1) Processing equipment, such as reactor vessels, mixers, blenders, pulverizers, mills, dryers, ovens, filters, screens, and dust collectors
- (2) Storage equipment, such as atmospheric or low-pressure tanks, pressure tanks, and mobile facilities
- (3) Material-handling equipment, such as pneumatic and screw conveyors and bucket elevators
- (4) Laboratory and pilot plant equipment, including hoods, glove boxes, test cells, and other equipment
- (5) Aerosol filling rooms

8.2 Limitations.

8.2.1 Deflagration suppression is successful only where the suppressant can be distributed during the early stages of flame development.

8.2.2 Deflagration suppression is limited by the physical and chemical properties of the reactants in the system, as well as the design and construction of the enclosure.

8.2.3 The strength of the protected enclosure shall be greater than the maximum suppressed deflagration pressure (including effects of suppressant discharge).

8.3 Personnel Safety.

8.3.1* Disarming and Lockout/Tagout Procedures.

8.3.1.1 Disarming and lockout/tagout procedures shall be followed prior to entering equipment protected by deflagration suppression systems.

8.3.1.2 The deflagration suppression system shall be disarmed prior to performing maintenance operations on the protected equipment if discharging the suppressant could result in injury.

8.3.1.3 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 armed.

8.3.2 Training. Personnel shall be trained in the safety procedures that are to be carried out prior to, during, and after maintenance.

8.4 Basic Design Considerations.

8.4.1 General. The design of a deflagration suppression system shall include, but shall not be limited to, the following:

- (1) Deflagration characteristics of the combustible material
- (2) Identification of equipment to be protected and its design specifications
- (3) Detection technique
- (4) Suppressant
- (5) Installation, operation, and test procedures

8.4.2 Process Analysis.

8.4.2.1 A thorough analysis of the process shall be conducted to determine the type and degree of deflagration hazards inherent in the process.

8.4.2.2 Factors such as the type of combustible, the internal geometry and total volume to be protected, and the operating conditions shall be reviewed in detail.

8.4.2.3 The potential malfunctions that could affect the extent of the deflagration hazard also shall be determined.

8.4.3 Actuation of Other Devices and Systems. The deflagration suppression system shall be permitted to actuate other devices and systems such as high-speed isolation valves, rapid pneumatic conveying system shutdowns, or deflagration vents.

8.4.4 Drawings and Design Calculations.

8.4.4.1 Drawings and design calculations shall be developed for each system.

8.4.4.2 Calculations of the final reduced deflagration pressures shall be provided.

8.5 Power/Control Units.

8.5.1 A power/control unit with a standby battery backup of no less than 24 hours shall be provided with each suppression system and shall supply energy to accomplish the following:

- (1) Power all detection devices

- (2) Energize all electrically fired initiators
- (3) Energize visual and audible alarms
- (4) Transfer all auxiliary control and alarm contacts
- (5) Control system-disabling interlock and process shutdown circuits

8.5.2 The power/control unit shall meet the applicable requirements of 1.5.2 and Chapter 3 of *NFPA 72, National Fire Alarm Code*.

8.5.3 The power/control unit shall, as a minimum, fully and continuously supervise the following:

- (1) Wiring circuits for opens and other faults
- (2) AC power supply (primary)
- (3) Battery voltage, presence, and polarity
- (4) System safety interlock circuitry
- (5) System-disabling interlock circuitry
- (6) Releasing outputs
- (7) Electrically fired initiators
- (8) Detectors
- (9) Visual and audible alarms
- (10) Circuit ground fault

8.5.4 In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

8.5.5 The supervisory signal circuits shall be provided with a visual and audible trouble signal.

8.6 Detectors.

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

8.6.2 Provisions shall be made to prevent obscuration of radiant energy detectors.

8.6.3 Detectors shall be protected from the accumulation of foreign material that would prevent functioning.

8.7 Electrically Fired Initiators.

8.7.1 Electrically fired initiators shall be mounted so that their maximum temperature rating, as specified by the manufacturer, is not exceeded.

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

8.8* Suppressant and Suppressant Storage Containers.

8.8.1 The suppressant shall be compatible with the combustible material in the protected enclosure.

8.8.2 The suppressant shall be effective at the expected extremes of temperature encountered in the protected enclosure.

8.8.3 Means shall be provided to verify the pressure of the pressurized reservoirs.

8.9 Installation.

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

8.9.2 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.

8.9.3 Means shall be used to protect detectors and suppressant discharge devices from accumulating foreign material that would prevent functioning.

8.9.4 Terminals and mechanical parts shall be protected from moisture and other contaminants.

8.9.5 The temperatures at mounting locations shall not exceed the maximum operating temperatures of system components.

8.10 Electrical.

8.10.1 Wiring for the control circuits shall be isolated and shielded from all other wiring to prevent possible induced currents.

8.10.2 Where environmental conditions warrant, conduits shall be sealed to prevent the entrance of moisture and other contaminants.

8.10.3 Where a conduit is used for wiring multiple installations, the wiring for each suppression system shall be run in separate conduits or wired with shielded cables run in common conduits.

8.10.4 All wiring shall meet the applicable requirements of NFPA 70, *National Electrical Code*.

8.11 Inspection and Maintenance of Deflagration Suppression Systems.

8.11.1* Equipment shall be designed to allow inspection of nozzles and detectors.

8.11.2 Suppression systems shall be inspected and tested at 3-month intervals by personnel trained by the system's manufacturer.

8.11.3* Containers of suppressant shall be checked for pressure and loss of agent.

8.11.4 A container having a pressure (corrected for temperature) that is less than the minimum value specified by the manufacturer shall be reconditioned or replaced.

8.11.5 Detectors shall be tested and calibrated as necessary to meet system specifications.

8.11.6 System interlocks shall be verified for functioning.

8.11.7 The control unit shall be tested to ensure that the system functions as required and that all external circuits are supervised.

8.11.8 A written report on the most recent inspection shall be kept on file for review.

8.11.9 The report of the most recent inspection shall include test and calibration data on all system components.

8.11.10 Extinguishing agent cylinders shall be hydrostatically tested consistent with DOT requirements.

8.12 Procedures After System Actuation. In the event of system actuation, inspection and testing as specified in 8.11.2 shall be performed before the system is returned to service.

Chapter 9 Deflagration Control by Isolation

9.1 Application.

9.1.1* The technique for deflagration isolation shall be permitted to be considered for interruption or mitigation of

flame, deflagration pressures, pressure piling, and flame-jet ignition between equipment that is interconnected by pipes or ducts.

9.1.2 One or more of the technologies described in this chapter shall be permitted to be used with other explosion prevention systems described in this standard, in addition to, or in conjunction with, deflagration venting.

9.1.3 Isolation methods shall be used to prevent the passage of, to arrest, to divert, or to extinguish the deflagration flame front and, in some cases, the combustion-generated pressure.

9.1.4 Isolation shall be permitted to be used for flammable gases or combustible dust systems.

9.1.5* Isolation system design shall be permitted to be based on various techniques that include, but are not limited to, the use of the following:

- (1) Rotary valves
- (2) Flame arresters
- (3) Automatic fast-acting valves
- (4) Flame front diverters
- (5) Flame front extinguishing systems
- (6) Liquid seals
- (7) Spark detection and spark extinguishing systems

9.1.6 The strength of piping, ducts, and enclosures in an isolation system shall be designed to withstand anticipated pressures.

9.2* Rotary Valves.

9.2.1 Rotary valves shall be used only for systems handling combustible dust.

9.2.2 Rotary valves intended for deflagration isolation systems shall be designed as follows:

- (1) A clearance that is small enough to prevent the passage of flame shall be provided between the rotor and the valve housing.
- (2) At least two vanes on each side of the valve housing shall be in a position of minimum clearance at all times.

9.2.3 Rotary valves shall be capable of withstanding the maximum expected pressure.

9.2.4* Rotary valves intended for deflagration isolation systems shall have metal bodies and vanes unless it is shown by test data that nonmetallic or composite materials prevent flame passage.

9.3* Flame Arresters.

9.3.1 Section 9.3 shall not apply to the following:

- (1) Devices that utilize a liquid seal to prevent the passage of flame
- (2) Devices that rely on gas flow velocity to prevent upstream propagation of flame
- (3) Systems handling combustible dusts

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

9.3.3 Flame arresters shall be installed in accordance with the manufacturer's instructions.

9.3.4* Flame arresters for in-line use shall be tested for such an application.

9.3.5* An in-line arrester that experiences continued burning for a time longer than that for which it was tested shall meet the following criteria:

- (1) A means of detecting the burning shall be provided on both sides of the arrester along with an alarm or automatic device to interrupt flow prior to failure.
- (2) If thermocouples are used, they shall not be placed in thermowells.

9.3.6* Arresters shall be inspected periodically, based on facility experience, and after each incident where they have been called upon to function.

9.3.6.1 The inspection shall determine whether any damage has occurred that could affect the performance of the device.

9.3.6.2 Damaged components shall be replaced.

9.4* Automatic Fast-Acting Valve Systems.

9.4.1 Automatic fast-acting valve systems shall be designed to detect a deflagration and to prevent propagation of flame and combustion-generated pressure beyond the fast-acting valves by providing a positive mechanical seal.

9.4.2 Factors that affect the performance of fast-acting automatic-closing valves shall be considered in the design and applications and shall include, but not be limited to, the following:

- (1) Deflagration characteristics of the combustible material
- (2) Volume, configuration, and operating characteristics of the vessel
- (3) Type of deflagration protection used on the vessel and piping
- (4) Volume, length, cross-sectional area, configuration, and strength of the piping
- (5) Velocity of the combustible air mixture in the pipe
- (6) Location of system components
- (7) Closure time of the valve, including control and detection components
- (8) Detection technique

9.4.3 Fast-acting valves and deflagration detectors shall be capable of withstanding the maximum expected deflagration pressures, including pressure piling.

9.4.4* The fast-acting valve systems shall be of a design that has been tested under deflagration conditions to verify their performance.

9.4.5 Spacing between a detector and the fast-acting valve shall be based on the maximum flame speed expected in the duct and the response time of the detector, the valve, and the actuator circuitry.

9.4.6 The diameter of the pipe leading to the automatic fast-acting valve shall not be decreased, unless the automatic fast-acting valve has been specifically tested for the configuration.

9.4.7 Personnel shall be trained in the safety procedures that are to be carried out prior to, during, and after maintenance.

9.4.8 A power/control unit with a minimum 24-hour standby battery backup shall be provided with each suppression system and shall supply energy to accomplish the following:

- (1) Power all detection devices
- (2) Energize all electrically actuated valve systems
- (3) Energize visual and audible alarms

- (4) Transfer all auxiliary control and alarm contacts
- (5) Control system—disabling interlock and process shutdown circuits

9.4.8.1 The power/control unit shall meet the applicable requirements of 1.5.2 and Chapter 3 of *NFPA 72, National Fire Alarm Code*.

9.4.8.2 The power/control unit shall, as a minimum, fully and continuously supervise the following:

- (1) Wiring circuits for opens and other faults
- (2) AC power supply (primary)
- (3) Battery voltage, presence, and polarity
- (4) System safety interlock circuitry
- (5) System-disabling interlock circuitry
- (6) Releasing outputs
- (7) Electrically actuated valves
- (8) Detectors
- (9) Visual and audible alarms
- (10) Circuit ground fault

9.4.8.3 The supervisory signal circuits shall be provided with a visual and audible trouble signal.

9.4.8.4 In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

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

9.4.9.1* Provisions shall be made to prevent obscuration of radiant energy detectors.

9.4.9.2 Detectors shall be protected from the accumulation of foreign material that would prevent functioning.

9.4.10 Electrically fired initiators shall be mounted so that their maximum temperature rating, as specified by the manufacturer, is not exceeded.

9.4.11 Pneumatic valve actuator systems shall comply with the following requirements:

- (1) Pneumatic valve actuators shall be mounted so that their maximum temperature rating, as specified by the manufacturer, is not exceeded.
- (2) Means shall be provided to verify the pressure of the pressurized reservoir for the pneumatic valve actuator.

9.4.12 Wiring for the control circuits shall be isolated and shielded from all other wiring to prevent possible induced currents.

9.4.12.1 Where environmental conditions warrant, conduits shall be sealed to prevent the entrance of moisture and other contaminants.

9.4.12.2 Where a conduit is used for wiring multiple installations, the wiring for each automatic fast-acting valve system shall be run in a separate conduit. Alternatively, each system shall be permitted to be wired with shielded cables run in common conduit.

9.4.12.3 All wiring shall meet the applicable requirements of *NFPA 70, National Electrical Code*.

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

9.4.13.1 Where necessary, measures shall be used to protect detectors and fast-acting valves from accumulating foreign material that would prevent operation.

9.4.13.2 Terminals and mechanical parts shall be protected from moisture and other contaminants.

9.4.13.3 The temperatures at mounting locations shall not exceed the maximum operating temperatures of system components.

9.4.14 Inspection and maintenance of automatic fast-acting valve systems shall comply with the following requirements:

- (1) Automatic fast-acting valve systems shall be inspected and maintained in accordance with the manufacturer's recommendations.
- (2) Containers of suppressant shall be checked for pressure and loss of agent.
- (3) A container having a pressure (corrected for temperature) that is less than the minimum value specified by the manufacturer shall be reconditioned or replaced.
- (4) A written report on the most recent inspection shall be kept on file for review. The report shall include test and calibration data on all system components.

9.4.15 In the event of system actuation, inspection and testing as specified by the manufacturer shall be performed before the system is returned to service.

9.5* Flame Front Diverters.

9.5.1 Flame front diverters shall be permitted to be used as a deflagration loss control measure.

9.5.2 Flame front diverter system design considerations shall include, but not be limited to, the following:

- (1) Deflagration characteristics of the combustible material
- (2) Volume, configuration, and operating characteristics of the equipment to be protected and the conveying system
- (3) Type of deflagration protection used on the vessel
- (4) Length, cross-sectional area, configuration, and strength of the piping
- (5) Velocity of the combustible air mixture in the pipe
- (6) Location of the flame front diverter and its associated piping
- (7) Turbulence-generating features in the piping such as fittings, valves, elbows, and wall roughness
- (8) Location of probable ignition sources

9.5.3 The body design shall divert the flame front to atmosphere and away from the downstream piping.

9.5.4 The body shall be capable of withstanding expected deflagration pressure.

9.5.5 The closure device shall be either a rupture disc or a cover plate.

9.5.6 Where the closure device could be a missile hazard, it shall be either tethered or contained in a cage.

9.5.7 The hazard of flame discharge from the flame front diverter shall be considered when designing the placement of the device.

9.5.8 The flame front diverter shall discharge to a safe, unrestricted, outdoor location.

9.5.9* Flame front diverters shall be tested for the application.

9.6 Chemical Isolation Systems.

9.6.1 General Requirements.

9.6.1.1 Chemical isolation systems shall be permitted to be used to isolate interconnected process volumes from the effects of deflagration flame passage through interconnecting pipe.

9.6.1.2 Chemical isolation systems shall be designed to detect a deflagration flame event and to cause discharge of an extinguishing agent into a length of pipe sufficient to prevent flame propagation past the point of agent discharge.

9.6.1.3 Chemical isolation system components exposed to the process environment shall be capable of withstanding the maximum expected deflagration pressure.

9.6.1.4 A chemical isolation system shall be of a design that has been tested under deflagration conditions to verify performance.

9.6.1.5 The distance between the position of a deflagration flame event detector and the associated agent discharge point shall be based on the following:

- (1) Maximum deflagration flame speed expected in the pipe
- (2) Response time characteristics of the detector
- (3) Discharge rate from the agent containers

9.6.1.6 Chemical isolation systems shall be disarmed before maintenance operations are performed on the system components.

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

9.6.2 Detectors.

9.6.2.1 Deflagration flame event detectors shall be of the pressure sensing or radiant energy sensing type.

9.6.2.2 Provisions shall be made to prevent obscuration of radiant energy detectors.

9.6.2.3 Provisions shall be made to prevent blockage of access to the sensing surface of pressure-type detectors.

9.6.3 Extinguishing Agent and Containers.

9.6.3.1 The extinguishing agent shall be chemically compatible with the material normally conveyed through the pipe system being protected.

9.6.3.2 The extinguishing agent shall be of a type that is effective at all temperatures to be encountered in the application.

9.6.3.3 Extinguishing agent containers, if used as shipping containers, shall be designed to meet the requirements of the U.S. Department of Transportation.

9.6.3.3.1 If not used as shipping containers, extinguishing agent containers shall be designed, fabricated, inspected, certified, and stamped in accordance with Section VIII of the ASME *Boiler and Pressure Vessel Code*.

9.6.3.3.2 The design pressure shall be suitable for the maximum pressure developed at 55°C (130°F) or at the maximum controlled temperature limit.

9.6.4 Electrically Fired Initiators. Electrically fired initiators shall be mounted so that their maximum temperature rating, as specified by the manufacturer, is not exceeded.

9.6.5 Power/Control Units.

9.6.5.1 A power/control unit with a minimum 24-hour standby battery backup shall be provided with each chemical isolation system and shall supply energy to accomplish the following:

- (1) Power all detection devices
- (2) Energize all electrically actuated chemical isolation systems
- (3) Energize visual and audible alarms
- (4) Transfer all auxiliary control and alarm contacts
- (5) Control system-disabling interlock and process shutdown circuits

9.6.5.2 The power/control unit shall meet the applicable requirements of 1.5.2 and Chapter 3 of *NFPA 72, National Fire Alarm Code*.

9.6.5.3 The power/control unit shall, as a minimum, fully and continuously supervise the following:

- (1) Wiring circuits for opens and other faults
- (2) AC power supply (primary)
- (3) Battery voltage, presence, and polarity
- (4) System safety interlock circuitry
- (5) System-disabling interlock circuitry
- (6) Releasing outputs
- (7) Electrical extinguishing actuators
- (8) Detectors
- (9) Visual and audible alarms
- (10) Circuit ground fault

9.6.5.4 The supervisory signal circuits shall be provided with a visual and audible trouble signal.

9.6.5.5 In addition to noncritical trouble alarms, the power/control unit shall have separate contacts capable of initiating an orderly shutdown of the protected process upon receipt of any trouble signal that indicates a disabled protection system.

9.6.5.6 The power and control unit shall meet applicable requirements of *NFPA 70, National Electrical Code*.

9.6.6 Electrical.

9.6.6.1 Wiring for the control circuits shall be isolated and shielded from all other wiring to prevent possible induced currents.

9.6.6.2 When a conduit is used for wiring multiple installations, the wiring for each chemical isolation system shall be run in separate conduit or wired with shielded cables run in common conduit.

9.6.6.3 All wiring shall meet the applicable requirements of *NFPA 70, National Electrical Code*.

9.6.7 Installation of Chemical Isolation Systems.

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

9.6.7.2 Where necessary, measures shall be used to protect detectors and extinguisher components from accumulating foreign material that would prevent operation.

9.6.7.3 Terminals and mechanical parts shall be protected from moisture and other contaminants.

9.6.7.4 The temperatures at mounting locations shall not exceed the maximum operating temperatures of system components.

9.6.8 Inspection and Maintenance of Chemical Isolation Systems.

9.6.8.1 Chemical isolation systems shall be inspected and maintained in accordance with the manufacturer's recommendations.

9.6.8.2 Containers of suppressant shall be checked for pressure and loss of agents.

9.6.8.3 A container having a pressure (corrected for temperature) that is less than the minimum value specified by the manufacturer shall be reconditioned or replaced.

9.6.8.4 A written report on the most recent inspection shall be kept on file for review.

9.6.8.5 The report shall include test and calibration data on all system components.

9.6.9 Procedures After System Trouble or Actuation. In the event of system actuation, inspection and maintenance as specified in 9.6.8 shall be performed before the system is returned to service.

9.7* Liquid Seals. A liquid seal shall be used for preventing the passage of flame by passing gas through a liquid.

9.7.1 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.

9.7.2 Liquid seals shall be designed in accordance with other recognized practices.

9.7.3* Means for providing and maintaining the liquid level shall be provided, as well as an alarm to detect malfunction.

Chapter 10 Deflagration Control by Pressure Containment

10.1 Application.

10.1.1 The technique for deflagration pressure containment shall be permitted to be considered for specifying the design pressure of a vessel and its appurtenances so they are capable of withstanding the maximum pressures resulting from an internal deflagration.

10.1.2 This chapter shall provide the basis for determining the vessel design pressure required to withstand the pressures resulting from an internal deflagration.

10.1.3 This chapter shall be limited to systems in which the oxidant is air.

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

10.1.5* Deflagration pressure containment shall be applied to a vessel with attached equipment to protect such equipment from imposed pressure loads that could equal or be greater than the pressure loads experienced by the protected vessel.

10.2 Design Limitations.

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

10.2.2* Deflagration pressure containment shall not be applied to systems where two or more vessels are connected by

large-diameter pipes or ducts, unless one of the following criteria is met:

- (1) Deflagration pressure containment shall be permitted to be used where interconnected piping is provided with deflagration isolation.
- (2) Deflagration pressure containment shall be permitted to be used where venting is provided for interconnected piping.
- (3) Deflagration pressure containment shall be permitted to be used where interconnected vessels are designed to contain the increased pressures due to the effects of pre-pressurization.
- (4) Deflagration isolation or venting of one vessel shall be permitted to be used.
- (5) Deflagration pressure containment shall be permitted to be used for initial gauge pressures exceeding 2 bar (30 psi) only when the maximum deflagration pressure ratio (R) is determined by test or calculations.

10.2.3* The alternative of 10.2.2(5) shall not be permitted where test data are available.

10.3 Design Bases.

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

10.3.2 The design pressure of the vessel, as calculated in 10.3.3, shall be based either on preventing rupture of the vessel (the ultimate strength of the vessel) or on preventing permanent deformation of the vessel (the yield strength of the vessel) from internal positive overpressure. Due to the vacuum that could follow a deflagration, all vessels whose deflagration pressure containment design is based on preventing deformation also shall be designed to withstand an absolute internal pressure of 68.95 kPa (10 psi), or they shall be provided with vacuum relief.

10.3.3* The design pressure shall be calculated according to the following equations:

$$P_f = \frac{1.5[R(P_i + 14.7) - 14.7]}{F_u} \quad (10.1)$$

$$P_d = \frac{1.5[R(P_i + 14.7) - 14.7]}{F_y} \quad (10.2)$$

where:

- P_f = design pressure to prevent rupture due to internal deflagration (psig)
- P_d = design pressure to prevent deformation due to internal deflagration (psig)
- P_i = maximum initial pressure at which combustible atmosphere exists (psig)
- R = ratio of maximum deflagration pressure, in absolute pressure units, to maximum initial pressure, inconsistent absolute pressure units
- F_u = ratio of the ultimate stress of the vessel to allowable stress of the vessel
- F_y = ratio of the yield stress of the vessel to allowable stress of the vessel

For U.S. Customary units, 6.89 kPa = 1 psi

10.3.3.1* 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.

10.3.3.2 For use as a practical design basis (since optimum conditions seldom exist in industrial equipment), the value of R shall be as follows:

- (1) For most gas/air mixtures, the value of R shall be 9.
- (2) For St-1 and St-2 dust/air mixtures, the value of R shall be 11.
- (3) For St-3 dust/air mixtures, the value of R shall be 13.

10.3.3.3 A value for R other than the values specified in 10.3.3.2 shall be permitted to be used if such value can be substantiated by test data or calculations.

10.3.3.4 The vessel design pressure shall be based on the wall thickness of the vessel, excluding any allowance for corrosion or erosion.

10.3.3.5 For operating temperatures below 25°C (77°F), the value of R' shall be calculated for use in Equation 10.1 and Equation 10.2:

$$R' = R \left(\frac{298}{273 + T_i} \right) \quad (10.3)$$

where:

- R = maximum deflagration ratio for the mixture measured at 25°C (77°F)
- T_i = operating temperature (°C)

10.3.4 The presence of any pressure relief device on the system shall not cause the design pressure calculated by the methods of 10.3.3 to be reduced.

10.3.5* The maximum pressure for positive pressure systems shall be as follows:

- (1) For positive pressure systems handling gases and liquids, the maximum initial pressure, P_i , shall be the maximum initial pressure at which a combustible atmosphere is able to exist, but a pressure not higher than the setting of the pressure relief device plus its accumulation.
- (2) For positive pressure systems handling dusts, the maximum initial pressure shall be the greater of the following two pressure values:
 - (a) Maximum possible discharge pressure of the compressor or blower that is suspending or transporting the material
 - (b) Setting of the pressure relief device on the vessel being protected plus its accumulation
- (3) For gravity discharge of dusts, the maximum initial pressure shall be the atmospheric gauge pressure (0.0 bar or 0.0 psi).

10.3.6 For systems operating under vacuum, the maximum initial pressure shall not be less than atmospheric gauge pressure (0.0 bar or 0.0 psi).

10.3.7 The vessel design shall take into consideration the minimum operating temperature at which a deflagration could occur, which shall be compared with the temperature characteristics of the vessel's construction material to ensure that brittle fracture cannot result from a deflagration.

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

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

10.5 Threaded Fasteners. Threaded fasteners on vessel appurtenances shall be inspected to ensure that design pressure ratings are maintained.

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

Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.3.2(2) For information on deflagration venting, see NFPA 68, *Guide for Venting of Deflagrations*.

A.1.3.2(8) For information on cutting and welding practices, see NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*. For information on preparation of tanks, piping, or other enclosures for hot work, see NFPA 326, *Standard for the Safeguarding of Tanks and Containers for Entry, Cleaning, or Repair*.

A.3.2.1 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, 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 that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase “authority having jurisdiction,” or its acronym AHJ, 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, or 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 or her 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.3.2.4 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations 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.3.3.5 Combustible Particulate Solid. Combustible particulate solids include dusts, fibers, fines, chips, chunks, flakes, or mixtures of these. A definition of this breadth is necessary because it is crucial to address the fact that there is attrition of the material as it is conveyed. Pieces and particles rub against each other and collide with the walls of the duct as they travel through the system. The rubbing and collision breaks down the material and produces a mixture of pieces and much finer particles, called “dusts.” Consequently, it is expected that every conveying system produces dusts, regardless of the starting size of the material, as an inherent byproduct of the conveying process.

A.3.3.14 Flame Arrester. The emerging gases are sufficiently cooled to prevent ignition on the protected side.

A.3.3.17 Flammable Limits. See NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*. (Note: Although NFPA 325 has been officially withdrawn from the *National Fire Codes*[®], the information is still available in NFPA’s *Fire Protection Guide to Hazardous Materials*.)

A.3.3.22 Isolation. Stream properties include deflagration, mass flow, ignition capability.

A.3.3.23 Limiting Oxidant Concentration (LOC). Materials other than oxygen can act as oxidants.

A.4.1 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.4.6 Inspection, maintenance, and operator training are necessary requirements of any explosion prevention system. Reliability of the system and its instrumentation is only 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, is only as good as the frequency and thoroughness of training provided.

A.4.6.1 Analyzers and other system instrumentation can require more frequent periodic inspection than that required for other components of the system. Inspections should be made according to the manufacturer’s recommendations or as required by operating conditions and inspection history.

A.5.1.1 Operation of a system with an oxidant concentration low enough to prevent a deflagration does not mean that incipient fires are prevented. Smoldering can occur in fibrous materials or dust layers at very low oxidant concentrations, which can ultimately result in a fire or explosion when exposed to higher oxidant concentrations. Caution should be exercised when opening such systems to the air. (See *Annex B* for a discussion of the control of combustible gas mixtures. Also see *Annex C* for limiting oxidant concentrations.)

A.5.2.1 Purge gases generated by any of the acceptable methods described in this standard might not necessarily be compatible for all applications. In general, the physical and chemical properties of the combustible materials involved 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 might be higher. The user is cautioned, however, that some halogenated hydrocarbons, carbon dioxide, and even nitrogen at elevated temperatures might react violently with certain dusts.

Also, such gases might 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 might 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 should use self-contained breathing apparatus, preferably the positive-pressure type. Canister-type gas masks should not be used; they do not supply oxygen and do not offer any protection. The toxicity of certain purge gases should be recognized. The potential for accidental release of purge gases into normally occupied areas should be recognized and the necessary precautions taken.

A.5.2.2.1 The values were obtained under the conditions specified in the Table C.1(a), Table C.1(b), Table C.1(c), and Table C.2. Higher energy ignition sources, higher temperatures, or higher pressures could reduce the LOC values shown. LOC values for dusts of a particular chemical composition could also differ with variations of physical properties such as particle size, shape, and surface characteristics. A particular dust could have combustion properties that differ from those shown in the tables in Annex C. Tabular data for combustion characteristics are provided as examples only.

A.5.2.3.4 Under certain conditions of reducing atmospheres in the presence of sulfur compounds, pyrophoric iron sulfides could form in air-starved atmospheres. When admitting air into such an atmosphere, the iron sulfides could ignite. A typical procedure for controlling such ignition is to thoroughly wet the iron sulfide deposits with water and maintain a wetted surface until all deposits are removed and disposed of safely and properly. Another method is to maintain an inert atmosphere in the tank or vessel containing pyrophoric iron sulfides. ANSI/API 2016, *Guidelines and Procedures for Entering and Cleaning Petroleum Storage Tanks* (August 2001), provides information covering the control and removal of pyrophoric iron sulfide deposits.

Rapid oxidation tends to occur when the deposits dry out. Thus, even though air is admitted slowly, nothing happens until the deposits dry out, a process that could take more time than used to admit air. A common practice in industries that deal with such deposits is to keep them wet until they can be removed to a safe location.

Iron sulfide deposits are often thick or are shielded from air by layers of nonreactive materials. When the layers are subsequently disturbed, the deposits could ignite. Furthermore, although procedures are often used to neutralize or remove such deposits before admitting air, it is often difficult to remove all traces of pyrophoric material.

A.5.3.2(4) The rate of application for steam inerting should be sufficient to maintain a steam concentration of at least 1.13 kg/min/2.83 m³ (2.5 lb/min/100 ft³).

A.5.5.5 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.5.5.7 Consideration should be given to providing a positive means of preventing the backflow of purge gas into other systems where such flow would present a hazard.

A.5.7.1 The objective is to maintain operation outside of the flammable region. This can be achieved by adding either

enrichment gas (natural gas or methane) or an inert gas such as nitrogen. In either case, a safety factor should be maintained between the operating condition and the closest point of the flammable region. Instrumentation should have redundancy, depending on the criticality of the operation.

A.5.7.2.1 As shown in Annex B, any system of fuel plus oxidant plus inert gas requires a certain minimum concentration of oxidant for combustion. For oxidant concentrations less than the limiting oxidant concentration (LOC), no combination of fuel plus diluent can result in a flammable mixture.

A.5.7.2.4 Calculation of the LOC can result in an overestimation of up to at least 2 volume percent oxygen relative to measured values, and this potential error should be taken into account when applying the safety margin.

A.5.7.2.7.1 Products with relatively high vapor pressures can, by themselves, maintain an atmosphere above the upper flammability limit of the vapor. Where flammable atmospheres are predicted, it is common practice to use a padding gas to maintain the oxygen content at less than the LOC. Because such maintenance typically involves almost complete replacement of air, oxygen analysis of the vapor space is not generally needed. It should be ensured that padding gas capacity maintains padding under adverse conditions, such as simultaneous pump-out of several tanks connected to the same padding supply, possibly with a contraction of vapor volume caused by a sudden summer rainstorm. Such conditions might cause air to be drawn into a container to avoid underpressure damage. Also, some monomer tanks need several percent of oxygen to activate dissolved inhibitors. Such tanks might need oxygen monitoring.

A.5.7.3.1 The use of enrichment gas (methane or natural gas) serves the following three purposes:

- (1) It elevates the total fuel concentration and can raise it to above the upper flammable limit (UFL).
- (2) It decreases the oxidant concentration in proportion to the concentration of enrichment gas.
- (3) It elevates the LOC due to the better diluent qualities of enrichment gas relative to nitrogen in the air.

Where header systems continuously convey vapors to a combustion device such as a flare, operation above the UFL can greatly reduce the quantity of enrichment gas relative to operation below the LOC.

Marine vent collecting header operation is regulated by 33 CFR 154.

Nonmarine vent collection headers operated near atmospheric pressure and not containing any vapor with a UFL greater than 75 percent in air, or oxygen in concentrations greater than can be derived from ambient air, can be rendered nonflammable by the addition of 25 volume percent or more of natural gas or methane. The use of oxygen analyzers to control enrichment gas flow is only practical in cases where the nitrogen-to-oxygen ratio is the same as in the air. Where a container has been partly inerted with a diluent such as nitrogen, enrichment gas should be added using flow control, since control via oxygen analyzers would otherwise add insufficient enrichment gas to provide nonflammability. The flow control system can be augmented with gas analyzers to verify correct operation during installation and for periodic performance checks.

No specific recommendations can be provided, and testing is necessary to develop an enrichment method under the following conditions:

- (1) Where system temperatures and pressures significantly exceed atmospheric conditions
- (2) Where gases with UFL above 75 percent in air are involved
- (3) Where oxygen enrichment might occur

The UFL generally increases with increased temperature and pressure; it can be sensitive to the precise gas composition and test conditions. Special procedures are needed for decomposable gases, and such procedures can involve inerting, enrichment, or deflagration isolation systems as described in Chapter 9.

The UFL is a continuous function of oxygen concentration. The greatest UFL corresponds to pure oxygen as the oxidant and the smallest corresponds to the LOC concentration of oxidant (see Figure B.1). Systems containing high concentrations of fuel might be safely operated above the LOC, provided that they are nonflammable with respect to the actual UFL envelope. If the oxygen concentration in a system is constrained below a value whose corresponding UFL is U , a safety factor should be applied such that the fuel concentration in the system is maintained at not less than $1.7 U$. This is consistent with the method in 33 CFR 154, for enrichment of marine vapor collection headers with air as the oxidant. Realistic testing is required to develop the ULF locus as a function of oxygen concentration under worst credible case operating conditions.

A.6.1 See Annex B for a discussion of the control of flammable gas mixtures. Also, see Annex D for information on calculating the time required for ventilation.

A.6.2.2 See NFPA 325, *Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*. (Note: Although NFPA 325 has been officially withdrawn from the *National Fire Codes*[®], the information is still available in NFPA's *Fire Protection Guide to Hazardous Materials*.)

A.6.3.2 The combustible concentration can be reduced by recirculating the atmosphere in which it is contained through a catalytic oxidation unit where the combustible material and oxidant undergo catalytic oxidation at concentrations below the lower flammable limit.

A.7.2.3 The effectiveness of spark detection and spark extinguishing systems is limited by detection of radiant energy emitted from sparks or embers in the material being conveyed and by the ability to deliver extinguishment medium (usually water) in a timely manner. For pneumatic conveying systems, detection of sparks or embers is a function of the following:

- (1) Pipe diameter
- (2) Material-to-air ratio
- (3) Conveying velocity
- (4) Material density and particle size distribution
- (5) Radiant energy absorption characteristic of the material

Manufacturers should be consulted for the applicability of spark detection and spark extinguishing systems for specific applications. In some cases, testing could be required.

A.7.3.1 Optical detectors operating in the infrared and near-infrared wavelength can be used for this technology. For information on detectors, see NFPA 72, *National Fire Alarm Code*.

A.8.3.1 Experience has shown that performing maintenance operations without disarming a suppression system could result in inadvertent discharge of the suppression system.

A.8.8 Halogenated hydrocarbons, such as bromochloromethane, or dry chemical agents might be used with most combustibles. The 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 might also be used as a suppressant if it can be demonstrated to be effective. If ambient temperatures below 0°C (32°F) are expected, freeze protection should be provided.

A.8.11.1 Ease of inspection should be taken into account when designing systems.

A.8.11.3 The quantity of agents in containers can be checked by weighing or by using a reliable level-measuring device.

A.9.1.1 It is frequently impossible to design and operate equipment without interconnecting pipes or ducts. Uses for pipes or ducts include conveying, transferring, and ventilating. Where the pipes or ducts contain flammable or combustible materials plus an oxidant, ignition can result in the communication of combustion between the interconnected equipment. Such communication of combustion can sometimes increase the violence of the deflagration, resulting in pressure piling and accelerated rates of pressure rise in the interconnected equipment from flame-jet ignition. Pressure piling can increase maximum pressure, P_{max} , thus increasing the demands of deflagration pressure containment; and flame-jet ignition can increase deflagration venting requirements (see NFPA 68, *Guide for Venting of Deflagrations*). In extreme cases, the accelerating effect of turbulent combustion through pipes or ducts plus any increased effects from pressure piling can result in detonations.

A.9.1.5 See Table A.9.1.5.

Table A.9.1.5 Isolation Features of Pipe and Duct Protection Systems

System	Deflagration Isolation	Ignition Source Isolation	Flow Isolation
Rotary valves*	Yes	Note	Yes
Flame arresters	Yes	Yes	No
Automatic fast-acting valves	Yes	Yes	Yes
Flame front diverters	No	No	Yes
Flame front extinguishing systems	Yes	Yes	No
Liquid seals	Yes	Yes	No

*Rotary valves are capable of preventing flame front passage under certain conditions but do not always prevent the passage of burning embers.

A.9.2 The acceptance of a rotary valve for use as a deflagration isolation device should consider the minimum ignition energy and the minimum ignition temperature of the dust. Additionally, the width and the length of the gap should be related to these dust characteristics. Information on testing techniques and the relationship of the factors is found in "Rotary Valves for Explosion Isolation" by G. Schuber.

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

the valve might be a source of ignition on the downstream side of the valve.

A.9.2.4 The use of plastics, elastomers, or other synthetic material for the full vane or as wear strips might allow the flame front to pass through the valve. The flame might pass through the valve because of a lack of mass and low specific heat that is not sufficient to cool the flame during its passage.

A.9.3 Flame arresters are manufactured in several mechanical configurations, which include, but are not limited to, the following:

- (1) Banks of closely spaced parallel plates
- (2) Banks of small-diameter tubes
- (3) Wire screens
- (4) Elements consisting of alternating flat and crimped plates that are spirally wound together to produce the equivalent of small-diameter tubes
- (5) Porous or sintered metal elements

A.9.3.2 The ignition source might be outside the protected system, as in the case of a flame arrester on a tank vent. Alternatively, the ignition source might be within the system, as in the case of a flame arrester installed in a pipe that connects two or more tank vents.

A.9.3.4 A deflagration flame front propagating in piping systems can transition to detonation velocities. In such situations, in-line flame arresters can be ineffective and detonation arresters should be considered. Flame arresters are reliable only where installed within the parameters for which they have been tested. Such parameters include the following:

- (1) The fuel mixture used in the test should be the same as, or have flame propagation characteristics similar to, those encountered in the application.
- (2) 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.
- (3) The smallest and largest size of a particular type of arrester should be tested.
- (4) The arrester should be tested in the same configuration in which it will be installed, including the following:

- (a) Arresting element
 - (b) Case where it is contained
 - (c) Hardware for mounting the element in its case
 - (d) Gaskets or seals required
 - (e) Flange or other connector used to attach the arrester to the system
 - (f) Materials of construction
- (5) The maximum temperature and pressure likely to exist at the arrester at the moment of ignition should be used.
 - (6) Where appropriate for the specific application, testing with ignition both upstream and downstream (relative to the gas flow direction) should be performed.
 - (7) The device should be tested over the range of flow velocities that could be encountered.
 - (8) If continuous burning can occur at the arrester, the test procedure should include a continuous burn test.

A.9.3.5 The functionality of a flame arrester can be destroyed if it is heated to an excessively high temperature by the combustion gases that reach it or by exposure to an external source of heat such as a flame.

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

A.9.3.6 If the arrester is used in a service where freezing or plugging might occur, some means of detecting the onset of plugging, such as a differential pressure switch, should be provided.

A.9.4 See Figure A.9.4.

A.9.4.4 Fast-acting valve systems are reliable only when designed and installed within the parameters for which they have been tested. Such parameters include, but are not limited to, the following:

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

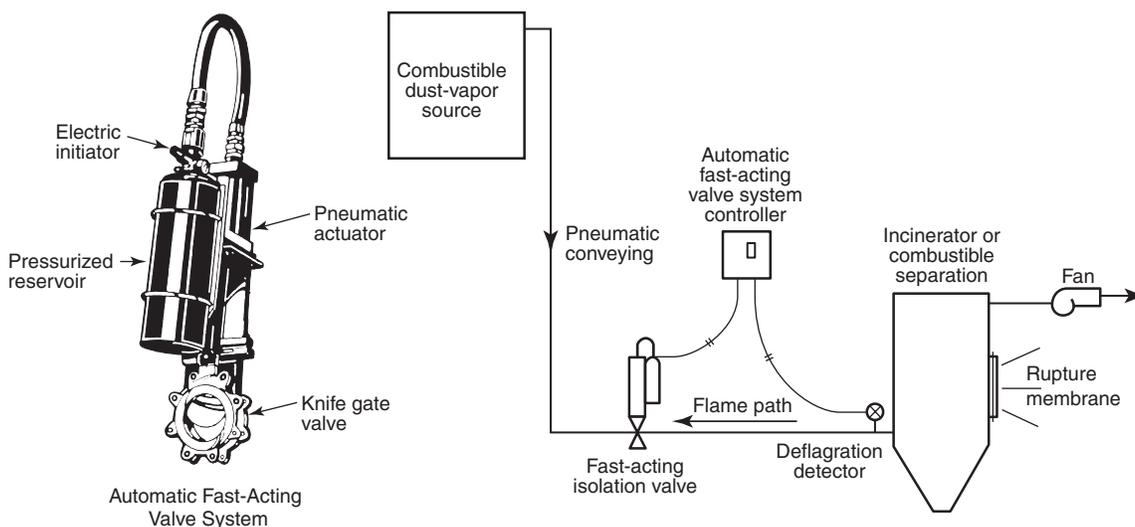


FIGURE A.9.4 Typical Application and Design of Fast-Acting Automatic-Closing Valve Assembly.

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

A.9.4.9.1 Detectors that respond to radiant energy might be used, provided that the application environment does not inhibit their proper operation. Airborne dust particles, dust coating of the detector viewing window, certain gases, and the distance to the ignition source might inhibit sufficiently rapid response to the hazard.

A.9.5 A flame front diverter is composed 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 the atmosphere. Some flame front diverters are equipped with an internal closure that, upon activation, creates a physical barrier to downstream flame propagation. Flame front diverters have demonstrated the ability to divert deflagration flames by directing them to the atmosphere. However, in some cases, 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 reduced. See Figure A.9.5.

A.9.5.9 The testing of flame front diverters should include, but not be limited to, the following:

- (1) The test fuel mixture should be the same as, or have flame propagation characteristics similar to, those encountered.
 - (2) 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.
 - (3) Ignition source location (upstream, downstream, or both locations) should be tested in the same configuration as the protection application.
- (4) 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 might develop as a result of ignition.
 - (5) Installation and maintenance should be as follows:
 - (a) Flame front diverters should be installed and maintained according to manufacturer's instructions.
 - (b) Flame front diverters should be inspected periodically, based on facility experience, and after each operation.
 - (c) Inspection should determine whether any damage that could affect the performance of the device has occurred.
 - (d) Damaged components should be repaired or replaced.

A.9.7 For most systems, API Recommended Practice 521, *Guide for Pressure-Relieving and Depressuring Systems*, should be used when designing liquid seals. For systems where the oxidant/flammable gas might approach a stoichiometric mixture, tests should be performed to determine the design of liquid seals.

A.9.7.3 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.

A.10.1.5 Pressure piling and flame-jet ignition can significantly increase deflagration pressures in attached equipment. Techniques such as isolation or venting should be considered.

A.10.2.1 Deflagration pressure containment is not adequate for detonable systems because the maximum pressure rise is much greater than the factors established in 10.3.3.1 through 10.3.3.4. It should be recognized that some systems might be capable of deflagration or detonation. For example, systems containing a substantial proportion of hydrogen are prone to

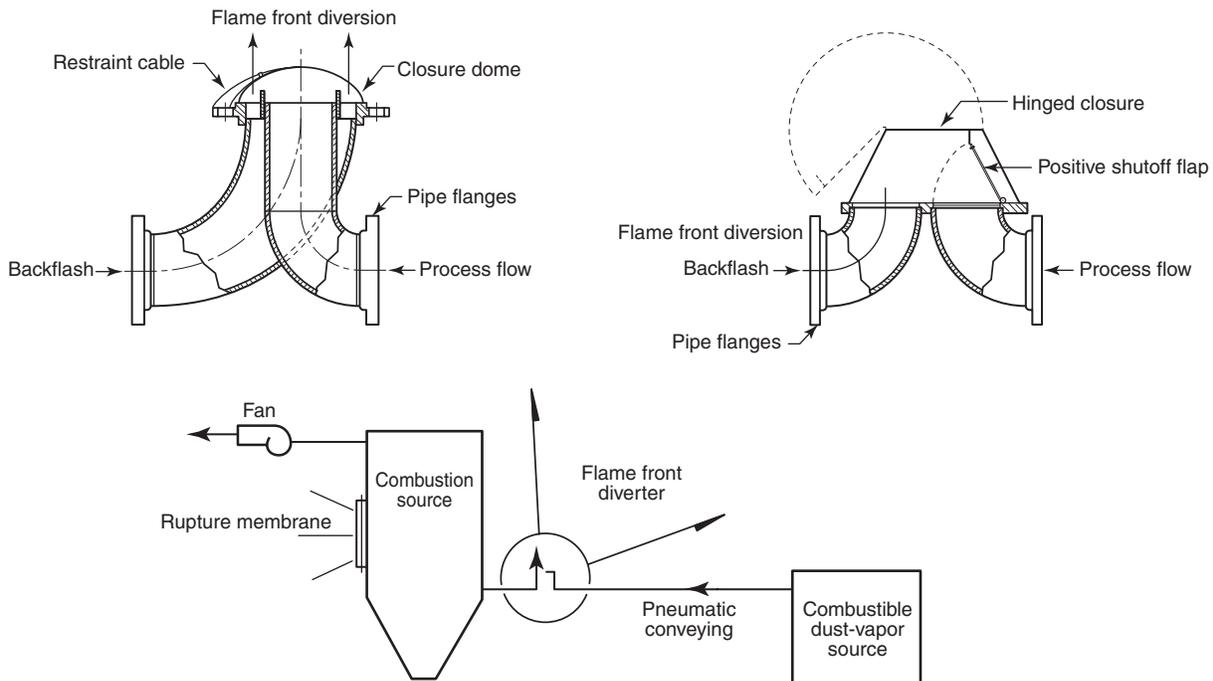


FIGURE A.9.5 Typical Application and Design of Flame Front Diverters.

detonation, as are systems containing acetylene or acetylenic compounds. Saturated organic compounds such as propane, ethane, and alcohols generally do not detonate in vessels but might do so in pipework. Internals in equipment can promote the transition from deflagration to detonation.

A.10.2.2 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 might be substantially greater than would normally happen in a single vessel. (See *W. Bartknecht, Explosions: Course, Prevention, Protection*, pp. 18–23.)

A.10.2.3 Only limited information is available for deflagration containment of systems with initial gauge pressures exceeding 2 bar (30 psi). Increased initial pressure might increase the potential for detonation. For this reason it is recommended that, for systems that might operate at an initial gauge pressure of 2 bar (30 psi) or higher, deflagration pressure containment should be used only where applicable test data are available. The testing should be carefully designed because the detonation potential of a system is affected by vessel dimensions.

A.10.3.3 For vessels fabricated of low-carbon steel and low-alloy stainless steel, F_u equals approximately 4.0 and F_l equals approximately 2.0. The formulas are based on a paper by Noronha et al., “Deflagration Pressure Containment for Vessel Safety Containment for Vessel Safety Design, Plant/Operations Progress.”

A.10.3.3.1 The maximum deflagration pressures for several dusts can be found in Annex D of NFPA 68, *Guide for Venting of Deflagrations*.

A.10.3.5 The maximum initial pressure depends on the origin of the pressure. In some cases, the maximum initial pressure is determined by the setting of a relief device on the system. In such 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 (for example, from external fire exposure) might raise the concentration of fuel in the vapor phase above its upper flammable limit and does not constitute a deflagration hazard.

Annex B Control of Flammable Gas Mixtures by Oxidant Concentration Reduction and Combustible Concentration Reduction

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

B.1 General. As covered in Chapters 5 and 6, a flammable gas/oxidant mixture might 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 formed by points *DABE*. A given mixture of the combustible gas and air, whether ignitable or not, is specified by a point on this line. Point *A* indicates the upper flammable limit of this mixture, and point *B* represents its lower flammable limit.

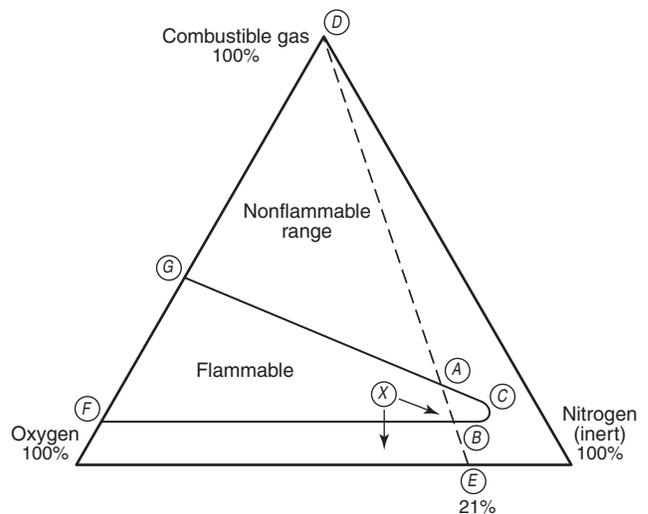


FIGURE B.1 Typical Flammability Diagram.

Any point within the area bounded by *FBCAGF* 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 Annex C.)

Any mixture of oxygen and combustible gas alone (that is without nitrogen) is represented by the left side of the triangle. Any mixture of nitrogen and combustible gas alone (that is without oxygen) is represented by the right side of the triangle.

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 points *C*, *C'*, and *C''*, to prevent ignition. There is a slight decrease on the lower flammable limit, but the effect is not as pronounced as that of the upper limit.

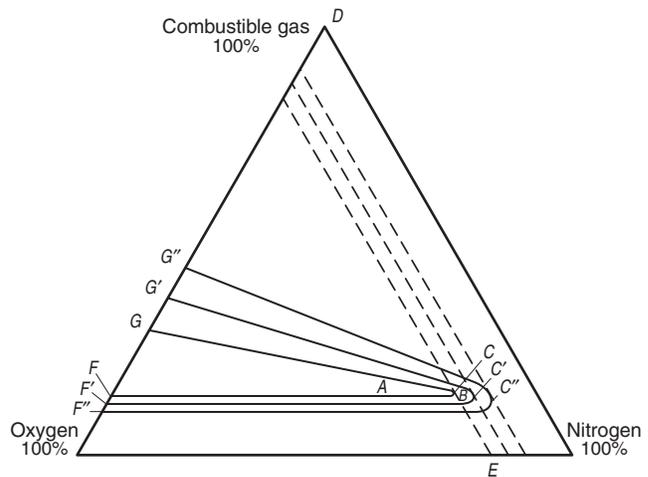


FIGURE B.2 Effect of Pressure on Flammability Diagram.

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, should be determined for each system.

B.3 Effect of Inert Diluents. The addition of an inert diluent to a mixture of combustible material and oxidant affects 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. Figure B.3 shows that nitrogen is more effective than helium and that carbon dioxide is more effective than nitrogen.

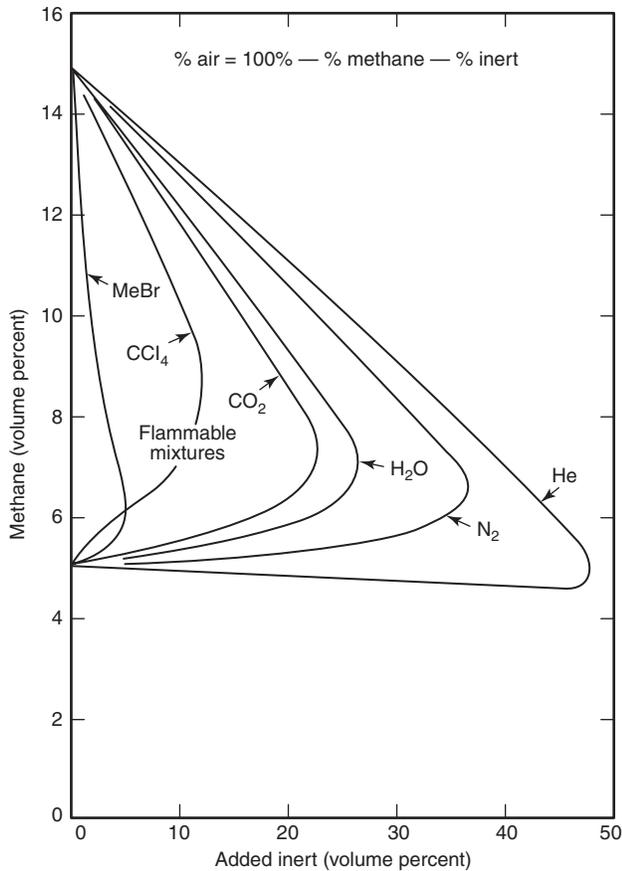


FIGURE B.3 Limits of Flammability of Methane-Inert Gas-Air Mixtures at 25°C (77°F) and Atmospheric Pressure. (Source: J. F. Coward and G. W. Jones, "Limits of Flammability of Gases and Vapors.")

B.4 Oxidant Concentration Reduction. In Figure B.1, point X represents an arbitrary mixture of flammable gas, oxygen, and nitrogen that lies well within the flammable range. If the composition of the mixture is to be changed so that it lies outside the flammable range, one method that can be used is to reduce 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. In Figure B.1, with point X in the flammable range, the composition of the mixture might be altered by reducing the concentration of flammable gas. In simpler terms, point X moves away from the

flammable gas apex and eventually drops below the lower flammability line *FBC*.

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

$$\text{LFL} = \frac{P_1 + P_2 + \dots + P_n}{\frac{P_1}{\text{LFL}_1} + \frac{P_2}{\text{LFL}_2} + \dots + \frac{P_n}{\text{LFL}_n}} \quad (\text{B.1})$$

$$\text{UFL} = \frac{P_1 + P_2 + \dots + P_n}{\frac{P_1}{\text{UFL}_1} + \frac{P_2}{\text{UFL}_2} + \dots + \frac{P_n}{\text{UFL}_n}} \quad (\text{B.2})$$

where:

$P_1 \dots P_n$ = volume fractions of components
1, 2, 3, . . . , n of the mixture

$\text{LFL}_1 \dots \text{LFL}_n$ = lower flammable limits of components
1, 2, 3, . . . , n of the mixture

$\text{UFL}_1 \dots \text{UFL}_n$ = upper flammable limits of components
1, 2, 3, . . . , n of the mixture

Annex C Limiting Oxidant Concentrations

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

C.1 General. The Table C.1(a), Table C.1(b), and Table C.1(c) provide values for limiting oxidant concentration (LOC) using nitrogen, carbon dioxide, and inert dust as the diluent. Table C.1(a) provides LOC values for flammable gases, and Table C.1(b) and Table C.1(c), provide data for combustible dust suspensions.

Table C.1(a) Limiting Oxidant Concentrations for Flammable Gases When Using Nitrogen or Carbon Dioxide as Diluents

Gas/Vapor	Limiting Oxidant Concentration (Volume % O ₂ Above Which Deflagration Can Take Place)		Reference
	N ₂ /Air	CO ₂ /Air	
Methane	12.0	14.5	1
Ethane	11.0	13.5	1
Propane	11.5	14.5	1
<i>n</i> -Butane	12.0	14.5	1
<i>n</i> -Butyl acetate	9.0	—	9
Isobutane	12.0	15.0	1
<i>n</i> -Pentane	12.0	14.5	1
Isopentane	12.0	14.5	2
<i>n</i> -Hexane	12.0	14.5	1
<i>n</i> -Heptane	11.5	14.5	2
Ethanol	8.7	—	9
Ethylene	10.0	11.5	1
Propylene	11.5	14.0	1
1-Butene	11.5	14.0	1
Isobutylene	12.0	15.0	4
Butadiene	10.5	13.0	1

Table C.1(a) *Continued*

Gas/Vapor	Limiting Oxidant Concentration (Volume % O ₂ Above Which Deflagration Can Take Place)		Reference
	N ₂ /Air	CO ₂ /Air	
3-Methyl-1-butene	11.5	14.0	4
Benzene	11.4	14.0	1, 7
Toluene	9.5	—	7, 9
Styrene	9.0	—	7
Ethylbenzene	9.0	—	7
Vinyltoluene	9.0	—	7
Divinylbenzene	8.5	—	7
Diethylbenzene	8.5	—	7
Cyclopropane	11.5	14.0	1
Gasoline			
(73/100)	12.0	15.0	2
(100/130)	12.0	15.0	2
(115/145)	12.0	14.5	2
Kerosene	10.0 (150°C)	13.0 (150°C)	5
JP-1 fuel	10.5 (150°C)	14.0 (150°C)	2
JP-3 fuel	12.0	14.5	2
JP-4 fuel	11.5	14.5	2
Natural gas (Pittsburgh)	12.0	14.5	1
<i>n</i> -Butyl chloride	14.0	—	3
	12.0 (100°C)	—	3
Methylene chloride	19.0 (30°C)	—	3
	17.0 (100°C)	—	3
Ethylene dichloride	13.0	—	3
	11.5 (100°C)	—	3
1,1,1-trichloroethane	14.0	—	3
Trichloroethylene	9.0 (100°C)	—	3
Acetone	11.5	14.0	4
<i>n</i> -Butanol	NA	16.5 (150°C)	4
Carbon disulfide	5.0	7.5	4
Carbon monoxide	5.5	5.5	4
Ethanol	10.5	13.0	4
2-Ethyl butanol	9.5 (150°C)	—	4
Ethyl ether	10.5	13.0	4
Hydrogen	5.0	5.2	4
Hydrogen sulfide	7.5	11.5	4
Isobutyl acetate	9.1	—	9
Isobutyl alcohol	9.1	—	9
Isobutyl formate	12.5	15.0	4
Isopropyl acetate	8.8	—	9
Isopropyl alcohol	9.5	—	10
Methanol	10.0	12.0	4
Methyl acetate	11.0	13.5	4
Propylene oxide	7.8	—	8
Methyl ether	10.5	13.0	4
Methyl formate	10.0	12.5	4
Methyl ethyl ketone	11.0	13.5	4
<i>n</i> -Propyl acetate	10.1	—	10
<i>n</i> -Propyl alcohol	8.6	—	9
UDMH (dimethylhydrazine)	7.0	—	6

Table C.1(a) *Continued*

Gas/Vapor	Limiting Oxidant Concentration (Volume % O ₂ Above Which Deflagration Can Take Place)		Reference
	N ₂ /Air	CO ₂ /Air	
Vinyl chloride	13.4	—	7
Vinylidene chloride	15.0	—	7

Notes:

- See 5.7.2 for the required oxygen level in equipment.
- 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 for Table C.1(a).

- J. F. Coward and G. W. Jones (1952).
- G. W. Jones, M. G. Zabetakis, J. K. Richmond, G. S. Scott, and A. L. Furno (1954).
- J. M. Kuchta, A. L. Furno, A. Bartkowiak, and G. H. Martindill (1968).
- M. G. Zabetakis (1965).
- M. G. Zabetakis and B. H. Rosen (1957).
- Unpublished data, U.S. Bureau of Mines.
- Unpublished data, Dow Chemical Co.
- U.S. Bureau of Mines.
- L.G. Britton (2002).
- Unpublished, Dow Chemical Co. (2002).

Table C.1(b) Limiting Oxidant Concentrations for Combustible Dust Suspensions When Using Nitrogen or Carbon Dioxide as Diluents

Dust	Limiting Oxidant Concentration (Volume % O ₂ Above Which Deflagration Can Take Place)	
	N ₂ /Air	CO ₂ /Air
<i>Agricultural</i>		
Coffee		17
Cornstarch		11
Dextrin	11	14
Soy flour		15
Starch		12
Sucrose	10	14
<i>Chemical</i>		
Ethylene diamine tetra-acetic acid		13
Isatoic anhydride		13
Methionine		15
Ortazol		19
Phenothiazine		17
Phosphorus pentasulfide		12
Salicylic acid	15	17
Sodium lignosulfate		17
Stearic acid & metal stearates	10.6	13
<i>Carbonaceous</i>		
Charcoal		17
Coal, bituminous		17

Table C.1(b) *Continued*

Dust	Limiting Oxidant Concentration (Volume % O ₂ Above Which Deflagration Can Take Place)	
	N ₂ /Air	CO ₂ /Air
Coal, sub-bituminous		15
Lignite		15
<i>Metal</i>		
Aluminum		2
Antimony		16
Chromium		14
Iron		10
Magnesium	0	0
Manganese		14
Silicon	11	12
Thorium	2	0
Titanium	4	0
Uranium	1	0
Vanadium		14
Zinc	9	10
Zirconium	0	0
<i>Miscellaneous</i>		
Cellulose		13
Paper		13
Pitch		11
Sewage sludge		14
Sulfur		12
Wood flour		16
<i>Plastics Ingredients</i>		
Azelaic acid		14
Bisphenol A		12
Casein, rennet		17
Hexamethylene tetramine	13	14
Isophthalic acid		14
Paraformaldehyde	8	12
Pentaerythritol	13	14
Phthalic anhydride		14
Terephthalic acid		15
<i>Plastics — Special Resins</i>		
Coumarone-indene resin		14
Lignin		17
Phenol, chlorinated		16
Pinewood residue		13
Rosin, DK		14
Rubber, hard		15
Shellac		14
Sodium resinate	13	14
<i>Plastics — Thermoplastic Resins</i>		
Acetal		11
Acrylonitrile		13
Butadiene-styrene		13
Carboxymethyl cellulose		16
Cellulose acetate	9	11
Cellulose triacetate		12

Table C.1(b) *Continued*

Dust	Limiting Oxidant Concentration (Volume % O ₂ Above Which Deflagration Can Take Place)	
	N ₂ /Air	CO ₂ /Air
Cellulose acetate butyrate		14
Ethyl cellulose		11
Methyl cellulose		13
Methyl methacrylate		11
Nylon		13
Polycarbonate		15
Polyethylene		12
Polystyrene		14
Polyvinyl acetate		17
Polyvinyl butyrate		14
<i>Plastics — Thermosetting Resins</i>		
Allyl alcohol		13
Dimethyl isophthalate		13
Dimethyl terephthalate		12
Epoxy		12
Melamine formaldehyde		15
Polyethylene terephthalate		13
Urea formaldehyde		16

Notes:

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.

2. Where nitrogen is used as the diluent and no data are listed in the table, the following equation should be used to calculate the oxygen value for carbonaceous dusts:

$$O_n = 1.3(O_c - 6.3) \quad (C.1)$$

where:

O_n = limiting oxygen concentration for dilution by nitrogen (N)

O_c = limiting oxygen concentration for dilution by carbon dioxide (CO₂)

3. See 5.7.2 for the required oxygen level in equipment.

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.

5. The values in this table can differ from those in Table C.1(c) because of differences in test methods and dust characteristics, such as particle size, and other factors.

Table C.1(c) Limiting Oxidant Concentrations for Combustible Dust Suspensions When Using Nitrogen as a Diluent

Dust	Median Particle Diameter by Mass (μm)	Limiting Oxidant Concentration (Volume % O_2 Above Which Deflagration Can Take Place) N_2/Air
<i>Cellulosic Materials</i>		
Cellulose	22	9
Cellulose	51	11
Wood flour	27	10
<i>Food and Feed</i>		
Pea flour	25	15
Corn starch	17	9
Waste from malted barley	25	11
Rye flour	29	13
Starch derivative	24	14
Wheat flour	60	11
<i>Coals</i>		
Brown coal	42	12
Brown coal	63	12
Brown coal	66	12
Brown coal	51	15
briquette dust		
Bituminous coal	17	14
<i>Plastics, Resins, Rubber</i>		
Resin	<63	10
Rubber powder	95	11
Polyacrylonitrile	26	10
Polyethylene, h.p.	26	10
<i>Pharmaceuticals, Pesticides</i>		
Amino-phenazone	<10	9
Methionine	<10	12
<i>Intermediate Products, Additives</i>		
Barium stearate	<63	13
Benzoyl peroxide	59	10
Bisphenol A	34	9
Cadmium laurate	<63	14
Cadmium stearate	<63	12
Calcium stearate	<63	12
Methyl cellulose	70	10
Dimethyl terephthalate	27	9
Ferrocene	95	7
Bis(trimethylsilyl)-urea	65	9
Naphthalic acid anhydride	16	12
2-Naphthol	<30	9
Paraformaldehyde	23	6
Pentaerythritol	<10	11

Table C.1(c) Continued

Dust	Median Particle Diameter by Mass (μm)	Limiting Oxidant Concentration (Volume % O_2 Above Which Deflagration Can Take Place) N_2/Air
<i>Metals, Alloys</i>		
Aluminum	22	5
Calcium/aluminum alloy	22	6
Ferrosilicon	17	7
magnesium alloy		
Ferrosilicon alloy	21	12
Magnesium alloy	21	3
<i>Other Inorganic Products</i>		
Soot	<10	12
Soot	13	12
Soot	16	12
<i>Others</i>		
Bentonite derivative	43	12

Source: R. K. Eckhoff, *Dust Explosions in the Process Industries*, 1991.

Note: The data came from 1-m³ and 20-L chambers using strong chemical igniters.

C.2 General. Table C.2 provides data on the concentration of inert dust required to inert selected combustible dusts.

Table C.2 Inerting of Dust Clouds by Mixing the Combustible Dust with Inert Dust

Dust	Combustible Dust		Inert Dust	
	Median Particle Size by Mass (μm)	Type of Dust	Median Particle Size by Mass (μm)	Minimum Mass % Inert of Total Mass Required for Inerting
Methyl cellulose	70	CaSO_4	<15	70
Organic pigment	<10	$\text{NH}_4\text{H}_2\text{PO}_4$	29	65
Bituminous coal	20		14	65
Bituminous coal	20	NaHCO_3	35	65
Sugar	30	NaHCO_3	35	50

Source: R. K. Eckhoff, *Dust Explosions in the Process Industries*, 1991.

Note: Data were obtained from tests conducted in 1-m³ Standard ISO (1985) vessel with a 10-kJ chemical igniter.

Annex D Ventilation Calculations

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

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

For an enclosed volume, V , the change in concentration, dC , over a given time, dt , using a fixed flow rate of fresh air, Q , is given by Equation D.1:

$$(V)dC = Q(C)dt \quad (\text{D.1})$$

By rearranging,

$$\int_{C_0}^C \frac{dC}{C} = \frac{Q}{V} \int dt \quad (\text{D.2})$$

where:

C_0 = initial concentration of gas

t = time required to reach the desired concentration

Integrating Equation D.2 yields the following:

$$\ln\left(\frac{C}{C_0}\right) = \left(\frac{-Q}{V}\right)t \quad (\text{D.3})$$

Equation D.3 assumes perfect mixing. Because this is not the case in actual practice, a correction factor, K , should be introduced as follows:

$$\ln\left(\frac{C}{C_0}\right) = \left(\frac{-Q}{V}\right)K(t) \quad (\text{D.4})$$

In perfect mixing, K equals 1.0. Table D.1 lists values of K for certain conditions. Few data exist on defining the degree of mixing. Most authorities recommend a K -value of not greater than 0.25.

Consider the problem of reducing the gasoline vapor concentration of an enclosure of 28 m³ (1000 ft³), using a 56 m³/min (2000 ft³/min) ventilation rate, from 20 volume percent to the following:

- (1) The upper flammable limit, or 7.6 percent
- (2) The lower flammable limit, or 1.4 percent
- (3) Twenty-five percent of the lower flammable limit, or 0.35 percent

The difference between $K = 1.0$ (perfect mixing) and $K = 0.2$ in calculating the time needed to reduce the concentration to the levels specified can be shown using Equation D.3 as follows:

$$\ln\left(\frac{7.6}{20.0}\right) = \left(\frac{-2000}{1000}\right)K(t) \quad (\text{D.5})$$

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

$$t = \frac{\ln 0.38}{-2K} = \frac{-0.97}{-2K} = \frac{0.485}{K} \quad (\text{D.6})$$

Table D.1 Mixing Efficiency for Various Ventilation Arrangements

Method of Supply	Efficiency (K) Values	
	Single Exhaust Opening	Multiple Exhaust Openings
<i>No Positive Supply</i>		
Infiltration through cracks	0.2	0.3
Infiltration through open doors or windows	0.2	0.4
<i>Forced Air Supply</i>		
Grilles and registers	0.3	0.5
Diffusers	0.5	0.7
Perforated ceiling	0.8	0.9

For $K = 1$, $t = 0.49$ min. For $K = 0.2$, $t = 2.5$ min.

$$\ln\left(\frac{1.4}{20.0}\right) = \left(\frac{-2000}{1000}\right)K(t) \quad (\text{D.7})$$

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

$$t = \frac{\ln 0.07}{-2K} = \frac{-2.66}{-2K} = \frac{1.33}{K} \quad (\text{D.8})$$

For $K = 1$, $t = 1.33$ min. For $K = 0.2$, $t = 6.65$ min.

$$\ln\left(\frac{0.35}{20.0}\right) = \left(\frac{-2000}{1000}\right)K(t) \quad (\text{D.9})$$

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

$$t = \frac{\ln 0.018}{-2K} = \frac{-4.02}{-2K} = \frac{2.01}{K} \quad (\text{D.10})$$

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 in Section D.1 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:

$$\frac{C}{C_0} = e^{-KN} \quad (\text{D.11})$$

where N = the required number of air changes. Equation D.11 can be rewritten as follows:

$$\ln\left(\frac{C}{C_0}\right) = -KN \quad (\text{D.12})$$