Examination Standard
for
Explosion Suppression
Systems

Class Number 5700

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Foreword

This standard is intended to verify that the products and services described will meet stated conditions of performance, safety and quality useful to the ends of property conservation. The purpose of this standard is to present the criteria for examination of various types of products and services.

Examination in accordance with this standard shall demonstrate compliance and verify that quality control in manufacturing shall ensure a consistent and reliable product.

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1 INTRODUCTION

1.1 Purpose

1.1.1 This standard states testing and certification requirements for explosion suppression systems. An explosion suppression system is designed to detect an incipient deflagration and suppress it in order to prevent the full impact of the deflagration from developing. Typically these systems consist of four basic components: the detector(s), a control unit, suppressant storage container(s), and suppressant dispersers.

1.1.2 An explosion is detected in the incipient stage, either by a rise in pressure or the presence of flame within the protected enclosure. The control unit then actuates the suppressant dispersers to envelop and arrest the explosion.

1.1.3 Certification criteria may include, but are not limited to, performance requirements, marking requirements, examination of manufacturing facility(ies), audit of quality assurance procedures, and a follow-up program.

1.2 Scope

1.2.1 This standard applies to the design, construction, operation, maintenance, and testing of a system for the suppression of a deflagration by introductions of a suppression medium.

1.2.2 This standard does not apply to devices or systems designed to protect against over-pressure due to phenomena other than internal explosions.

1.2.3 This standard only applies to systems designed to limit the pressure developed in the protected enclosure to a level that does not exceed the design strength of the enclosure.

1.2.4 This standard does not apply to systems for explosion isolation or suppression of detonations.

1.3 Basis for Requirements

1.3.1 The requirements of this standard are based on experience, research and testing, and/or the standards of other organizations. The advice of manufacturers, users, trade associations, jurisdictions and/or loss control specialists was also considered.

1.3.2 The requirements of this standard reflect tests and practices used to examine characteristics of explosion suppression systems for the purpose of obtaining certification. Systems having characteristics not anticipated by this standard may be certified if performance equal or superior to that required by this standard is demonstrated.

1.4 Basis for Certification

Certification is contingent upon satisfactory results of analysis of the product (compliance with this standard) and the manufacture of the product in the following major areas:

1.4.1 Examination and tests on production samples shall be performed to evaluate:

- the suitability of the product,
- the proper operation and performance of the product as specified by the manufacturer and required by the certification agency and, as far as practical,
- the durability and reliability of the product.

1.4.2 An examination of the manufacturing facilities and audit of quality control procedures may be made to evaluate the manufacturer's ability to consistently produce the product, which is examined and tested, and the marking procedures used to identify the product. Subsequent surveillance may be required by the certification agency in accordance with the certification scheme to ensure ongoing compliance.

1.5 Basis for Continued Certification

Continued certification is based upon:

- production or availability of the product as currently certified;
- the continued use of acceptable quality assurance procedures;
- satisfactory field experience;
- compliance with the terms stipulated by the certification;
- satisfactory re-examination of production samples for continued conformity to requirements; and
- satisfactory surveillance audits conducted as part of the certification agencies product surveillance program.

1.6 Effective Date

The effective date of this certification standard mandates that all products tested for certification after the effective date shall satisfy the requirements of this standard.

The effective date of this Standard is eighteen (18) months after the publication date of the standard for compliance with all requirements.

1.7 System of Units

Where units of measurement are expressed in U.S. customary units, they are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. Conversions are in accordance with ANSI/IEEE/ASTM SI-10. Where units of measurement are expressed in SI units, no US customary units are provided.

1.8 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI/IEEE/ASTM SI-10, *American National Standard for Metric Practice*

ANSI/IEC 60529 *Degrees of Protection provided by Enclosures (IP Code)*

ASME BPVC, *Boiler and Pressure Vessel Code*

ASTM B117, *Standard Practice for Operating Salt Spray (Fog) Apparatus*

ASTM D412, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers*

ASTM E1226-19, *Standard Test Method for Explosibility of Dust Clouds*

ASTM G36 – 94, *Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution*

ASTM G155, *Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic*

Materials

CGA S-1.1, *Pressure Relief Standards Part 1 - Cylinders for Compressed Gases*

FM 3010, *Approval Standard for Fire Alarm Signaling Systems*

NEMA 250, *Enclosures for Electrical Equipment*

NFPA 68, *Guide for Venting of Deflagrations*

NFPA 69, *Standard on Explosion Prevention Systems*

NFPA 72, *The National Fire Alarm and Signaling Code*

NFPA 70, *The National Electrical Code*

Title 49, *Code of Federal Regulations (CFR), Hazardous Materials Regulations of the Department of Transportation*

1.9 Definitions

For purposes of this standard, the following terms apply:

Acknowledge — To confirm that a message or signal has been received, such as by the pressing of a button on the control unit or the selection of a software command.

Actuation Device — a means of initiating the explosion suppression system discharge that is installed on the suppressant storage releasing device or actuation cartridge and is capable of operation by electrical means.

Amplitude — The maximum displacement of sinusoidal motion from position of rest, or one—half the total table displacement, during a vibration test.

Authority Having Jurisdiction — The organization, office, or individual responsible for certifying equipment, materials, an installation, or a procedure.

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

Combustible Dust — a fine combustible particulate solid that presents a fire or explosion hazard when suspended in air.

Corrosion Resistant — a material that can withstand damage caused by oxidation or other chemical reactions.

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

Design Strength of Enclosure — The design pressure sufficient to withstand p_{red}. See NFPA 69 for further information.

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

Deflagration Parameters — Deflagration parameters are numerical terms, determined in accordance with the test methods specified in this standard that characterize the contained deflagration of a specified concentration of reactants in a vessel having a volume of 1 m^3.

- Maximum Pressure, P_{max} (bar(g))

The parameter P_{max} is the maximum pressure developed by a deflagration as determined by tests over a wide range of concentrations and under unvented conditions.

- Reduced Explosion Pressure, P_{red} (bar(g))

  The peak pressure reached in an explosion test vessel during a suppressed explosion test.

- Deflagration Index, K (bar-m/s)

  The deflagration index K is a constant of direct proportionality which defines the maximum rate of pressure rise with time $(dp/dt)_{max}$ of a deflagration in a volume V, according to the equation:

$$K = \left(\frac{dp}{dt}\right)_{max} \; x \; \sqrt[3]{V}$$

  K_g is used for gases, K_{st} for dusts.

  Deflagration indices measured in large-scale explosion test are identified as effective deflagration indices K_{eff}, since the conditions of large-scale tests differ from those present in standard test equipment commonly used for dust explosibility testing.

  Note: While used widely for engineering purposes, there are limits to the significance of the parameter K as a measure of mixture reactivity.

  In general, K cannot always be considered a finite property of the explosive mixture as its value depends on the volume and geometry of the test vessel, and on the presence or absence of turbulence.

- Fundamental Burning Velocity, S_u (cm/sec)

  The burning velocity of a laminar flame under stated conditions of composition, temperature, and pressure of the unburned mixture.

- Effective Burning Velocity, S_{eff} (cm/sec)

  The burning velocity of a reactive mixture that may be affected by turbulence, obstacles, or other factors. These factors produce a faster rate of flame propagation into the unburned mixture than that associated with a laminar flame for the same mixture. The effective burning velocity can be determined from the initial portion of the pressure trace in a full-volume, unsuppressed, unvented explosion.

Expellant Gas — The medium used to facilitate the discharge of the suppressant from the suppressant storage container.

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

Fire Alarm Signal — A signal following a detected explosion event requiring that a general alarm signal be sent to the local protective signaling system at the protected property, if so equipped.

Half Power Field of View — The half power field of view (HPFV) is defined as the off-axis angle where a radiant energy detector responds to a flame source at no less than ½ the distance it is capable of detecting on-axis.

Initiating Device — A system component that originates transmission of a change-of-state condition, such as in an explosion detector.

Maximum Working Pressure — The pressure in a suppressant storage container associated with the maximum operating temperature.

Minimum Bending Radius — The smallest radius (expressed in inches [mm]) specified by the manufacturer to which a flexible hose is safely allowed to bend without damage.

Minimum Working Pressure — The pressure in a suppressant storage container associated with the minimum operating temperature.

Operable Pressure Range — The minimum and maximum pressures of the suppressant storage container over which the system is intended to be functional. These pressures result from the minimum and maximum operating temperature range and the physical characteristics of the suppressant and expellant gas.

Proof Test Pressure — The factory test pressure used to verify the structural integrity of the suppressant storage container.

Resonance — The maximum magnification of applied vibration during a vibration test.

Supervisory Signal — A signal that results from the detection of a supervisory condition that impairs the proper operation of the explosion suppression System, such as a reduction in suppressant pressure.

Suppressant — The suppression agent used by the explosion suppression system to suppress the deflagration.

Suppressant Container — The assembly holding the suppressant supply for the explosion protection system. This includes the pressure vessel and various accessories necessary to discharge the suppressant, such as valves, pressure gauges, and pressure relief devices.

Suppressant Container Capacity — Nomenclature specified by the manufacturer of either the volume of suppressant or volume of the suppressant storage container.

Suppressor Configuration — A unique combination of suppressant container capacity, suppressant container working pressure, suppressant releasing device, suppressant type, suppressant disperser, etc.

Trouble Signal — A signal that results from the detection of a trouble condition within the explosion suppression System or its supervised components, such as faulty wiring or other equipment problems.

Working Pressure — The pressure in a fully charged suppressant storage container or gas cartridge, as applicable, at 70°F (21°C) or other temperature appropriate for the local jurisdiction.

2 GENERAL INFORMATION

2.1 Application

2.1.1 The technique of explosion suppression may be considered for any enclosure in which flammable gases, vapors, mists, or combustible dusts are subject to deflagration in a gas phase oxidant.

2.1.2 Typical equipment that may be protected by an explosion suppression system includes:

- processing equipment, such as mixers, blenders, pulverizers, mills, driers, ovens, filters, screens, and dust collectors;
- storage equipment, such as atmospheric or low pressure tanks and bins;
- material handling equipment, such as pneumatic and screw conveyors, and bucket elevators; and
- laboratory and pilot plant equipment, including hoods, glove boxes, test cells, and other equipment.

2.2 Certification Categories

2.2.1 Systems can be certified for suppression of flammable dust, gas, and vapor explosions.

2.2.2 Dusts are categorized in hazard classes from ST 0 to ST 3, based on K_{st} values in bar-m/sec:

ST 0 = K_{st} 0

ST 1 = K_{st} 1 to 200

ST 2 = K_{st} 201 to 300

ST 3 = $K_{st} > 300$

Certification listings will indicate the hazard class, by specific test(s), and system limitations for which an explosion suppression system has been certified.

Note: A typical representative dust for Class ST 1 would be cornstarch.

2.2.3 In general, certification of explosion suppression systems for gas and vapor explosion hazards shall be granted for either quiescent or turbulent mixture conditions; certification granted for turbulent conditions shall be deemed to also apply for quiescent conditions. The required turbulence shall be such that the measured effective burning velocity under turbulent conditions be at least four (4) times the value of the burning velocity of the same mixture under quiescent conditions. The actual multiplying value, determined by tests, shall be stated in the certification agent's listing. Certification shall apply only to the tested mixture and may be expanded to include other materials/mixtures if a review of data indicates that the following conditions are met:

1. The fundamental burning velocity of the material(s)/mixture(s) is less than or equal to the material/mixture tested; and

2. The material(s) are in the same chemical family such as alcohols, aliphatic hydrocarbons, aldehydes, ketones, etc., or it has been demonstrated that the material(s)/mixture(s) can be suppressed with equal or greater efficiency compared to the material/mixture tested, using a given suppressant.

2.3 Limitations

2.3.1 Performance of a suppression system can be adversely affected by obstructions within the protected enclosure.

2.3.2 The effectiveness of an explosion suppression system is limited by the physical and chemical properties of the reactants in the system.

2.3.3 Explosion suppression is applicable only to systems involving deflagrations that take place in a gaseous oxidant.

2.3.4 This standard does not apply to explosion suppression involving deflagrations in hybrid (dust/vapor) systems due to the variability in constituents and/or constituent concentrations.

2.4 Certification Application Requirements

To apply for a certification examination the manufacturer, or its authorized representative, should submit a request to the certification agency.

The manufacturer shall provide the following preliminary information with any request for certification consideration:

- A complete list of all models, types, sizes, and options for the products or services being submitted for certification consideration.
- Assembly drawings, component drawings, materials list, anticipated marking format, nameplate format, brochures, sales literature, specification sheets, and installation, operation and maintenance instructions.
- The number and location of manufacturing facilities.
- All documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level. All documents shall be provided with English translation.

2.5 Requirements for Samples for Examination

2.5.1 Following authorization of a certification examination, the manufacturer shall submit samples for examination and testing. Sample requirements are to be determined by the certification agency following review of the preliminary information provided.

2.5.2 Requirements for samples may vary depending on design features, results of prior testing, and results of any foregoing tests.

2.5.3 The manufacturer shall submit samples representative of production. Any decision to use data generated using prototypes is at the discretion of the certification agency.

2.5.4 It is the manufacturer's responsibility to provide any necessary test fixtures that may be required to evaluate the system.

3 GENERAL REQUIREMENTS

3.1 Review of Documentation

During the initial investigation and prior to physical testing, the manufacturer's specifications, technical datasheets, and design details shall be reviewed to assess the ease and practicality of installation and use. The system and its components shall be suitable for use within the defined limits of the certification investigation.

3.2 Operational, Physical, or Structural Features

3.2.1 Control Units (Panels)

3.2.1.1 Controls shall be powered by commonly available AC line voltage and shall be equipped with a battery backup system of sufficient capacity to power all detectors, suppressant actuation devices, and alarms for a period of 4 hours. The control shall have a means of maintaining the backup battery at full charge (typically a “trickle charger”) during normal operation.

3.2.1.2 They shall be equipped with audible and visual alarms and a means for automatic shutdown of a process, blower, conveyor, etc.

3.2.1.3 Controls shall be provided with some means of detecting faults in the actuation and detection circuits.

3.2.1.4 Fault detection or discharge of the explosion suppression system shall result in the activation of audible and visual alarms and activation of the shutdown circuit.

3.2.1.5 The control panel shall be equipped with a switch to activate or deactivate the suppression system. Switch operation shall require a key or other suitable means of preventing unauthorized operation. Deactivation of the suppression system shall activate the shutdown circuit and a visual alarm.

3.2.1.6 The control must be capable of operating properly between 85 and 110 percent of its nominal input power voltage.

3.2.1.7 Activation of the system control circuitry shall result in power-up of detectors and actuators, to ensure that the system is armed and providing active protection.

3.2.1.8 The control unit shall be capable of operating over a temperature range shown in Table 3.1 Required Operation Temperature Range.

3.2.1.9 The controls shall be enclosed by an appropriately rated housing capable of protecting components from normally expected adverse environmental conditions such as corrosive atmospheres, dust, and rain, see Section 4.17.1 (Electronics Enclosures).

3.2.1.10 Means shall be provided to mount control panel equipment securely and independently of the wiring.

3.2.1.11 The control panel equipment shall be capable of withstanding normal handling and installation.

3.2.1.12 Equipment intended for use in hazardous (classified) locations shall comply with the certification agency’s requirements for hazardous (classified) location electrical equipment in addition to this standard.

3.2.1.13 The control panel equipment and enclosure shall be suitable for the intended environmental exposures as determined by testing in accordance with acceptable national, regional, or international codes and standards.

3.2.1.14 The control panel equipment shall accommodate secure wiring methods in accordance with NFPA 70, National Electrical Code and NFPA 72, National Fire Alarm Code, or the governing codes and standards/authority for the installed jurisdiction.

3.2.1.15 Although not mandatory, the control panel may be connected to a certified fire alarm control unit. In such cases, the requirement of 3.2.1.16 shall apply, and the system output circuits shall be compatible with a certified fire alarm control unit that will produce distinctive alarm, supervisory and trouble fire alarm signals.

3.2.1.16 When the explosion suppression control unit is interfaced with a Fire Alarm Signaling System, the combination shall have response times in accordance with NFPA 72 The National Fire Alarm Code and within those defined in the manufacturer's specifications and installation and operational manual. The maximum response values as found in NFPA 72 are as follows:

- Alarm - 10 seconds (10.11.1) (applies when connected to a local alarm system)
- Supervisory – 90 seconds (10.13.1)
- Trouble – 200 seconds (10.14.1)

Note: Typical detection occurs in milliseconds When the explosion suppression control unit is interfaced with a Fire Alarm Signaling System, the Alarm Response cannot exceed 10 seconds.

3.2.1.17 Equipment rated at or above 30 V ac and 60 V dc requires a proper (protective) ground terminal to be provided.

3.2.1.18 For products intended for use in unsecured (public) areas, the controls for signal acknowledgement, reset, optional program initiation, manual override of any control sequence, or altering of system parameters, shall be of restricted access requiring software security code or other equivalent protection. For installations in secured, non-public areas (for example, within a manufacturing plant), this requirement shall not apply.

Note: If the manual controls are accessed via the opening of the key-locked enclosure, the equipment shall be arranged so that access does not result in the exposure of live electrical parts. A permanent warning / caution label with legible wording to avoid high voltage live parts can satisfy this requirement.

3.2.1.19 At a minimum, all control equipment and their displays shall use the following basic indicators:

- GREEN (Normal) **-** This green indicator shall illuminate when all power is applied to the system and no off-normal situations exist.
- RED (Explosion Alarm) **-** This red indicator shall illuminate when an explosion has been detected, flashing or steady state until the condition is resolved and cleared.
- YELLOW (Supervisory Alarm) **-** This yellow indicator shall illuminate when any supervisory condition exists, flashing or steady state until the condition is resolved and cleared.

- YELLOW (Trouble Alarm) **-** This yellow indicator shall illuminate when any trouble condition exists, flashing or steady state until the condition is resolved and cleared.

If an acknowledge feature is provided, the above indications shall be flashing until acknowledged, and steady state following acknowledgement.

3.2.2 Detectors

3.2.2.1 Explosion suppression systems shall be supplied with a minimum of two detectors. If a single detector has redundant means of detection, only one detector shall be required. The detectors shall be "cross-zoned" (i.e. both detectors must be activated) to minimize false actuation of the suppression system.

3.2.2.2 An incipient explosion shall be detected by pressure or radiant energy sensors. Pressure sensors may respond to a rate of pressure rise or at a preset pressure level. Radiant energy may be detected by infrared (IR), ultraviolet (UV), UV/IR combination or optical flame sensors.

3.2.2.3 Pressure detectors shall be capable of withstanding 150 percent of their rated operating pressure without permanent deformation or change in their system actuation settings.

3.2.2.4 Radiant energy sensors shall be equipped with a means of detecting sensitivity changes due to viewing lens obscuration, or a method of preventing obscuration. Detection of obscuration shall result in a visual and audible alarm.

3.2.2.5 Radiant energy sensors shall be of the rapid response type. Delayed reaction is allowable only for applications where there is a possibility for false discharge. The delay shall not be field adjustable, unless performed by a manufacturer's service technician with approval from the AHJ.

3.2.2.6 The detectors shall be capable of operating over a temperature range shown in Table 3.1 Required Operation Temperature Range.

3.2.2.7 Detectors and mounting hardware shall be capable of operating in, or be protected from, the normally expected adverse atmosphere or vibration in the protected enclosure.

3.2.2.8 For installations where radiant energy detectors can be exposed to direct or reflected sunlight or artificial light, they shall not react (alarm) to these sources, nor shall these sources prevent or delay the response to an explosive event.

3.2.3 Software Requirements

For equipment, including initiating devices that are dependent on software/firmware programs for normal operation:

- All software and firmware shall be identified by release level which shall be clearly marked on, or which can be displayed by, the product for ease of identification;
- All changes to the software shall result in a revision to the release level;
- The software/firmware shall not be accessible for and changes or modifications beyond what it has been certified for; and
- Any software failure that renders the detector inoperable shall result in a trouble condition at the detector and be appropriately transmitted to the fire alarm control (e.g. watchdog timer).

3.2.4 Actuation Devices

3.2.4.1 Actuators shall consist of an electrically fired pyrotechnic or propellant driven device (initiator), and a high speed suppressant releasing mechanism. Activation of the device shall cut, fracture, or otherwise open the suppressant releasing mechanism, thereby releasing the suppressant into the protected enclosure. Other types of actuators will be considered on an individual basis.

3.2.4.2 The actuation device and suppressant releasing mechanism shall be protected from adverse environments that could hinder or cause inappropriate operation.

3.2.4.3 The actuators shall be capable of operating over a temperature range shown in Table 3.1 Required Operation Temperature Range.

3.2.4.4 Galvanic action between the actuator and suppressant container shall be prevented by use of suitable materials, isolation from direct contact, or protective coatings.

3.2.4.5 The device which actuates the explosion suppressor shall either be an independent actuation device attached to the unit, or an internal component of the explosion suppression assembly itself.

3.2.4.6 Actuation devices shall be actuated automatically by a compatible certified detection and control system.

3.2.4.7 Where puncturing mechanisms are used, all exposed parts shall be made of corrosion resistant material.

3.2.5 Operating Range

All system components shall operate within the temperature ranges of Table 3.1. System and component evaluations will be based on the specified minimum and maximum operating temperatures. Operating temperatures outside of these limits shall be specified at discrete 5°F (3°C) increments.

Table 3.1 *Required Operation Temperature Range*

System Component	**Highest Allowable Minimum Operating Temperature**		**Lowest Allowable Maximum Operating Temperature**	
	°F	**(°C)**	**°F**	**(°C)**
Electronic Equipment	32	(0)	120	(49)
All other components	32	(0)	140	(60)

3.2.6 Materials

3.2.6.1 All components shall be made of materials suitably corrosion resistant for their intended use.

3.2.6.2 Any elastomers/seals used in the system shall be compatible with the suppressant and expellant gas. Compatibility shall be determined by successful performance when subjected to the requirements listed in Sections 4.3.2 (Long Term Leakage Test), 4.3.4 (30-Day Maximum Temperature Leakage Test), 4.3.3 (30-Day Minimum Temperature Leakage Test), and 4.14 (Elastomeric Materials Tests).

3.2.7 Gauges and Indicators

3.2.7.1 A pressure gauge shall be included with all suppression systems to indicate the pressure in the suppressant storage container and/or expellant storage containers/cartridges, as applicable, and shall comply with the following requirements:

- The face of the gauge shall indicate the appropriate units of pressure for which it is calibrated;
- The range of the gauge shall be based on the system's operable pressure range;
- The minimum indicated gauge pressure shall be marked on the left side of the gauge's range;
- A 70°F (21ºC) value shall be marked at the system's working pressure;
- The maximum gauge pressure shall be between 150 and 250 percent of the system working pressure at 70°F (21°C), and shall be marked on the right side of the gauge's range;
- The gauge shall be provided with a means of pressure relief to allow venting in the event of an internal leak; and
- The face of the gauge shall identify the suppressant/expellant with which it is intended to be used.

3.2.7.2 Pressure gauges are not required when pressures are monitored constantly by pressure transducers, provided that the presence of suitable pressure for the system is displayed locally, or at the control panel. Alternate methods of pressure indication shall be evaluated at the discretion of the certification agency.

3.2.7.3 Suppressant storage containers that need to be pressurized in order to expel suppressants shall be equipped with a pressure gauge marked to indicate an acceptable pressure range for effective dispersion of the suppressant. Pressure gauges, similar to those found on fire extinguishers, that use a green band to indicate an acceptable range are considered suitable.

3.2.7.4 Suppressant storage containers for high vapor pressure suppressants, that do not require auxiliary pressurization, shall be easily weighable or equipped with some means of determining suppressant quantity, at regular required maintenance intervals, after installation.

3.2.8 Pressure Relief Devices

Calculations shall be submitted to verify that pressure relief devices used on suppressant storage containers are designed to comply with the flow capacity and operating pressure requirements specified in CGA S-1.1, or equivalent regulations acceptable to the authority having jurisdiction. The construction and size of the pressure relief device shall, at a minimum, be appropriate for the system pressure at the maximum specified operating temperature.

3.2.9 Maintenance Lockout Devices

3.2.9.1 The explosion suppressant releasing device shall be provided with a maintenance lockout device for the purpose of shipping, handling, maintenance, and storage. For maintenance purposes, the device shall be an integral part of or attached to the container via a chain, or otherwise designed to minimize the likelihood of removal from the suppressor.

3.2.9.2 Systems that are equipped with lockout device for maintenance shall provide supervision to indicate that the suppression system is impaired.

3.2.10 Protective Covering

All explosion suppression systems with exterior movable parts that are vulnerable to obstruction or physical damage shall be protected by paneled enclosures or cages. Operating, levers, handles, or buttons requiring manual access for operation shall be exempt from this requirement to the extent necessary to allow for their unimpeded operation. Appropriate NEC cabling methods shall be used for electrical cables and wires, or pressurized tubes outside the enclosures. The manufacturer's installation and maintenance instructions shall include this requirement.

3.2.11 Suppressant Dispersers (Nozzles)

3.2.11.1 Suppressant dispersers and associated mounting hardware shall be capable of withstanding the effects of any corrosive atmosphere created by the gases or dusts within the protected enclosure. This may be accomplished by use of corrosion resistant materials, protective coatings, or any other suitable method.

3.2.11.2 Nozzle design and required maintenance intervals shall be such as to minimize the possibility of clogging by the material in the protected area.

3.2.12 Suppressant Containers (Cylinders)

3.2.12.1 Suppressant containers shall comply with ASME boiler and pressure vessel code, DOT, UN/ISO, or other national or international requirements as applicable. certification of other types of containers shall require a special investigation.

3.2.12.2 The container shall be capable of operating over a temperature range shown in Table 3.1 Required Operation Temperature Range.

3.2.12.3 The following documents shall be submitted for each storage container design, to demonstrate compliance with the relevant design standard:

- Calculation of wall thicknesses per the method specified in the applicable standard, with appropriate supporting references as necessary
- Certificate of chemical analysis of materials
- Certificate of physical properties of materials

3.2.13 Suppressant

3.2.13.1 Generally, suppressants shall be of the dry chemical type, one of the clean agents listed in NFPA 2001, or water. Other types of suppressants will be considered on an individual basis.

3.2.13.2 The suppressant shall be effective at the specified extremes of temperature for the explosion suppression system.

3.2.13.3 Expellant Gases

Nitrogen used in an explosion suppression system shall have a dew point of no greater than -60°F (-51.1°C) and shall have a purity greater than or equal to 99.99 % (mole/mole). The use of any other expellant gas shall be evaluated at the discretion of the certification agency.

3.2.14 System Operation – General

A visual indication that the explosion suppression system is in normal operating condition is required. This is permitted to be at the control unit.

3.2.15 Electrical Wiring

3.2.15.1 All wiring to the explosion suppression system and between components of the system shall be grounded and shall be isolated and shielded from all other wiring to prevent induced currents that could affect operation of the system.

3.2.15.2 When environmental conditions warrant, wiring shall be sealed in accordance with NFPA 70, or equivalent to prevent entrance of moisture and other contaminants.

3.2.15.3 When conduit is used for wiring multiple installations, the wiring for each suppression system shall be run in separate conduits. Alternatively, each system may be wired with shielded cables run in common conduits.

3.3 Drawings, Plans, and Specifications

The manufacturer shall provide the following items:

- Drawings and/or specifications for all the major components of the suppression system. This includes the control panel and its major components, suppressant actuators and suppressant storage containers, detectors, and suppressant dispersing nozzles;
- Schematics, final assembly layout, and bills of material (BOM) pertaining to electronic circuit boards. Information concerning common electronic components and circuit board artwork is not needed;
- Safety data sheets (SDS) for the explosion suppressant;
- Drawings and/or samples of all labels attached to the system and an indication of their location;
- A copy of the installation, operation, and maintenance manual for the system;
- The Deflagration Index K, burning velocity, and chemical family for all combustibles for which the system is designed; and
- Information relating to the calculations and/or formulas for determining type and quantity of suppressant; dispersing nozzle location, quantity, and size; and detector location, quantity, and type.

3.4 Markings

3.4.1 Easily visible nameplates shall be affixed to the suppressant storage container assembly of the explosion suppression system and shall display the following markings at a minimum. Any additional markings required by the authority having jurisdiction shall also be provided:

- Manufacturer’s name and address;
- System type and model number;
- Serial number;
- Applicable electrical ratings;
- The certification agency’s mark of conformity;
- Suppressant identification;
- Quantity of suppressant;
- System working pressure;
- Operating and storage temperature limitations;
- Factory test pressure of the storage container;

- Year of manufacture of the storage container (if not directly stamped on the container);
- Reference to the relevant NFPA standard and/or any other relevant local standards; and
- Reference to the manufacturer's installation, operation, recharge, and maintenance instructions.

3.4.2 When hazard warnings are needed, the markings should be universally recognizable.

3.4.3 Explosion suppression systems shall be labeled with a model number, part number, or by some other type of identification that will allow an observer to determine that the correct system components have been supplied.

3.4.4 Labeling shall be capable of withstanding prolonged exposure to normally expected environmental conditions without loss of legibility or detachment from its mounting surface, as verified by Section 4.12 (Corrosion – Salt Spray).

3.4.5 The model or type identification shall correspond with the manufacturer's catalog designation and shall uniquely identify the product as certified. The manufacturer shall not place this model or type identification on any other product unless covered by a separate agreement.

3.4.6 The certification agency's mark of conformity shall be displayed visibly and permanently on the product and/or packaging as appropriate and in accordance with the mark of conformity guidelines. The manufacturer shall not use this Mark on any other product unless such product is covered by a separate report.

3.4.7 Detection and control system components shall be marked at minimum with the following information:

- The manufacturer's name and address, or equivalent;
- The model or type designation, which shall uniquely identify the product and correspond to the manufacturer's catalog designation;
- The serial number or an equivalent means to identify date of manufacture, a code traceable to date of manufacture or lot identification;
- Identification of controls and indicators;
- Operational and environmental suitability ratings (if not possible due to size, this information must be provided in other included installation and use materials);
- The certification agency's mark of conformity; and
- Inter-equipment wiring diagrams (if not possible due to size, this information must be provided in other included installation and use materials).

3.4.8 All markings shall be legible and durable.

3.5 Manufacturer's Installation and Operation Instructions

3.5.1 The manufacturer shall provide information required to properly install, operate, and maintain the system. These instructions shall be submitted to the certification agency prior to the examination of a system.

3.5.2 Section 5.6 (Installation, Operation, and Maintenance Manual) provides further guidance on the requirements for the installation, operation, and maintenance manuals.

3.6 Calibration

3.6.1 Each piece of equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose, and usage. A copy of the calibration certificate for each piece of test equipment is required for the certification agency's records. The certificate shall indicate that the calibration was performed against working standards whose calibration is certified as traceable to the National Institute of Standards and Technology (NIST) or traceable to other acceptable reference standards and certified by an ISO/IEC 17025 accredited calibration laboratory. The test equipment shall be clearly identified by label or sticker showing the last date of the calibration and the next due date. A copy of the service provider's accreditation certificate as an ISO/IEC 17025 accredited calibration laboratory is required for the certification agency's records

3.6.2 The calibration of new equipment is also required. Documentation indicating either the date of purchase or date of shipment, equipment description, model and serial number is required for identification. The new test equipment shall be clearly identified by label or sticker showing the date of initial calibration and the next due date.

3.6.3 When the inspection equipment and/or environment is not suitable for labels or stickers, other methods such as etching of control numbers on the measuring device are allowed, provided documentation is maintained on the calibration status of thus equipment.

3.7 Tolerances

Tolerances on units of measure shall be as described in APPENDIX B: TOLERANCES, unless otherwise specified.

4 PERFORMANCE REQUIREMENTS

4.1 Open Air Discharge Baseline

4.1.1 Requirements

Each suppressor configuration at working pressure shall be discharged to characterize the growth of the suppressant cloud. All system components subject to suppressant discharge, such as protective nozzle covers, maintenance lockout devices, vibration isolation devices, and telescoping nozzles shall be included in the tests below.

4.1.2 Tests/Verification

An explosion suppressor shall be mounted to a test stand next to a black fiducial marker that is at least the size of the maximum suppressant dispersion pattern. A high speed video camera, capable of at least 1000 frames per second, shall be positioned perpendicular to the discharge at the level of the dispersion nozzle. The field of view shall capture the dispersion nozzle and the maximum dispersion pattern at a minimum.

A piezoresistive pressure transducer, suitable for the pressure range to be measured, shall be used to measure suppressant storage container pressure during the discharge at a sampling rate of 25 kHz. The manufacturer shall provide a ¼ in. NPT connection that is capable of monitoring the pressure in the suppressant storage container.

A visual indicator, such as an electric match, shall be placed within the field of view of the high speed video camera to synchronize the high speed video with the pressure measurement.

Ambient temperature, pressure, and wind speed at the test stand location shall be recorded; wind speed shall be less than 7 MPH (11.2 km/hr) for all open air discharge tests.

The suppressor shall be discharged and the high speed video, visual indicator and pressure measurement shall be simultaneously triggered at the same time as the suppressor.

The radial growth of the suppressant cloud shall be measured, and the radial expansion velocity and radial throw distance shall be determined according to Appendix C: PERFORMANCE LIMITS METHODOLOGY.

The open air discharge shall be repeated with a second explosion suppression suppressor, and the results for each parameter shall be averaged together. These tests shall be completed prior to performing the tests in Section 4.2 (Full Scale Suppression Performance Tests). Components from Section 4.12 (Corrosion – Salt Spray) shall also be subjected to these baseline tests, as required.

4.2 Full Scale Suppression Performance Tests

Full scale explosion tests include unsuppressed tests that are used to characterize the reactivity of the explosions, followed by suppression tests that are used to quantify the performance of the suppression system. Dust and gas explosion tests shall be conducted based on the intended certification categories for the explosion suppression system.

These tests are intended to be performed with proprietary FM Global explosion test setups. Qualification of equivalency for setups other than those owned by FM Global shall be performed at the sole discretion of the certification agency.

All full scale explosion tests shall be conducted in one of FM Global’s three explosion vessels unless other vessels are deemed necessary or acceptable by the certification agency. Explosion vessels are selected depending on the suppressant bottle capacity. The recommended vessels for a range of suppressant bottle capacities are shown in Table 4.1 for the FM Global vessels.

Table 4.1 *Recommended Vessel Size and Nominal Ignition Distance*

Suppressant Bottle Capacity		**Recommended Vessel Volume**		**Distance From Ignition to Injection, *d***					
L	(gal)	m^3	(gal)	m			(ft)		
< 10	< 2.6	2.5	660	0.7	0.8	1.2	2.3	2.6	3.9
10 – 30	2.6 – 7.9	8	2100	1.0	1.2	1.7	3.3	3.9	5.6
> 30	> 7.9	25	6600	1.5	1.8	2.5	4.9	5.9	8.2

4.2.1 Dust Ignition Time Delay

4.2.1.1 Requirements

Unsuppressed dust explosion tests must first be conducted in the selected vessel in order to determine the appropriate ignition time delay such that the effective reactivity of the dust, K_{eff}, is within ± 10% of the upper limit of the desired reactivity class.

In general, 46.8 lb/ft^3 (750 g/m^3) of cornstarch shall be used in dust explosion tests to emulate an ST1 or ST2 reactivity class. The dust shall be dried prior to each test and the moisture content of the dust shall be no more than 1.5% by weight.

The manufacturer may request alternative dusts to be used provided that the optimal concentration is determined through the test method of ASTM E 1226-19. This optimal concentration of alternate dusts will be in lieu of the 46.8 lb/ft^3 (750 g/m^3) concentration of cornstarch. Only organic dusts can be evaluated.

4.2.1.2 Tests/Verification

The test vessel shall be filled with dry air and it shall be verified that the oxygen concentration inside the vessel is within 21.0 ± 0.5%. The pressure and temperature inside the vessel when it has equilibrated with the ambient atmosphere shall be recorded.

Two piezoresistive pressure transducers with a minimum range of 0-150 psia (0-10.3 bar) shall be used to measure the pressure histories inside the vessel at a sampling rate of 25 kHz.

The required amount of the dust necessary to achieve the intended concentration (i.e., mass = concentration x vessel volume) shall be loaded into the dust injectors.

The vessel shall be partially evacuated, and the dust injectors shall be pressurized and discharged to disperse the dust into the vessel. The vessel pressure after injecting the dust shall be between 95% and 100% of the recorded ambient pressure.

The dust shall be ignited by two 5 kJ chemical ignitors mounted at the center of the vessel after an ignition time delay that is suitable to reach the desired K_{eff}.

Results are considered acceptable if K_{eff} is found to be in the range of 180 < K_{eff} < 220 bar m/s for ST1 and 270 < K_{eff} < 330 bar m/s for ST2. If it is not, the ignition time delay shall be adjusted. Once an appropriate ignition time delay is found, two repeat tests shall be conducted to confirm.

The vessel shall be thoroughly cleaned to remove any particulate from previous tests.

4.2.2 Suppression of Dust Explosions

4.2.2.1 Requirements

A minimum of four full scale suppression tests shall be conducted. In these tests, the distance from ignition to injection, *d*, shall be varied in order to maximize the range of the reduced pressures that is achieved. At least two different values of *d* will be required, with two tests conducted for each value of *d*, such that reduced pressures of $\Delta p_{red} < 0.4$ bar and $\Delta p_{red} \geq 0.5\ \Delta p_{max}$ are achieved in the tests.

All system components subject to suppressant discharge, such as protective nozzle covers, maintenance lockout devices, vibration isolation devices, and telescoping nozzles, shall be included for evaluation. If multiple suppressor configurations are submitted for examination, the results from Section 4.1 (Open Air Discharge Baseline) shall be reviewed by the certification agency for similarities in performance and grouped together, if applicable, to reduce the total number of suppression tests required.

4.2.2.2 Tests/Verification

Prior to conducting the suppressed dust explosion tests, two repeat dust ignition time delay tests shall be conducted in accordance with Section 4.2.1.

From Table 4.1, a distance from the suppressant injection location to the ignitor, *d*, shall be selected such that a reduced overpressure of $\Delta p_{red} < 0.4$ bar can be achieved in the test.

An explosion suppression system at working pressure shall be installed onto the vessel. The manufacturer shall provide mating flanges for the suppressor and detector as needed. See Appendix D for flange dimensions. Detection and control systems shall be calibrated to the ambient pressure at the time of testing and the activation method (e.g., pressure threshold/pressure rate of rise) shall be relative to the starting ambient pressure. Detection and control systems shall be configured such that unwanted system activation prior to ignition is prevented, mainly during dust injection. Pre-tests shall demonstrate the appropriate system configuration.

The test vessel shall be filled with dry air and it shall be verified that the oxygen concentration inside the vessel is within 21 ± 0.5%. The pressure and temperature inside the vessel when it has equilibrated with the ambient atmosphere shall be recorded.

Two piezoresistive pressure transducers with a minimum range of 0-150 psia (0-10.3 bar) shall be used to measure the pressure histories inside the vessel at a sampling rate of 25 kHz.

The required amount of the dust necessary to achieve the intended concentration (i.e., mass = concentration x vessel volume) shall be loaded into the dust injectors.

The vessel shall be partially evacuated, and the dust injectors shall be pressurized and discharged to disperse the dust into the vessel. The vessel pressure after injecting the dust shall be between 95% and 100% of the recorded ambient pressure.

The dust shall be ignited with two 5 kJ chemical ignitors after an ignition time delay that is suitable to reach the desired K_{eff}, as determined in Section 4.2.1.

If $\Delta p_{red} < 0.4$ bar, a repeat test using the steps outlined above shall be conducted. If $\Delta p_{red} \geq 0.4$ bar, *d* shall be adjusted in order to achieve a reduced overpressure of $\Delta p_{red} < 0.4$ bar, and two additional tests shall be performed.

A second value of *d* shall be similarly evaluated such that an overpressure of $\Delta p_{red} \geq 0.5\ \Delta p_{max}$ can be achieved. If the largest experimentally feasible value of *d* for the selected explosion test vessel cannot produce $\Delta p_{red} \geq 0.5\ \Delta p_{max}$, lower values of Δp_{red} may be acceptable at the sole discretion of the certification agency.

The vessel shall be thoroughly cleaned to remove any particulate from previous tests.

The maximum quench distance, *MQD*, shall be determined for each tested explosion suppressor configuration, using the methods described in Appendix C: PERFORMANCE LIMITS METHODOLOGY.

4.2.3 Constant Volume Gas Explosion Test

4.2.3.1 Requirement

Two unsuppressed gas explosion tests shall be conducted. The fuel shall be selected to meet the intended certification category according to Section 2.2.3.

4.2.3.2 Tests/Verification

The test vessel shall be filled with dry air and it shall be verified that the oxygen concentration inside the vessel is within 21.0 ± 0.5%. The temperature and pressure inside the vessel when it has equilibrated with the ambient atmosphere shall be recorded.

Two piezoresistive pressure transducers with a minimum range of 0-150 psia (0-10.3 bar) shall be used to measure the pressure histories inside the vessel at a sampling rate of 25 kHz.

The required amount of gaseous fuel shall be filled into the vessel to obtain the desired composition of the fuel-air mixture at ambient pressure. The mixture shall be circulated to ensure uniform mixing and the composition shall be verified by gas analysis and recorded.

The mixture shall be ignited with an electric spark mounted at the center of the vessel.

Results are considered acceptable if p_{max} is within 15% of the theoretical constant volume explosion pressure.

4.2.4 Suppression of Gas Explosions

4.2.4.1 Requirement

A minimum of four full scale suppression tests shall be conducted. In these tests, the distance from ignition to injection, *d*, shall be varied in order to maximize the range of the reduced pressures that is achieved. At least two different values of *d* will be required, with two tests conducted for each value of *d*, such that reduced pressures of $\Delta p_{red} < 0.4$ bar and $\Delta p_{red} \geq 0.5\ \Delta p_{max}$ are achieved in the tests.

All system components subject to suppressant discharge, such as protective nozzle covers, maintenance lockout devices, vibration isolation devices, and telescoping nozzles, shall be included for evaluation. If multiple suppressor configurations are submitted for examination, the results from Section 4.1 (Open Air Discharge Baseline) shall be reviewed by the certification agency for similarities in performance and grouped together, if applicable, to reduce the total number of suppression tests required.

4.2.4.2 Tests/Verification

From Table 4.1, a distance from the suppressant injection location to the ignitor, *d*, shall be selected such that a reduced overpressure of $\Delta p_{red} < 0.4$ bar can be achieved in the test.

An explosion suppression system at working pressure shall be installed onto the vessel. The manufacturer shall provide mating flanges for suppressor and detector as needed. See Appendix D for flange dimensions. Detection and control systems shall be calibrated to the ambient pressure at the time of testing and the activation method (e.g., pressure threshold/pressure rate of rise) shall be relative to the starting ambient pressure. Detection and control systems shall be configured such that unwanted system activation prior to ignition is prevented, mainly during mixture preparation. Pre-tests shall demonstrate the appropriate system configuration.

The test vessel shall be filled with dry air and it shall be verified that the oxygen concentration inside the vessel is within 21 ± 0.5%. The temperature and pressure inside the vessel when it has equilibrated with the ambient atmosphere shall be recorded.

Two piezoresistive pressure transducers with a minimum range of 0-150 psia (0-10.3 bar) shall be used to measure the pressure histories inside the vessel at a sampling rate of 25 kHz.

The required amount of gaseous fuel shall be filled into the vessel to obtain the desired composition of the fuel-air mixture. The mixture shall be circulated to ensure uniform mixing, and the composition shall be verified by gas analysis and recorded.

The mixture shall be ignited with an electric spark.

If $\Delta p_{red} < 0.4$ bar, a repeat test using the steps outlined above shall be conducted. If $\Delta p_{red} \geq 0.4$ bar, *d* shall be adjusted in order to achieve a reduced overpressure of $\Delta p_{red} < 0.4$ bar, and two additional tests shall be performed.

A second value of *d* shall be similarly evaluated such that an overpressure of $\Delta p_{red} \geq 0.5\ \Delta p_{max}$ can be achieved. If the largest experimentally feasible value of *d* for the selected explosion test vessel cannot produce $\Delta p_{red} \geq 0.5\ \Delta p_{max}$, lower values of Δp_{red} may be acceptable at the sole discretion of the certification agency.

The maximum quench distance, *MQD*, shall be determined for each tested explosion suppressor configuration, using the methods described in Appendix C: PERFORMANCE LIMITS METHODOLOGY.

4.2.5 Certification Limitations

4.2.5.1 Applications are limited to the specific explosion suppressor, system charge pressure, dispersion nozzle configuration, suppressant, suppressant capacity, and system-activation method and threshold that were represented in the suppression tests.

4.2.5.2 Applications are limited by reactivity class:

a. For gases/vapors, the certification is granted as described in Section 2.2.3.

b. For dusts, the reactivity class (ST1 or ST2) of the tested dust explosion, provided that the actual maximum K_{eff} of the dust used in the suppression tests is within ±10% of the upper limit of the dust reactivity class. For lower values of K_{eff} the certification is granted for dust reactivities up to the specific value tested.

c. For reactivity class ST3, certification is granted up to the specific value of K_{eff} tested.

4.2.5.3 Applications are limited to the protection of enclosures that withstand the reduced overpressure predicted by Equation A9 in Appendix C, using either the CAD-based method [A] or the analytical method [B] (see Appendix C) to estimate the unprotected volume. If the analytical method [B] is used, applications are further limited in terms of suppressor arrangement and maximum protected distance as described in Appendix C.

4.3 Suppressant Storage Containers (Cylinders)

4.3.1 Construction Design

4.3.1.1 Requirement

Suppressant storage containers shall be fabricated, tested, certified, equipped, and provided with labeling in accordance with recognized international standards, such as the current specifications of the ASME Boiler and Pressure Vessel Code, Section VIII, or the requirements of U.S. Department of Transportation, Title 49, Code of Federal Regulations, Parts 171 to 180, or equivalent national codes for the country of use. The design working pressure shall be in accordance with the pressure at the manufacturer’s nominal operating temperature at 70oF (21oC). Certification of other types of suppressant storage containers shall require a special investigation.

4.3.1.2 Tests/Verification

All documentation concerning the fabrication and testing of the suppressant storage container shall be provided to the certification agency for initial evaluation of the following:

- Verification that the pressure vessel standard is appropriate for the system storage pressure, and appropriate to the jurisdiction in which the equipment will be used. If the standard does not meet this requirement, there may be additional minimum criteria established by the certification agency; and
- Verification that the design is in accordance with the standard. Typical verification includes a review of certification to manufacture to the standard, minimum wall thickness calculations, authorized materials, material tests, and general chemical analysis tests.

Further verification that the manufacturer is capable of producing storage containers in accordance with the relevant standard shall be required at the discretion of the certification agency. Typically, verification includes volumetric expansion and hydrostatic pressure tests in accordance with the applicable standard(s).

4.3.2 Long Term Leakage

4.3.2.1 Requirement

Stored-pressure dry chemical and water suppressant storage containers shall not leak in excess of the mass equivalent to 0.5 percent of the nominal storage pressure, when monitored over a one year period at 70°F ± 5°F (21°C ± 3°C).

Stored-pressure clean agent suppressant storage containers shall not leak in excess of 0.5 percent of the minimum suppressant weight for each explosion suppressor size, when monitored over a one year period at 70°F ± 5°F (21°C ± 3°C).

External expellant storage containers/cartridges used for non-pressurized suppressant storage containers shall not leak in excess of the mass equivalent to 0.5 percent of the nominal storage pressure, based upon the minimum size container, when monitored over a one year period at 70°F ± 5°F (21°C ± 3°C).

Subsequent to the one year test period, one sample of each leak path design and size shall be successfully discharged using one of the manufacturer's compatible operating devices and shall discharge no less than 98 percent (by weight) of suppressant. The duration of this test may be reduced at the sole discretion of the certification agency.

The allowable leakage value is based upon a 2 to 1 safety factor applied to a maximum 5 percent total leakage over a five year inspection period.

4.3.2.2 Tests/Verification

A minimum of three stored-pressure suppressant storage containers of each leak path design and size shall be filled to the highest rated capacity with the applicable suppressant and pressurized to the normal working pressure. For external expellant storage containers, a minimum of three samples shall be pressurized to the working pressure. All test samples shall incorporate all components subjected to the working pressure, including operating devices.

Each sample shall be weighed at 0, 1, 3, 6, and 12 months, and where applicable, the projected weight loss over a one year period shall be extrapolated. The test shall be suspended if the calculated leakage at any time exceeds the allowable quantity, or any leakage is visible.

Samples shall be discharged, then re-weighed to determine overall compliance.

4.3.3 30-Day Minimum Temperature Leakage Test

4.3.3.1 Requirement

Stored-pressure suppressant storage container assemblies and external expellant storage containers/cartridges shall be conditioned to the specified minimum system operating temperature for 30 days. There shall be no visible signs of leakage from the container, including any pressurized actuation devices, during or after the conditioning period. Samples shall be of the smallest container size that will be supplied with the suppressant releasing device.

Stored-pressure dry chemical and water suppressant storage containers shall not leak in excess of the mass equivalent to 0.042 percent of the nominal storage pressure.

Stored-pressure clean agent suppressant containers shall not leak in excess 0.042 percent of the minimum suppressant weight for each explosion suppressor size.

External expellant storage containers/cartridges used for non-pressurized suppressant storage containers shall not leak in excess of the mass equivalent to 0.042 percent of the nominal storage pressure.

All samples shall be conditioned to the specified minimum system storage temperature for a 30 day period. The allowable leakage value is 1/12 of the one year allowable leakage, as specified in Section 4.3.2 (Long Term Leakage).

Subsequent to the minimum temperature leakage test, one sample of each leak path design and size shall be successfully discharged using one of the manufacturer's compatible operating devices and shall discharge no less than 98 percent (by weight) of suppressant.

4.3.3.2 Tests/Verification

A minimum of three stored-pressure suppressant storage containers of each leak path design and size shall be filled to the highest rated capacity with the applicable suppressant and pressurized to the normal working pressure. For external expellant storage containers, a minimum of three samples shall be pressurized to the working pressure. All test samples shall incorporate all components subjected to the working pressure, including operating devices.

The samples shall be weighed prior to the minimum temperature exposure and shall be subjected to the minimum specified storage temperature for 30 days. Following the exposure period, the samples shall be weighed to determine the amount of suppressant or pressure lost. Samples shall be discharged, then re-weighed to determine overall compliance.

4.3.4 30-Day Maximum Temperature Leakage Test

4.3.4.1 Requirement

Stored-pressure suppressant storage container assemblies and external expellant storage containers/cartridges shall be conditioned to the specified maximum system operating temperature for 30 days. There shall be no visible signs of leakage from the container, including any pressurized actuation devices, during or after the conditioning period. Samples shall be of the smallest container size that will be supplied with the suppressant releasing device.

Stored-pressure dry chemical and water suppressant storage containers shall not leak in excess of the mass equivalent to 0.042 percent of the nominal storage pressure.

Stored-pressure clean agent suppressant containers shall not leak in excess 0.042 percent of the minimum suppressant weight for each explosion suppressor size.

External expellant storage containers/cartridges used for non-pressurized suppressant storage containers shall not leak in excess of the mass equivalent to 0.042 percent of the nominal storage pressure.

All samples shall be conditioned to the specified maximum system storage temperature for a 30 day period. The allowable leakage value is 1/12 of the one year allowable leakage, as specified in Section 4.3.2 (Long Term Leakage).

Dry chemical explosion suppressors that are not normally pressurized shall be subjected to the same 30 day maximum temperature exposure, but with the addition of humidity. No visible moisture shall be present after the temperature conditioning period. Clumping, or caking of the suppressant from its original form is not acceptable.

Subsequent to the maximum temperature leakage test, one sample of each leak path design and size shall be successfully discharged using one of the manufacturer's compatible operating devices and shall discharge no less than 98 percent (by weight) of suppressant.

4.3.4.2 Tests/Verification

A minimum of three stored-pressure suppressant storage containers of each leak path design and size shall be filled to the highest rated capacity with the applicable suppressant and pressurized to the normal working pressure. For external expellant storage containers, a minimum of three samples shall be pressurized to the working pressure. All test samples shall incorporate all components subjected to the working pressure, including operating devices.

The samples shall be weighed prior to the maximum temperature exposure and shall be subjected to the maximum specified storage temperature for 30 days. Following the exposure period, the samples shall be weighed to determine the amount of suppressant or pressure lost. Samples shall be discharged using, then re-weighed to determine overall compliance.

Dry chemical explosion suppressors that are not normally pressurized shall be subjected to the maximum storage temperature for 30 days with humidity at 93 ± 3 %. Samples will be weighed prior to the maximum temperature exposure and inspected for the presence of moisture. Following the exposure period, the samples shall be weighed, and inspected for moisture intrusion.

4.3.5 Hydrostatic Integrity

4.3.5.1 Requirement

Suppressant storage containers and gas cartridges shall be hydrostatically tested without failure at a pressure equal to 1.5 times the rated pressure of the pressure relief device, or in accordance with the applicable published standard, whichever pressure is greater. Allowable standards shall be those acceptable to the authority having jurisdiction, based on the intended market for the system. Certification shall be limited to installations within jurisdictions accepting the standard to which the containers have been manufactured. No cracking, fracture, or failure to retain the test pressure shall be allowed.

Containers designed to standards other than accepted national or international described in section 3.2.12, shall be pressurized to three times their proof pressure for one minute. There shall be no evidence of leakage or rupture.

4.3.5.2 Tests/Verification

Each sample shall be subjected to the required test pressure, using water as the pressurizing medium. For the final 20 percent of the required pressure, the rate of pressure increase shall be no more than 10 percent per minute. The required test pressure shall be maintained for a minimum of one minute, or in accordance with the applicable published standard, whichever is longer.

Two samples of each container size intended for use with the system shall be tested. Container designs consisting of the same diameter, wall thickness, and material of construction, but with differing heights, may be evaluated by testing selected representative samples rather than samples of all container heights.

Samples that deviate from the calculated minimum wall thickness specified in 4.3.1 (Construction Design), may be accommodated by increasing the test pressure in proportion to the wall thickness. This may be used for up to a maximum difference of 20 percent.

At the sole discretion of the certification agency, physical testing may be waived for pressure vessels being manufactured under continuous third-party surveillance to a recognized and appropriate pressure vessel regulation. In these circumstances, in lieu of physical testing, the manufacturer shall provide adequate documentation detailing continuous (every lot) third-party oversight of the pressure vessel manufacturing, sample test results, and appropriate certification documentation for the overseeing body.

4.3.6 Permanent Volumetric Expansion

4.3.6.1 Requirement

Permanent volumetric expansion testing is required under some pressure vessel standards. If required by the standard to which the suppressant storage container or expellant cartridge is designed, such tests shall be conducted in accordance with that standard.

When subjected to the proof test pressure, the permanent volumetric expansion of a storage container shall not exceed 10 percent of the total expansion. The proof test pressure shall be as specified in the ASME Boiler and Pressure Vessel Code, Section VIII, or the U.S. Department of Transportation, Title 49, Code of Federal Regulations, Parts 171 to 180, or the equivalent national codes for the country of use. In cases where the pressure vessel is not tested or marked in accordance with one of these specifications, the proof test pressure shall be equal to three times the suppression system's working pressure.

When permanent volumetric expansion testing is required, the container shall be pressurized to their proof pressure for 30 seconds. Permanent volumetric expansion shall not exceed 10 percent of the total expansion that occurred under pressure.

4.3.6.2 Tests/Verification

Each sample shall be subjected to the required test pressure, using water as the pressurizing medium. For the final 20 percent of the required pressure, the rate of pressure increase shall be no more than 10 percent per minute. The required test pressure shall be maintained for a minimum of one minute, or in accordance with the applicable published standard, whichever is longer. The total expansion of the suppressant storage container shall be measured. The applied pressure shall then be removed from the sample, and the permanent volumetric expansion shall be measured.

Two samples of each container size intended for use with the system shall be tested. Suppressant storage container designs consisting of the same diameter, wall thickness, and material of construction, but with differing heights, may be evaluated by testing selected representative samples rather than samples of all suppressant storage container heights.

At the sole discretion of the certification agency, physical testing may be waived for pressure vessels being manufactured under continuous third-party surveillance to a recognized and appropriate pressure vessel regulation. In these circumstances, in lieu of physical testing, the manufacturer shall provide adequate documentation detailing continuous (every lot) third-party oversight of the pressure vessel manufacturing, sample test results, and appropriate certification documentation for the overseeing body.

4.4 Actuation Device Operation

4.4.1 Electrically Operated Devices

4.4.1.1 Requirement

Electrically operated actuation devices shall be conditioned for a minimum of 16 hours and shall operate properly at 85 and 110 percent of the rated voltage while at the maximum and minimum specified operating temperatures.

4.4.1.2 Tests/Verification

A minimum of one sample of each device shall be conditioned in accordance with the parameters described in Section 4.4.1.1 above. Following the conditioning period, each sample shall operate when supplied with 85 percent of rated voltage, and again when supplied with 110 percent of rated voltage. The device shall display no hesitation, partial operation, or other failure and shall be tested with the suppressant release device.

Electrically operated devices shall be test fired using the system limitations as specified by the manufacturer. A minimum of four groups of actuators shall be test fired. Each group shall consist of the maximum number of actuators, in series that would be allowed by the specified control panel, and maximum length of wire or cable. Two groups shall be conditioned at the minimum system operating temperature and the remaining groups at the maximum temperature. All samples shall be operated simultaneously at the minimum rated operating current, but no more than the output of the control releasing panel. All samples must operate.

4.4.2 No-Fire / All-Fire Current Test

4.4.2.1 Requirement

Electrically operated actuation devices shall be conditioned for a minimum of 16 hours and shall not operate when subjected to the specified no-fire current while at the maximum and minimum specified operating temperatures.

4.4.2.2 Tests/Verification

Electrically operated actuation devices shall be conditioned in accordance with the parameters described in Section 4.4.2.1 above. A minimum of three samples are required for each conditioning temperature. Following the conditioning period, each sample shall be subjected to the maximum no-fire current for five minutes to verify the maximum current that would result in a no-fire condition.

Each sample will then be subjected to the minimum all-fire current and nominal firing voltage to verify normal operation.

4.5 Cycle Operation Test

4.5.1 Requirement

All reusable components required for system operation having moving parts shall operate through a total of 500 cycles at the working pressure without damage. Any system components that are inspected and replaced after each operation per the Installation, Operation, and Maintenance manual, such as rupture discs or pyrotechnic actuators, shall be evaluated by operation of a minimum of 30 samples. All shall operate within the manufacturer's specified parameters. Following the test, all components shall continue to operate normally.

4.5.2 Tests/Verification

The test samples shall include all components undergoing mechanical movement during system operation including suppressant releasing devices, electrical, pneumatic, and mechanical operating devices such as switches, relays, and indicators. Components shall be subjected to the working pressure and cycled from the fully closed to fully open position per Section 4.5.1. At minimum, the largest and smallest sizes of each device and design shall be tested.

Subsequent to the cycle operation test, each component shall be visually inspected for damage. All components included in the test shall show no sign of physical deterioration that would affect performance and shall continue to operate normally. Suppressant releasing mechanisms shall be actuated by all available discharge devices. The pressure required for pneumatic operating devices shall be recorded.

Components and pressure containing devices shall be tested for leakage at their working pressures for one minute subsequent to the cycle operation test. No leakage shall be visible.

4.6 Hydrostatic Pressure Tests

4.6.1 Requirement

All components subjected to system pressure, either during storage or system discharge, shall withstand the pressure described in Section 4.3.5 (Hydrostatic Integrity) for one minute. No cracking, fracture, or failure to retain the test pressure shall be permitted.

4.6.2 Tests/Verification

Each sample shall be subjected to the required test pressure. For the final 20 percent of the required pressure, the rate of pressure increase shall be no more than 10 percent per minute. The required test pressure shall be maintained for a minimum of one minute, or in accordance with the applicable published standard, whichever is longer.

Leakage is acceptable during the hydrostatic tests, as long as the pressure source is adequate to maintain the required test pressure.

For suppressant dispersers (nozzles), Finite Element Analysis (FEA) will be accepted in place of physical testing, if the design is such that the disperser cannot retain pressure, or that no "blanks" are available due to the manufacturing process used.

4.7 Pressure Relief Devices

4.7.1 Pressure Relief Operation

4.7.1.1 Requirement

The pressure relief device pressure ratings of a suppressant storage container and expellant gas cartridge assemblies shall be selected as specified in Section 3.2.8 (Pressure Relief Devices). The average operating pressure of the device plus two standard deviations shall not exceed the cylinder test pressure, and the average operating pressure of the device less two standard deviations shall not fall below the container pressure at maximum temperature. In addition, no individual tested sample shall operate outside of those pressure constraints.

4.7.1.2 Tests/Verification

A minimum of 30 pressure relief device assemblies shall be pressurized until operation. If the device does not contain a rupturing component, but rather operates similarly to a pressure relief valve, the same device shall be subjected to all 30 trials. Pressure may be increased rapidly to 85 percent of the device's rated pressure, then shall be increased until operation at a rate no greater than 10 percent per minute. The operating pressure shall be recorded.

4.7.2 Pressure Relief Calculations

4.7.2.1 Requirement

Documentation shall be submitted to verify that the construction and size of a suppressant storage container and gas cartridge pressure relief device complies with the flow capacity requirements.

The construction and size of the burst disc and dispersion device shall, at a minimum, be appropriate for the system pressure at the maximum specified operating temperature.

4.7.2.2 Tests/Verification

Appropriate documentation and calculations shall be submitted to verify that the construction and size of the pressure relief device complies with the flow capacity requirements specified in CGA Pamphlet S-1.1, Safety Relief Devices Standards – Cylinders for Compressed Gases, or equivalent. Burst discs used as a part of the suppressant discharge system, and not intended to protect the suppressant storage container, shall not be evaluated per this requirement. Instead, their capacity shall be verified as a part of the Section 4.2 (Full Scale Suppression Performance Tests).

4.8 Flexible Hose

4.8.1 Low Temperature Resistance

4.8.1.1 Requirement

Flexible hoses shall withstand damage when conditioned at the minimum specified suppression system operating temperature. Following the conditioning period, the flexible hose shall withstand the minimum specified bending radius, as well as the hydrostatic pressure described in Section 4.6 (Hydrostatic Pressure Test) for a period of one minute. No cracking, fracture, or failure to retain the test pressure shall be permitted.

4.8.1.2 Tests/Verification

One sample of each representative size flexible hose shall be tested. Each hose assembly shall be conditioned for 16 hours at the minimum specified storage temperature. The sample shall be maintained at the minimum temperature and bent to the minimum specified bending radius. Bending shall be performed smoothly and continuously within an approximate 10 second time interval.

The flexible hose shall be visually inspected for cracking or other damage. Subsequent to this inspection, hose shall be subjected to the required test pressure for a period of one minute, or in accordance with the applicable standard, whichever is longer. No rupture or separation from end connections shall occur.

4.8.2 Resilience

4.8.2.1 Requirement

Flexible hoses shall withstand damage and remain functional after 3000 cycles of flexure to the maximum specified angle from straight. Hose lengths of 6 ft (1.83 m) are typically recommended. Following the cycle test, flexible hose shall withstand the hydrostatic pressure described in Section 4.6 (Hydrostatic Pressure Test) for one minute. No cracking, fracture, or failure to retain the test pressure shall be permitted.

4.8.2.2 Tests/Verification

Each hose assembly shall be conditioned for 16 hours at 70°F ± 5°F (21°C ± 3°C). The sample shall be maintained at this temperature and bent to the minimum specified bending radius or to the maximum specified angle. Bending shall be performed smoothly and continuously. The sample shall then be straightened to complete one cycle. The bending and straightening cycle shall be repeated for a total of 3000 cycles.

The flexible hose shall be visually inspected for cracking or other damage. Subsequent to this inspection, hose shall be subjected to the required test pressure for a period of one minute, or in accordance with the applicable standard, whichever is longer. No rupture or separation from end connections shall occur.

4.9 Mounting Device Test

4.9.1 Requirement

Mounting brackets for components placed remotely from the explosion suppressor shall not show evidence of permanent distortion or other damage when subjected to a static load equal to five times the weight of the suppression system at its highest rated capacity.

4.9.2 Tests/Verification

A component mounting bracket shall be assembled in its intended orientation. A static load equal to five times the weight of the system at its highest rated capacity, but not less than 100 pounds (45.3 kg), shall be applied vertically downward to the bracket. The load shall be maintained for 5 minutes. The mounting bracket shall be observed for damage throughout the 5 minute period. Physical testing may be waived if the mounting device has successfully completed the requirements of Section 4.15 (Vibration Resistance Test).

4.10 Dielectric Withstand

4.10.1 Requirement

Electrical system components shall withstand for one minute an applied test voltage between all terminals provided for external connections and the component body or enclosure. Non-metallic components shall be wrapped in conductive foil for this test. There shall be no breakdown of the insulation between the test points. Components shall continue to function normally subsequent to this test.

4.10.2 Tests/Verification

There shall be no indication of a dielectric breakdown or leakage current greater than 0.5mA during the one minute test exposure. The test voltages are described below.

Circuit Ratings	**Dielectric Test Voltage**
≤ 30 Vac (60 Vdc)	500 Vac (707 Vdc)
≥ 30 Vac (60 Vdc)	1,000 Vac +2x rated (1414 Vdc)

4.11 Pressure Indicator and Supervisory Pressure Switches

4.11.1 Accuracy

4.11.1.1 Requirement

Suppressant storage container pressure gauges and indicators shall exhibit accuracy within the limits of Table 4.2.

Table 4.2 *Pressure Gauge Limits*

Area of Range	**Accuracy Required, percent**
Zero Point	-0/+12
Low Pressure Alarm Point	± 6
Working Pressure	± 4
Full Scale	± 15

Supervisory pressure switches shall activate within ±6 percent of the low pressure alarm point under falling pressure. Samples must be tested after being conditioned at the minimum specified operating temperature, at 70ºF ±10ºF (21ºC ±5.5ºC), and at the maximum specified operating temperature for a period of four hours.

4.11.1.2 Tests/Verification

Readings of a minimum of three sample suppressant storage container gauges and switches of each type at each of the points specified shall be compared to readings of a calibrated test gauge having a minimum accuracy of ±1 percent. A test gauge having a minimum accuracy of ± 0.25 percent shall be used to evaluate an inert gas system maintenance gauge at each of its major scale divisions. Readings shall be taken in both ascending and descending order. All sample gauge readings and pressure switch activation points shall match those of the test gauge within the tolerances specified in Section 4.11.1.1, above.

4.11.2 Impulse Resistance

4.11.2.1 Requirement

Pressure gauge, indicator, or supervisory pressure switch accuracy shall remain within the limits of Table 4.2 after 1000 cycles of pressure impulse from zero to 125 percent of the system's nominal operating pressure, or from zero to 60 percent of the gauge capacity, whichever is higher.

4.11.2.2 Tests/Verification

One sample gauge and supervisory pressure switch of each type shall be connected to an apparatus capable of varying pressure from over the range described in Section 4.11.2.1, above, six times per minute. After 1000 cycles have been completed, the sample shall be retested for accuracy as described in Section 4.11.1.1, above.

4.12 Corrosion – Salt Spray

4.12.1 Requirement

System components shall withstand a 240 hour exposure to the test described in Section 4.12.2 below, without incurring damage that would impair function. Following the exposure period, the system shall be successfully discharged using one of the manufacturer's compatible release devices.

4.12.2 Tests/Verification

Test samples shall be selected to represent all material combinations and configurations. A minimum of one suppressant storage container assembly, including the mounting bracket and labels, shall be included among the test samples. Devices with moving parts subject to fouling from external corrosion shall also be subject to this test. Test sample suppressant storage containers shall be pressurized to the working pressure but need not contain the actual suppressant. Discharge nozzles manufactured from a corrosion resistant material are not subject to salt fog testing, provided that material specifications are submitted for review, and the design does not feature moving parts.

The samples shall be exposed to salt spray (fog) as specified by ASTM B117, Standard for Salt Spray (Fog) Testing. The salt solution shall consist of 20 percent (by weight) of common salt (sodium chloride) dissolved in deionized water with a pH between 6.5 and 7.2 and a specific gravity between 1.126 and 1.157.

Following the exposure to the salt fog, the sample shall remain fully functional and exhibit no corrosion, galvanic action, loss of legibility of markings, or separation of protective coatings which would impair future functionality. Superficial discoloration with no substantial attack of the underlying material shall be acceptable. The fully charged explosion suppression system shall be successfully discharged using one of the manufacturer's compatible release devices. Additionally, blow off nozzle caps, telescoping nozzles, and similar devices shall be subjected to Section 4.1.2 (Open Air Discharge Baseline).

Control devices shall continue to demonstrate proper function subsequent to this exposure.

4.13 Corrosion – Stress Cracking

4.13.1 Requirement

Critical system components required for system actuation and suppressant release shall be resistant to stress corrosion cracking resulting from exposure to the processes described in

Section 4.13.2, below. Following the exposure period, the samples shall not show evidence of cracking, delamination, or degradation.

4.13.2 Tests/Verification

4.13.2.1 Copper Based Parts (Ammonia Test)

Devices manufactured of copper alloys with a zinc content exceeding 15 percent shall be exposed to a moist ammonia environment. The inlet end of each sample shall be filled with deionized water and sealed with a non-reactive material (e.g., plastic cap) so as to prevent the introduction of the ammonia atmosphere to the interior of the component. The samples to be tested shall be free from any non-permanent protective coating and, if necessary, shall be degreased. If a permanent coating is an inherent part of the design, such coating shall be subjected to tests as deemed necessary by the certification agency to evaluate its protective integrity. The samples shall be tested in their intended orientation. Samples shall be assembled using the manufacturer's specified torque on threaded connections and flange bolts to replicate the as-installed loads.

There shall be provisions in the test chamber to prevent droplets of condensation from falling from the top of the enclosure directly onto the samples. Such a shield or other means shall be constructed of glass or other non-reactive materials.

The samples shall be exposed to the moist ammonia-air mixture maintained in a glass chamber with a volume of 0.73 ± 0.34 ft^3 (0.02 ± 0.01 m^3).

Aqueous ammonia having a density of 5.86x10-5 lb/ft^3 (0.94 g/cm^3) shall be maintained in the bottom of the chamber, approximately 1.5 in. (40 mm) below the bottom of the samples. The volume of ammonia to be used shall be determined by multiplying the enclosure volume in ft^3 (L) by 0.075 gal/ft^3 (10 L/m^3). This will result in approximately the following atmospheric concentrations: 35 percent ammonia, 5 percent water vapor, and 60 percent air. Prior to beginning the exposure, the chamber shall be conditioned to a temperature of 93°F ± 4°F (34°C ± 2°C) for a period of not less than one hour and shall be maintained at this temperature throughout the exposure period. The moist ammonia-air mixture shall be maintained at essentially atmospheric pressure. Provision shall be made for venting the chamber, such as by the use of a capillary tube, to avoid buildup of pressure.

Following exposure to the moist ammonia environment for a period of 10 days, the samples shall be removed, rinsed in potable water, and air dried. Following a minimum two-day drying period, visual examination of the samples shall be made.

4.13.2.2 Austenitic, Ferritic, and Duplex Stainless Steel Parts (Boiling Magnesium Chloride Test)

Samples shall be degreased and exposed to a boiling magnesium chloride solution for a period of 500 hours, in accordance with ASTM G36, Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution.

Samples are to be placed in a flask fitted with a wet condenser. The flask shall be approximately half filled with a nominal 42 percent by weight magnesium chloride solution, placed on a thermostatically controlled electrically-heated mantle, and maintained at a boiling temperature of 302 °F ± 4 °F (150 °C ± 2 °C).

Following exposure, the samples shall be removed and rinsed in potable water. Following a two-to four-day drying period, visual examination of the samples shall be made.

4.13.2.3 Parts Manufactured from Other Materials

Parts manufactured from other materials shall withstand comparable tests, based on the type of material employed, at the sole discretion of the certification agency.

4.14 Elastomeric Materials Tests

4.14.1 Requirement

Elastomers used in explosion suppression systems shall have a tensile strength of not less than 500 psi (34.5 bar), an ultimate elongation of not less than 100 percent, and a tensile set of not more than 19 percent. Tensile strength, ultimate elongation, and tensile set shall be determined in accordance with ASTM D 412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers - Tension, Method A, with exceptions as stated in Section 4.14.2, below.

4.14.2 Tests/Verification

For standard elastomers, the material manufacturer's certificates of compliance verifying the conformance to the performance requirements listed in Section 4.14.1, above, shall be considered acceptable. The test certificates shall demonstrate that the tests were conducted by an ISO 9000 certified facility, and that the test equipment was calibrated by an ISO 17025 (General Requirements for the Competence of Testing and Calibration Laboratories) certified agency. Where such certifications are not available, tests of the elastomer shall be conducted.

Tensile strength, ultimate elongation, and tensile set shall be determined in accordance with ASTM D 412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension, Method A, with the exception that, for tensile set determinations, the elongation shall be maintained for 3 minutes, and the tensile set shall be measured 3 minutes after release of the specimen. The elongation of a specimen for a tensile set determination shall be such that the 1 in. (25 mm) spacing of the benchmarks increases to 3 in. (76 mm). If a specimen breaks outside the benchmarks, or if either the measured tensile strength or ultimate elongation of the specimen is less than the required value, an additional specimen shall be tested, and those results shall be considered final. Results of tests for specimens that break in the curved portion just outside the benchmarks shall be allowed if the measured strength and elongation values are within the minimum requirements.

Physical testing may be waived if the elastomeric material has successfully completed the requirements of Section 3.2.6.2 (Materials) and Section 4.5 (Cycle Operation Test) as applicable.

4.15 Vibration Resistance Test

4.15.1 Requirement

An explosion suppression device and any relevant accessories shall withstand exposure to vibration. Following the tests, the devices shall remain operable, shall not display a potential to cause injury, and shall not experience any damage or deterioration which requires repair or replacement of the device.

4.15.2 Tests/Verification

Explosion suppression components that are installed on vibrating equipment shall be vibration tested to the following profile. If vibration isolation is required, then each component shall be tested with its intended isolation method, simulating the installed configuration, in accordance with the manufacturer's installation guidance.

One representative sample of each device shall be tested in its intended installation configuration. At minimum, the largest and smallest sizes of each design shall be tested.

Duration	**4 hours**
Displacement	0.060 in. (1.52 mm)
Sweep Frequency Range	10 Hz-60 Hz-10 Hz
Sweep Rate	4 minute cycles

Following completion of the vibration test in the first plane, the test shall be repeated in the remaining two planes until the sample has been subjected to vibration tests in all three rectilinear orientation axes (horizontal, lateral, and vertical).

Subsequent to the completion of the vibration tests, the devices shall be visually inspected for damage, and shall be successfully discharged using one of the manufacturer's compatible operating devices and shall discharge no less than 98 percent (by weight) of suppressant. Hose assemblies shall be subjected to the Hydrostatic Pressure Test of Section 4.6 (Hydrostatic Pressure Test) to verify continued integrity.

Control components isolated from vibrating equipment shall be vibration tested to the following profile. With the equipment powered and installed in accordance with the manufacturer's instructions, the equipment shall be subjected to a vertical movement as described below.

Duration	**4 hours**
Displacement	0.022 in. (0.55 mm)
Sweep Frequency Range	10 Hz-30 Hz-10 Hz
Sweep Rate	2 cycles/min.

Following the 4 hour vibration exposure, the equipment shall:

- not have loose parts;
- not have visible signs of permanent deformation that would compromise the electrical safety of the equipment; and
- operate as intended.

4.16 Aging Tests – Plastic Materials

4.16.1 Air Oven Aging

4.16.1.1 Requirement

Critical nonmetallic components shall be subjected to air-oven aging tests at 212°F (100°C). There shall be no cracking or crazing as a result of this test. Subsequent to exposure, the nonmetallic parts shall then be subjected to the requirements of Section 4.6 (Hydrostatic Pressure Test), and mounting brackets shall be subjected to the requirements of Section 4.9 (Mounting Device Test).

4.16.1.2 Tests/Verification

Samples shall be subjected to air-oven aging tests for 180 days at 212°F (100°C), and then allowed to cool a minimum of 24 hours in air at 74°F (23°C) at 50 percent relative humidity. At the conclusion of the test, the samples shall be inspected for cracking or crazing. The samples shall then be subjected to the applicable tests listed in Section 4.16.1.1, above.

4.16.2 Ultraviolet Light and Water Test

4.16.2.1 Requirement

Nameplates and critical nonmetallic components, including valves, exposed valve parts, and mounting brackets, shall be exposed to ultraviolet light and water for 720 hours in accordance with Table X3.1, Condition 1, of ASTM G 155-00, Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials. At the conclusion of the test, there shall be no cracking or crazing of the component. Valves and valve parts shall then be subjected to the requirements of Section 4.6 (Hydrostatic Pressure Test), and mounting brackets shall be subjected to the requirements of Section 4.9 (Mounting Device Test).

4.16.2.2 Tests/Verification

Samples shall be exposed to ultraviolet light and water for 720 hours. The samples shall be inspected for cracking and crazing after 360 hours. If no cracking or crazing is apparent, the exposure shall continue for the full 720 hours. During each operating cycle, each sample shall be exposed to light and water spray for 18 minutes and to only light for 102 minutes (total 120 minutes). The air temperature within the apparatus during operations shall be 109 ± 4.5ºF (43 ± 2.5ºC) and the relative humidity 30 ± 5 percent. At the conclusion of the test, the samples shall be inspected for cracking or crazing. The samples shall then be subjected to the applicable tests listed in Section 4.16.2.1, above.

4.17 Electronics Enclosures (Including Polymeric Housings)

4.17.1 Requirement

4.17.1.1 The enclosure must meet the ingress protection requirement for a NEMA 250, Type 1 and/or ANSI/IEC 60529, IP30 enclosure ratings as a minimum for indoor applications. It is not necessary to mark the product for Type 1 / IP30 enclosures. Additional claims made by the manufacturer will be verified according to specified enclosure classifications.

4.17.1.2 Polymeric Materials used as an enclosure (or the sole support of current carrying parts) shall not warp to an extent that it impairs the intended operation or exposes high voltage components.

4.17.2 Tests/Verification

4.17.2.1 The enclosure will be evaluated according to acceptable national, regional or international electrical codes.

4.17.2.2 When constructed of Polymeric Materials, an enclosure sample shall be mounted as intended and placed in a circulating air-oven shall be aged at 194°F (90℃) for seven days or at 158°F (70°C) for twenty eight days.

Following the aging tests, the samples are to be viewed for:

- No evidence of warping and distortion;
- No exposure to high voltage components;
- The unit shall operate normally following this test; and
- Flammability.

4.18 Normal Operations – Detection & Control System

4.18.1 Requirement

4.18.1.1 Representative samples of the equipment (system or modules) will be powered according to the manufacturer's instructions and programmed (if applicable) for proper operation and application. Re-wiring, re-configuring or programming to satisfy different types of applications is often required. Demonstrations or simulations at maximum rated loads of power supplies, initiating circuits and extinguishing circuits will be required.

4.18.1.2 Basic operation and function of a system shall include all of the following features:

- Automatic alarm signal initiation (via explosion detectors);
- Monitoring of abnormal conditions in all field wiring connections; and
- Activation of explosion detection and extinguishing operation.

4.18.1.3 Optionally, the explosion suppression control system may provide the capability to activate additional process protection functions (e.g. process shutdown) as well as activation of local protective signaling equipment when provided with independent alarm, supervisory and trouble signals

4.18.2 Tests/Verification

Basic operation to NFPA 69 will be verified and documented as specified in the owners or instruction manual.

4.19 Power Supply / Electrical Supervision

4.19.1 Requirement

At least two independent, reliable and supervised power sources are required for any explosion suppression control system. A primary dedicated branch electrical circuit and a dedicated storage battery system are the most common. Other options, if intended to be used, must be specified in the installation manual and would be at the discretion of local on-site verification and AHJ acceptance.

4.19.2 Tests/Verification

4.19.2.1 Failure of either one of the power supplies shall result in proper annunciation, be seamless and not result in any loss of data, signal transmission or annunciation that differs from normal primary power (except the loss of an AC power indication).

4.19.2.2 Any secondary power supply shall have sufficient capacity to power the system for a minimum of 4 hours of standby operation and 15 minutes at the maximum alarm load specified by the manufacturer. If the system provides fire alarm and signaling features (FM 3010) in addition, 24 hour secondary power is required.

4.19.2.3 Both primary and secondary source are to be monitored at the point of connection to the explosion suppression equipment.

4.19.2.4 The secondary power supply shall automatically provide power to the explosion suppression system immediately and seamlessly whenever the primary power supply fails to provide the minimum voltage required for proper operation.

4.20 Circuit Supervision

4.20.1 Requirement

Proper monitoring and operation of all circuits to the electronic control unit shall comply with basic supervision requirements (open/short/ground) and proper identification of each in accordance with FM 3010, NFPA 72, NFPA 69 and the manufacturer's data. The wiring to detectors that initiate explosion suppression systems shall meet the requirements of a Class A or Class B initiating device circuit.

4.20.2 Tests/Verification

Each circuit shall:

- Be supervised for open, short and ground conditions of each conductor, appropriate to the Class designation for the circuit. Detector circuits for initiating explosion suppression systems will be tested for Class A or Class B operation; and
- Be supervised for the integrity and presence of each explosion device.

Any failure to properly operate as the result of any of the single fault conditions described above shall result in a trouble condition indicated at the control.

Exception*: Any circuit specified to remain in the same room or 20 ft (6 m) or less in length and in conduit and limited to the connection of a single device (detector or solenoid).*

4.21 Explosion Detector Compatibility

4.21.1 Explosion detector compatibility shall be verified with respective control equipment and or explosion detector interface circuits and defined in the installation instructions or on a label affixed to the control panel itself.

4.21.2 Detectors shall demonstrate compatibility as specified in the manufacturers installation instructions and be supervised for presence.

4.22 Voltage Variations

4.22.1 Requirement

It shall be verified that the explosion suppression control system maintains the normal operational capability and functionality throughout typical voltage extremes of both the primary and secondary power supplies from which they are powered.

4.22.2 Tests/Verification

As a minimum, the operation of the equipment in normal supervisory and alarm conditions shall be verified at 85% to 110% of the rated primary (AC) and secondary (DC) power sources. If the manufacturer specifies a voltage range beyond these extremes, the equipment will be tested using those values specified by the manufacturer.

Typical Voltage Ranges are defined as shown in the table below:

Nominal	**+10%**	**-15%**
120 Vac	132Vac	102Vac
240 Vac	264Vac	204Vac
12 Vdc	13.2 Vdc	10.2 Vdc
24 Vdc	26.4 Vdc	20.4 Vdc

4.23 Environmental Conditioning – Detection and Control Components

4.23.1 Requirement

It shall be verified that the explosion suppression control system is designed so that it is capable of performing its intended normal operational capability and functionality throughout temperature extremes and high humidity conditions that are typical of equipment intended for indoor applications. If the manufacturer specifies a temperature range beyond those typical for indoor/dry locations, the equipment will be tested using the values specified by the manufacturer.

4.23.2 Tests/Verification

As a minimum, all equipment shall be subjected to the following environmental extremes. If rated for extremes beyond these values, the equipment will be tested using those values specified by the manufacturer.

- For a period of 4 hours at 32°F (0°C) and 120°F (49°C); and
- For a period of 24 hours at a relative humidity of 90% and ambient temperature of 100°F (37.8°C).

The equipment shall operate as intended and show no signs of instability or false alarms during these exposures.

4.24 Battery Charge/Discharge

4.24.1 Requirement

It shall be verified that the control equipment is capable of recharging the secondary batteries fully within 24 hours following a single discharge cycle as specified in 4.19.2 (Power Supply / Electrical Supervision).

4.24.2 Tests/Verification

The equipment is allowed to be powered in a normal condition for a minimum of 72 hours to ensure that the batteries are fully charged, and the charge voltage and current levels recorded. With the equipment configured to simulate the worst case standby load or condition and the primary power is disconnected (turned OFF) and the equipment is powered solely from the secondary power source for a period of 4 hrs.

Following this standby (discharge) time, the equipment is then placed into an alarm condition (with outputs at the maximum rated load) for a period of 15 minutes and the secondary battery voltage and current reading recorded.

Following the alarm (discharge) time, the primary power is restored (turned ON), the equipment is returned to a normal standby condition and allowed to charge the secondary batteries for a period of 24 hours. At the end of the 24 hour recharge, the voltage and current readings are made at the battery and compared to those obtained at the start of the test. The readings are required to be similar to the initial readings indicating a fully charged battery for the results to be acceptable. The battery trickle or charge current should not exceed 5mA/AH rating of the battery under test.

4.25 Equipment Load Rating – Line Powered Control Equipment

4.25.1 Requirement

The standby or alarm current necessary to power the equipment shall not exceed 110% of the rated value over the entire voltage range that the equipment is rated or intended for.

4.25.2 Tests/Verification

With the equipment configured for its maximum rated current draw (outputs at full rated load). The input voltage is varied over the extremes as determined in Section 4.22 (Voltage Variation). At no time shall the current value measured exceed 110% of that rated on the nameplate or the manufacturers installation instructions.

4.26 DC Circuit Reverse Polarization

4.26.1 Requirement

All DC supply circuits, including the battery circuit, shall be tested with the connections in a reverse polarity condition if such installation is possible without mechanically altering, modifying or damaging the equipment or battery.

4.26.2 Tests/Verification

The DC power leads are reversed while the primary power is OFF, and if possible, the primary power is turned ON. Normal operation is not required following this test, but the equipment shall fail in a safe mode (no indication of continued heating, visible fire or molten material) and indicate a trouble condition if no longer operational.

4.27 Protective Grounding/Bonding

4.27.1 Requirement

Any equipment that contains or connects to a high voltage circuit shall provide a positive grounding system for all exposed dead metal parts to reduce the risk of electrical shock.

4.27.2 Tests/Verification

The grounding system shall consist of a dedicated (green head) screw or terminal and clearly marked (G, GR, GND, Ground, International Ground Symbol or the like), or dedicated, flexible green (or green and yellow) bonding conductors.

- The bonding resistance shall be measured at $\leq$ 0.1 ohm.

- All bonding conductors shall be 14 AWG minimum.

Exception*: Metal-foil markings, screws, handles, etc., which are located on the outside of the enclosure and isolated from electrical components or wiring by grounded metal parts so that they are not liable to become energized or those which are positively separated from wiring and un-insulated live parts.*

4.28 Power Supply Failure

4.28.1 Requirement

The equipment shall provide the required degree of protection from fault as demonstrated by the simulation of a worst case condition failure, shorting the secondaries of line voltage connected equipment for linear power supplies, or worst case overload for switching power supplies.

4.28.2 Tests/Verification

With the equipment connected to an appropriately rated, time delayed, fused branch circuit in accordance with the manufacturer's instructions. All field serviceable fuses on the equipment under test are replaced with those of maximum current ratings.

The unit shall be powered and produce or result in:

- operation of the branch circuit fuse;
- operation of any of the field serviceable fuses (when replaced with those of the maximum rated value);
- operation of any non-replaceable protection components; or
- temperature stabilization where there is no further change due to the fault.
- And there shall be no emission of flame, escape of molten metal, or infringement of the protection against electrical shock.

4.29 Internally Induced Transients

4.29.1 Requirement

No false signal will be generated when the equipment (controls, detection and actuators) is subjected to extraneous transients from source described below.

4.29.2 Tests/Verification

One powered sample of the explosion suppression system will be subjected to 500 on/off cycles by the interruption of the primary AC mains, the transfer to the secondary power supply and the return to AC mains.

The unit shall produce:

- No non-resettable false signals (alarm or trouble) and
- No evidence of instability during or at the end of this test.
- The unit shall operate normally following this test.

4.30 Extraneous Transients (RFI Immunity)

4.30.1 Requirement

No false signal will be generated when the equipment (controls, detection as appropriate) is subjected to extraneous transients from sources which are described below.

4.30.2 Tests/Verification

One powered sample of the control equipment will be subjected to extraneous transients described below with Field strength of 40 V/m to the DUT.

Radio frequency transmissions with equivalent power levels.

Frequency	Watts	*12 in. distance
27 MHz	5	√
150-174 MHZ	5	√
450-467 MHZ	5	√
850-870 MHz	3	√
900-920 MHz	4	√

*The distance from radiating antennas to the product under test.

The system shall produce:

- No false signals (alarm or trouble)
- No reset in alarm
- No false actuation of outputs including releasing device(s)

Exception*: self restoring or manually resettable trouble signal is acceptable.*

4.31 Field Wiring Transient (low voltage circuits)

4.31.1 Requirement

Protection against line surge transients will be a requirement for any control and detection field wiring circuit (power, input and outputs).

4.31.2 Tests/Verification

This test applies to all field wiring terminals that have a possibility of being subjected to line-induced voltage (i.e., initiating device circuits, release circuits, power circuits and auxiliary connections). One powered sample of the control equipment shall be subjected to transient waveforms having peak levels of:

- 100 V dc
- 500 V dc
- 1,000 V dc
- 2,400 V dc

The unit shall produce:

- No latched or constant alarm (intermittent or spurious alarms are possible) or non-restoring trouble signals and
- No evidence of instability during or at the end of this test and
- The unit shall operate normally following this test.

Exception*: Any circuit specified to remain in the same room or 20 ft (6 m) or less in length and in conduit.*

4.32 AC Surge Line Transients

4.32.1 Requirement

The explosion suppression Systems AC voltage supplied circuits shall be protected against AC line surge transients.

4.32.2 Tests/Verification

One powered sample shall be subjected to 6 kV oscillatory (100 kHz) transient pulses. Each transient pulse shall have a rise time of less than 0.5 microseconds and a total duration of 20 microseconds. The pulse decay shall result in each peak being no more than 60% of the amplitude of the preceding pulse. Each pulse shall be applied at the peak of the AC waveform.

500 transitory pulses are to be applied at a rate of 6 transients per minute. [250 positive pulses with reference to earth ground and 250 negative pulses with reference to earth ground. Each set of pulses is to consist of 225 pulses in supervisory condition and 25 pulses in the alarm condition]

The system shall produce:

- No latching false signals
- No evidence of instability during or at the end of this test including memory [ex. retention event history], and
- The system shall operate normally following this test.

4.33 Actuation (Release) Circuits

4.33.1 Requirement

The proper monitoring, supervision and operation of actuation circuits shall be verified in accordance with the manufacturer's instructions. Compatible actuator device combinations shall be identified in the manufacturer's instructions with specifications (limitations) on its proper use.

4.33.2 Tests/Verification

Release circuit shall be:

- Supervised for open and ground conditions;
- Supervise the integrity and presence of the releasing device;
- Each circuit must remain within 85% or 110% of rated voltage, or within manufacturer's specified limits (when the circuit is dedicated to specific actuators), under all conditions; and

- Each actuator must remain operational at maximum specified distance and/or load.

4.34 Radiant Energy Detector Sensitivity Test

4.34.1 Requirement

Detectors shall be tested to confirm response to flame radiation of the appropriate wavelength when installed in accordance with the manufacturer's instructions.

4.34.2 Tests/Verification

Each detector sample shall be subjected to a small-scale sensitivity test, specified by the manufacturer, with specified fuel, size, and distance. The detector shall react immediately upon exposure to the flame radiation. There shall be no indication of delay in response beyond that inherent in the sensing element of the detector.

4.35 Radiant Energy Detector Field of View

4.35.1 Requirement

The radiant energy detector's Half Power [50%] Field of View (HPFV) will be verified to the manufacturer's claims and instructions.

4.35.2 Tests/Verification

Tests are conducted on the sensitivity test fixture that allow for off-axis measurement of the DUT to determine the Half Power Field of View (HPFV).

a) The HPFV distance is set to one half of the distance used for the sensitivity as determined in the on-axis testing.

b) The minimum angle for the HPFV will be verified in four quadrants (up/down/left/right) from on-axis to the flame source. The minimum HPFV must match the manufacturer's specification when installed in accordance with the manufacturer's instructions, but not less than 50%.

4.36 Pressure Type Detectors Sensitivity Test

4.36.1 Requirement

For preset level and differential type detectors, the actual actuation point shall be within the manufacturer's specification for accuracy or within ± 5% of specified value, whichever is less.

For rate of rise type detectors, the rate of rise actuation pressure shall conform to the manufacturer's specifications.

4.36.2 Tests/Verification

A minimum of three samples of each type shall be tested. For preset level type detectors, input pressure shall be increased gradually until the device actuates. The actual actuation point shall be within the manufacturer's specification for accuracy or within ±5 percent of specified value, whichever is less. The test shall be conducted for a minimum of three times.

For rate of rise type detectors, input pressure shall be applied at the manufacturer's specified rate of rise until the device actuates. The test shall be conducted for a minimum of three times. There shall be no failure to actuate.

For differential type detectors, differential pressure, at minimum and maximum static pressure, shall be increased gradually until the device actuates. The actual actuation point shall be within the manufacturer's specification for accuracy or within ±5 percent of specified value, whichever is less. The test shall be conducted for a minimum of three times.

4.37 Pressure Type Detectors Environmental Conditioning

4.37.1 Requirement

The sensitivity of the detector shall not be affected by conditioning at the extremes of the temperature range.

4.37.2 Tests/Verification

After conducting the conditioning test of section 4.23 (Environmental Conditioning – Detection and Control Components), the test sample shall be subjected to the sensitivity test of Section 4.36 (Pressure Type Detectors Sensitivity Test).

4.38 Pressure Type Detectors Endurance Cycling

4.38.1 Requirement

The sensitivity of the detector shall not be affected by 1000 operational cycles over the maximum operating pressure range.

4.38.2 Tests/Verification

After pressure cycling the test sample for 1000 operational cycles over the maximum operating pressure range, the sample shall be subjected to the sensitivity test of section 4.36 (Pressure Type Detectors Sensitivity Test) and shall also conform to the manufacturer's specifications.

4.39 Pressure Type Detectors Over Pressurization Test

4.39.1 Requirement

The detector shall not be damaged, distorted, ruptured or leak and shall work within the required accuracy following the application of 1.5 times the maximum rated pressure.

4.39.2 Tests/Verification

A pressure equal to 1.5 times the maximum rated pressure shall be applied to the inlet of any one of the detector samples for a period of 5 minute. There shall be no evidence of leakage, permanent distortion, or rupture. The sample shall operate properly and there shall be no significant change in the operating characteristics after repeating the Sensitivity Test of 4.36 (Pressure Type Detectors Sensitivity Test).

4.40 Static Discharge

4.40.1 Requirement

The explosion suppression control system shall be protected against electrostatic discharges.

4.40.2 Tests/Verification

The enclosure is to be connected to earth ground.

Time between discharges is to be at least 1 sec.

Products intended to interconnect to releasing devices shall be tested with each releasing device connected as specified in the installation wiring diagram/instructions.

Twenty 10,000 V discharges, with at least 3 discharges for each operation feature, are to be applied to the accessible points of the product.

Ten discharges shall be applied with positive polarity on the product and ten discharges with the polarity reversed.

The system shall operate normally following this test, and produce:

- No false signals (alarm or trouble);
- No reset in alarm;
- No false actuation of outputs including releasing device(s); and
- No evidence of instability during or at the end of this test, including memory [ex. retention event history].

4.41 Test Failure Disposition

Any test following a failure shall be acceptable only at the discretion of the certification agency and with a technical justification of the conditions or reasons for failure.

4.42 Additional Tests

Additional tests may be required, at the discretion of the certification agency, depending on design features and results of any foregoing tests. A retest following a test failure shall be acceptable only at the discretion of the certification agency, and with adequate technical justification of the conditions or reasons for failure.

5 OPERATIONS REQUIREMENTS

5.1 Demonstrated Quality Control Program

5.1.1 A quality assurance program is required to assure that subsequent equipment produced by the manufacturer shall present the same quality and reliability as the specific equipment examined. Design quality, conformance to design, and performance are the areas of primary concern.

- Design quality is determined during the examination and tests and is documented in the certification report.
- Continued conformance to this Standard is verified by the Surveillance Audit.
- Quality of performance is determined by field performance and by periodic re-examination and testing.

5.1.2 The manufacturer shall demonstrate a quality assurance program which specifies controls for at least the following areas:

- existence of corporate quality assurance guidelines;
- incoming quality assurance, including testing;
- in process quality assurance, including testing (if applicable);
- final inspection and tests;
- equipment calibration;
- drawing and change control;
- packaging and shipping; and
- handling and disposition of non-conforming materials.

5.1.3 Documentation/Manual

There shall be an authoritative collection of procedures/policies. It shall provide an accurate description of the quality management system while serving as a permanent reference for implementation and maintenance of that system. The system shall require that sufficient records are maintained to demonstrate achievement of the required quality and verify operation of the quality system.

5.1.4 Records

To assure adequate traceability of materials and products, the manufacturer shall maintain a record of all quality assurance tests performed, for a minimum period of two years from the date of manufacture.

5.1.5 Drawing and Change Control

- The manufacturer shall establish a system of product configuration control that shall allow no unauthorized changes to the product. Changes to critical documents, identified in the certification report, must be reported to, and authorized by, the certification agency prior to implementation for production.
- Records of all revisions to all certified products shall be maintained.

5.2 Surveillance Audit

5.2.1 An audit of the manufacturing facility is part of the certification investigation to verify implementation of the quality assurance program. Its purpose is to determine that the manufacturer's equipment, procedures, and quality program are maintained to ensure a uniform product consistent with that which was tested and certified.

5.2.2 These audits shall be conducted periodically but at least annually by the certification agency or its representatives.

Certified products or services shall be produced or provided at or from the location(s) audited by the certification agency and as specified in the certification report. Manufacture of products bearing the certification agency's mark of conformity is not permitted at any other location without prior written authorization by the certification agency.

5.3 Installation Inspections

Field inspections may be conducted to review an installation. The inspections are conducted to assess ease of application, and conformance to written specifications. When more than one application technique is used, one or all may be inspected at the discretion of the certification agency.

5.4 Manufacturer's Responsibilities

The manufacturer shall notify the certification agency of changes in product construction, components, raw materials, physical characteristics, coatings, component formulation or quality assurance procedures prior to implementation.

The manufacturer shall also provide complete instructions for the usage and recharge of systems. The instructions shall provide specific quality assurance procedures on the use of calibrated equipment, such as scales, pressure gauges, and other critical equipment, in the recharging of a system.

5.5 Manufacturing and Production Tests

5.5.1 The manufacturer shall design systems in accordance with NFPA 69 and/or any other standard specifically referenced in the certification report and listing.

5.5.2 The manufacturer shall leak test all filled suppressant storage containers prior to release for shipment. The leak test method shall employ appropriately calibrated and sensitive leak detection devices.

5.6 Installation, Operating, and Maintenance Manual

5.6.1 An installation, operation, and maintenance manual shall be provided with each suppression system or be made available upon request. A copy of the manual shall be provided to the certification agency as a reference prior to the examination and testing of the system. Subsequent to the successful completion of the examination, an electronic copy of the manual shall be provided to the certification agency for reference in the review of systems proposed for installation in FM Global insured properties. This manual may be shared within FM Global, as needed, for its property loss prevention engineering. Updated electronic copies of the manual shall be provided to the certification agency as revisions are made.

5.6.2 The manual shall include the following information, at a minimum, if applicable:

- Manufacturer's name and address;
- Date and part number designation on each page of the manual;
- Description of equipment and accessories, including part numbers and model numbers;
- Safety Data Sheets;
- Piping and fitting limitations;

- System limitations;
- Detection devices and control panels for use with the suppression system;
- Range of filling weights for each suppressant storage container size;
- System working pressure at 70ºF (21ºC);
- Installation instructions;
- Inspection requirements;
- Maintenance requirements;
- Recharge instructions;
- Reference to any relevant national or local standards;
- Acceptance test form to document satisfactory operational status of the system upon completion of installation; and
- A clearly labeled section listing any part numbers included in the manual, but not within the scope of the certification.
- Design methodology for suppressor scaling or contact information for the design engineering support team
- Vibration isolation guidance, if applicable
- A change log for revisions

5.6.3 The manufacturer's design instructions for a system shall be evaluated based on FM Global recommendations, NFPA 68 and NFPA 69 standards, and any other relevant standards required by local authority having jurisdiction.

5.6.4 For detection and control components, installation, operating, and maintenance instructions shall be provided for each model and type of the product. The instructions or manual must be identifiable by a document name, number, revision, and/or date. The instructions or manual shall include the following:

- Manufacturer's name and address;
- Date and part number designation on each page of the manual;
- Product specifications, including operating temperatures and relative humidity ranges, identification of intended power supply sources with ratings and connection details, and enclosure environmental ratings;
- Description of controls and indicators, audible and visual;
- Inter-equipment wiring diagrams and identification of wiring terminals;
- Identification, including specifications and location, of necessary current limiting devices
- Startup and operating procedures;
- Specific sensitivity of the detectors;
- Calibration schedule for maintenance of equipment such as flame and pressure detectors.
- Any detector limitations: For Example, Radiant Energy Detectors are adversely affected by the accumulations of dust or other coating on the lens or other sensitive element of the detector. The product literature shall include cleaning and maintenance instructions and stress the need for regular response testing. There may be environments with heavy floating particulates that would restrict the ability of a Radiant Energy Detector to respond quickly, or the geometry of the protected enclosure may obscure some areas

from the detector; and

- A "thru-the-lens monitoring capability" if provided will indicate when a detector is no longer capable of detection due to lens contamination. This feature or capability would reduce the interval and amount of manual testing required at the installation and its operation will be verified as a part of the certification process.

6 BIBLIOGRAPHY

ISO/IEC 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*.

B. Lewis and G. von Elbe (1987) "*Combustion, Flames and Explosions Gases". Orlando: Academic Press*

CGA G10.1, *Commodity Specification for Nitrogen*.

FM Global Property Loss Prevention Data Sheet 7-17, *Explosion Protection Systems*.

APPENDIX A:

Appendix A is intentionally blank.

APPENDIX B: TOLERANCES

Unless otherwise stated, the following tolerances shall apply:

Angle:	±2°
Frequency (Hz):	±5 percent of value
Length:	±2 percent of value
Volume:	±5 percent of value
Rotation:	±1 RPM
Pressure:	±3 percent of value
Temperature:	±3°F
Time:	+5/–0 seconds +0.1/–0 minutes +0.1/–0 hours +0.25/–0 days

Unless stated otherwise, all tests shall be carried out at a room (ambient) temperature of 68 ± 9°F (20 ± 5°C).

APPENDIX C: PERFORMANCE LIMITS METHODOLOGY

This appendix provides additional detail on the methods used to infer the performance of single suppressors from open-air discharge and full-scale explosion tests and provides methods to design and verify adequate protection for enclosures using single or multiple suppressors, considering the enclosure design strength and geometry and the suppressor performance.

C.1. Performance measurement of a single suppressor:

The method used to assess the performance of a single suppressor is based on a simplified physics-based model of the explosion suppression mechanism in vessels. The reduced pressure of a suppressed explosion can be related to the fraction of mixture in the vessel that remains unsuppressed:

$$\frac{m_{\mathrm{u}}}{m_0} = \frac{p_{\mathrm{max}} - p_{\mathrm{red}}}{p_{\mathrm{max}} - p_0} \qquad \text{A1}$$

where m_{u} is the unburned mass, m_0 is the total mass inside the vessel, p_0 is the initial pressure, p_{max} is the maximum constant-volume explosion pressure, and p_{red} is the reduced explosion pressure.

Assuming isentropic compression, this equation can be written as:

$$\left(\frac{p_{\mathrm{red}}}{p_0}\right)^{\frac{1}{\gamma}} \left(1 - \frac{V_{\mathrm{f}}}{V_0}\right) = \frac{p_{\mathrm{max}} - p_{\mathrm{red}}}{p_{\mathrm{max}} - p_0} \qquad \text{A2}$$

where V_0 is the vessel volume and γ is the heat capacity ratio, which is approximated as $\gamma = 1.4$. This expression relates p_{red} to the unsuppressed flame volume, V_{f}.

For a single suppressor, it is assumed that the flame is quenched successfully when the suppressant cloud (of sufficient concentration and approximated as a hemisphere) expands quickly enough to traverse the distance between the injector and the farthest portion of the flame front propagating away from the suppressant cloud, i.e.,

$$\frac{r_{\mathrm{s}}}{\alpha} = r_{\mathrm{f}} + d \qquad \text{A3}$$

where r_{s} is the radius of the hemispherical suppressant cloud, d is the distance between the injection and ignition locations, r_{f} is the flame radius, and α is a parameter specific to the particular experimental condition and suppressor configuration.

The radius of a hemispherical suppressant cloud is modeled as $u_{\mathrm{s}}t$, where u_{s} it the expansion velocity of the suppressant cloud, until a maximum cloud radius, $r_{\mathrm{s,max}}$, (that is equivalent to the maximum radial throw distance, l_{throw}) is reached.

The values of $r_{\mathrm{s,max}}$ and u_{s} are measured from high-speed open-air discharge video obtained according to Section 4.1.2 (Open Air Discharge Baseline) using FM Global's proprietary image processing algorithm and by assuming a constant expansion velocity up to the maximum radial throw distance of the suppressant cloud, i.e.,

$$r_{\mathrm{s}}(t) = \min\left(u_{\mathrm{s}}t, l_{\mathrm{throw}}\right) \qquad \text{A4}$$

An example is shown in Figure A1; the least-squares fit is shown in comparison to the radial suppressant-cloud length, which yields values of u_{s} = 38.1 m/s and l_{throw} = 1.27 m.

During open-air discharge tests, the suppressor pressure is recorded to support the comparison of suppressor configurations and the selection of configurations for suppression performance tests according to Section 4.2 (Full Scale Suppression Performance Tests).

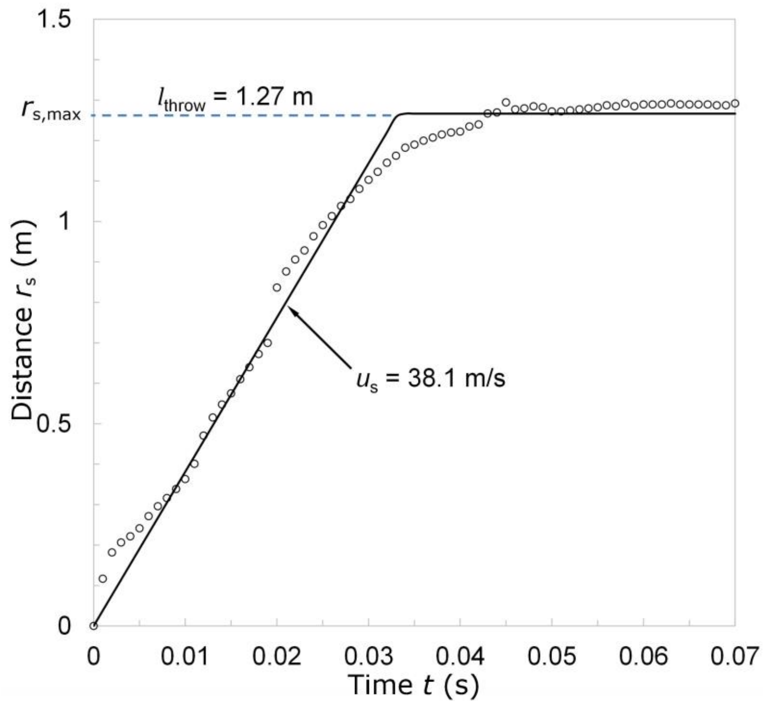


Figure A1: Least-squares fit of the radial suppressant-cloud length as a function of time. Time zero marks the beginning of visible suppressant discharge. Detection and system response times are not included in this illustration.

Equation A3 can be rewritten as:

$$r_s = \alpha\left(\sigma S_u\left[t + t_{inj}\right] + d\right) \qquad \text{A5}$$

where σ is the expansion ratio of the explosive mixture, S_u is the burning velocity, t is the time for suppression to occur, and t_{inj} is the time between ignition and suppressant injection.

Parameters in Equation A5 are determined as follows:

- σ is taken from thermochemical calculations for gases or is approximated as $\sigma = (p_{max} - p_0)/p_0$ for dusts.
- S_u is determined from the early pressure-time history of explosion tests conducted in Section 4.2 (Full Scale Suppression Performance Tests) using Equation A6.

$$\Delta p^{1/3} = \left[p_0 \frac{4\pi}{3V_0}\left(\frac{p_{max}}{p_0} - 1\right)\left(\frac{p_{max}}{p_0}\right)^2\right]^{1/3} S_u\, t \qquad \text{A6}$$

The flame volume can generally be calculated from:

$$V_f = \frac{4}{3}\pi r_f^3\left(1 - \frac{\beta}{d^3}\frac{2}{3}\pi r_s^3\right) \qquad \text{A7}$$

where $r_f = \sigma S_u(t + t_{inj})$ and β is a fitted parameter that is normalized by d^3 and represents the volume of the flame where the suppressant cloud has effectively quenched the combustion reaction.

Equation A7 is then substituted into Equation A2 to determine the reduced pressure. The parameters α and β are optimized such that the least-squares difference between the calculated p_{red} and the values measured in full-scale suppressed explosions (see Sections 4.2.2 or 4.2.4) is minimized.

The Maximum Quench Distance, *MQD*, is then determined:

$$MQD = \frac{r_{\mathrm{s,max}}}{\alpha}\left(1 - \frac{\alpha\sigma S_{\mathrm{u}}}{u_{\mathrm{s}}}\right) - \sigma S_{\mathrm{u}} t_{\mathrm{inj}} \qquad \text{A8}$$

This parameter describes the maximum distance a suppressor can protect, i.e., the maximum distance between the injection location and a hypothetical ignition source that still allows for successful quenching of the flame. The approach inherently ensures that a sufficient concentration of suppressant is present within the *MQD* envelope.

C.2. Evaluation of explosion suppression installations:

Because the location of ignition in a real application is unknown, the suppressors should be arranged such that there is sufficient coverage to protect the enclosure regardless of where ignition occurs. In the configuration shown in Figure A2, the suppressant clouds provide protection throughout the enclosure with the exception of the yellow region in the center, which remains unprotected. This region represents the volume where ignition could occur beyond the *MQD* envelopes measured from each injection location, and the suppressant clouds would not expand quickly enough (or far enough) to envelop an explosion initiated in the unprotected region.

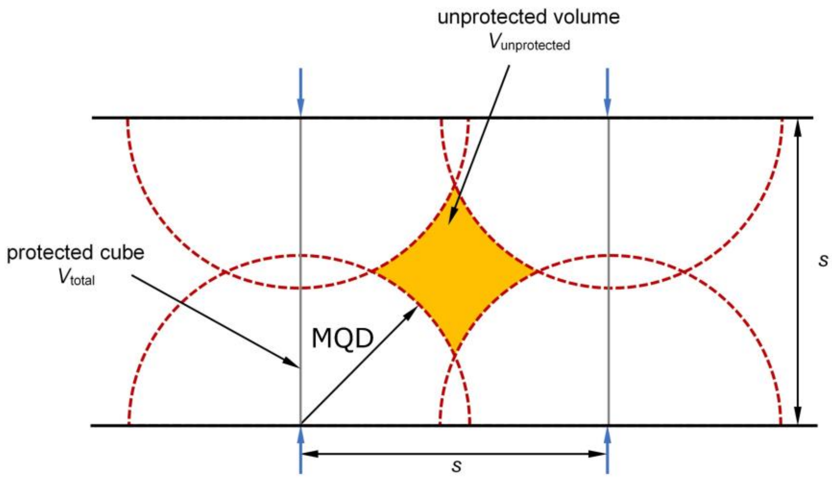


Figure A2: Locus of ignition locations at the Maximum Quench Distance (*MQD*) from the injection point of each suppressant bottle; each suppressor location is denoted by a blue arrow.

For a given protected enclosure, the reduced pressure of a suppressed explosion, Δp_{red}, can be predicted as:

$$\Delta p_{\mathrm{red}} = \Delta p_{\mathrm{max}} \frac{V_{\mathrm{unprotected}}}{V_{\mathrm{total}}} + \Delta p_{\mathrm{act}} + \Delta p_{\mathrm{inj}} \qquad \text{A9}$$

where Δp_{max} is the nominal constant-volume (unsuppressed) explosion overpressure, $V_{\mathrm{unprotected}}$ is the unprotected volume, V_{total} is the total internal volume of the enclosure, Δp_{act} is the overpressure that activates the suppression system, and Δp_{inj} is the overpressure caused by the injection of the suppressant into the enclosure. This approach assumes that the initial pressure of the protected enclosure is atmospheric.

The predicted reduced overpressure, Δp_{red}, must not exceed the enclosure design strength.

This method does not consider the effects of specific geometrical features of the protected enclosure, such as internal obstructions and occluded volumes, on the resulting reduced overpressure. These features may prevent the suppressant from freely spreading throughout the entire enclosure and these effects should be addressed as part of the specific installation design.

The individual terms and parameters in Equation A9 shall be evaluated as follows:

- Δp_{max} of combustible dusts is determined through the test method of ASTM E1226. Δp_{max} of flammable gases/vapors is determined by thermochemical calculation at constant-volume adiabatic conditions.
- Two alternative methods are available to estimate the unprotected volume, $V_{\mathrm{unprotected}}$. These methods are described in Sections C.2.1 and C.2.2, respectively.
- The system activation overpressure, Δp_{act}, is equal to the system activation setpoint in the case of pressure-threshold detection. For alternative detection methods, including pressure rate-of-rise and optical detection, Δp_{act} will be determined as part of the certification testing.
- The overpressure generated by the injection of suppressant, Δp_{inj} , can be estimated from Equation A10.

$$\Delta p_{\mathrm{inj}} = \frac{V_{\mathrm{s,gas}}}{V_{\mathrm{total}}} N \Delta p_{\mathrm{s}} \qquad \text{A10}$$

$V_{\mathrm{s,gas}}$ is the free internal volume of each suppressor (total suppressor volume minus the solid volume of suppressant), N is the number of suppressors installed at the enclosure, and Δp_{s} is the charge pressure of the suppressor (relative to atmosphere) prior to injection.

C.2.1. Method [A] CAD:

The unprotected volume, $V_{\mathrm{unprotected}}$, used by Equation A9, can be directly evaluated using CAD and geometric models of the protected enclosure and the suppressant clouds. From each suppressant injection location, regions within the *MQD*, determined by testing of the suppressor configuration used, can be deducted from the total enclosure volume. The remaining unprotected volume can then be used to evaluate Equation A9. An example for a simple enclosure protected by a single suppressor centered at the top enclosure wall is shown in Figure A3. The volume remaining after intersecting the enclosure and the suppressant cloud is the unprotected volume, $V_{\mathrm{unprotected}}$.

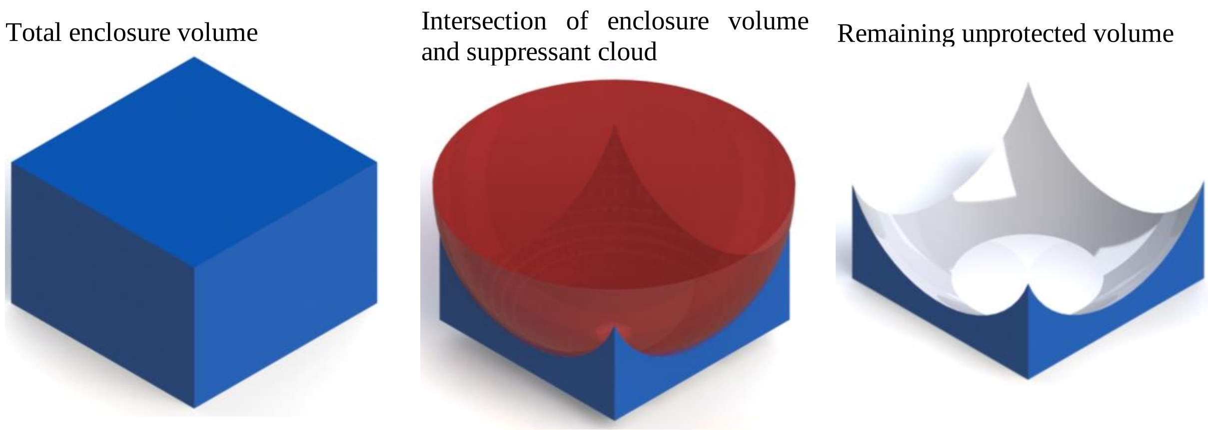


Figure A3: Method A] (CAD) used to determine the unprotected volume, $V_{\mathrm{unprotected}}$, for an enclosure (blue) protected by a single suppressor. The suppressant cloud (red) is centered at the location of the suppressor nozzle and has a radius equal to the *MQD* of the suppressor.

$V_{\mathrm{unprotected}}$ is then used in Equation A9 to determine the reduced overpressure, Δp_{red}, which must not exceed the enclosure design strength.

C.2.2. Method [B] Analytical method:

A generalized analytical method was developed as an alternative to the CAD-based method [A] to predict the ratio between the unprotected volume and total enclosure volume, $V_{\text{unprotected}}/V_{\text{total}}$, used to evaluate Equation A9. Depending on the suppressor arrangement, this analytical framework requires each suppressor to protect either the entire distance between the injection location and the opposite enclosure wall, or the distance to the enclosure center. Note that this limitation is not relevant when applying method [A] using CAD.

These two suppressor arrangements are distinguished as:

(i) Linear: all suppressors are located along one side of the enclosure and protect the entire distance to the opposite enclosure wall.

(ii) Facing: suppressors are located on opposite sides of the enclosure (or distributed symmetrically around the circumference of the enclosure), and each suppressor protects the distance to the center of the enclosure.

The shape and size of the protected enclosure determines whether a linear arrangement is acceptable, a facing arrangement is needed, or suppressors with a larger MQD are required.

Enclosures with a rectangular cross section (planar walls) are evaluated as follows:

> For $MQD \geq \sqrt{2}D$, suppressors can be installed on one wall in a linear pattern and protect the entire transverse distance to the opposite wall, *D*.
>
> For $D/\sqrt{2} \leq MQD < \sqrt{2}D$, suppressors must be installed on opposite walls in a facing pattern.
>
> For $MQD < D/\sqrt{2}$, the suppression system is not acceptable in the framework of the analytical method.

For enclosures with a circular cross section (curved walls), credit is given to the focusing of suppressant by the curved wall:

> For $MQD \geq D$, suppressors can be installed at one wall in a linear pattern and protect the entire transverse distance to the opposite wall, *D*.
>
> For $D/2 \leq MQD < D$, suppressors must be installed on opposite walls in a facing pattern.
>
> For $MQD < D/2$, the suppression system is not acceptable in the framework of the analytical method.

To determine the ratio $V_{\text{unprotected}}/V_{\text{total}}$, the method considers the number of suppressors, N, the total volume of the protected enclosure, V_{total}, and the total internal surface area of the enclosure, A_{total}. Given these parameters, two distance parameters s_{A} and s_{V} are calculated:

$$s_{\text{A}} = \left(\frac{A_{\text{total}}}{SF_{\text{A}} * N}\right)^{1/2} \qquad \text{A11}$$

$$s_{\text{V}} = \left(\frac{2V_{\text{total}}}{N}\right)^{1/3} \qquad \text{A12}$$

The area shape factor SF_{A} used in Equation A11 depends on which enclosure walls a suppressor can reach, i.e., which enclosure walls are less than a distance of $MQD/\sqrt{2}$ away from the injection location. Examples of area shape factors are given in Table A1. These examples consider a single suppressor installed at the center or the enclosure back-wall. For multi-suppressor systems, individual shape factors $SF_{\text{A,i}}$ are determined for each individual suppressor and averaged when used in Equation A11.

Next, the maximum of s_{A} and s_{V} is determined:

$$s_{\max} = \max(s_{\mathrm{A}}, s_{\mathrm{V}}) \qquad \text{A13}$$

The ratio $V_{\mathrm{unprotected}}/V_{\mathrm{total}}$ is then calculated from either Equation A14 or A15, depending on the ratio $MQD/s_{\max}$:

If $\frac{MQD}{s_{\max}} < 0.75$:

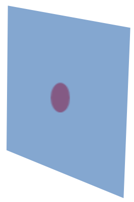
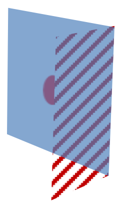
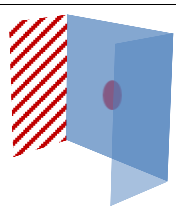
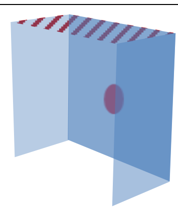
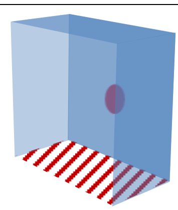
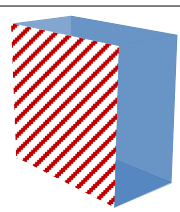
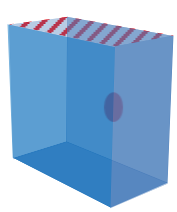
$$\frac{\mathrm{V}_{\mathrm{unprotected}}}{V_{\mathrm{total}}} = \left[\frac{8\pi}{3}\left(\frac{MQD}{s_{\max}}\right)^3 - 3\pi\left(\frac{MQD}{s_{\max}}\right)^2 + \frac{\pi+4}{4}\right] \qquad \text{A14}$$

If $\frac{MQD}{s_{\max}} \geq 0.75$:

$$\frac{\mathrm{V}_{\mathrm{unprotected}}}{V_{\mathrm{total}}} = 0.018 \qquad \text{A15}$$

The ratio $V_{\mathrm{unprotected}}/V_{\mathrm{total}}$ is used in Equation A9 to determine the reduced overpressure, Δp_{red}, which must not exceed the enclosure design strength.

Table A1: Examples of area shape factors SF_A. The suppressor is centered at the back wall.

Case	Wall configuration	Area shape factor	Explanation
1		$SF_A = 1$	The suppressor protects the wall at which it is installed. It does not reach any side walls.
2		$SF_A = 1.5$	The suppressor protects the wall at which it is installed and reaches one side wall.
3		$SF_A = 2$	The suppressor protects the wall at which it is installed and reaches two side walls.
4		$SF_A = 2.5$	The suppressor protects the wall at which it is installed and reaches three side walls.
5		$SF_A = 3$	The suppressor protects the wall at which it is installed and reaches four side walls.
6		$SF_A = 3.5$	The suppressor protects the wall at which it is installed, three side walls, and the opposite wall.
7		$SF_A = 4$	The suppressor protects all walls of the enclosure.

APPENDIX D: SCHEMATICS OF FM GLOBAL'S EXPLOSION VESSELS

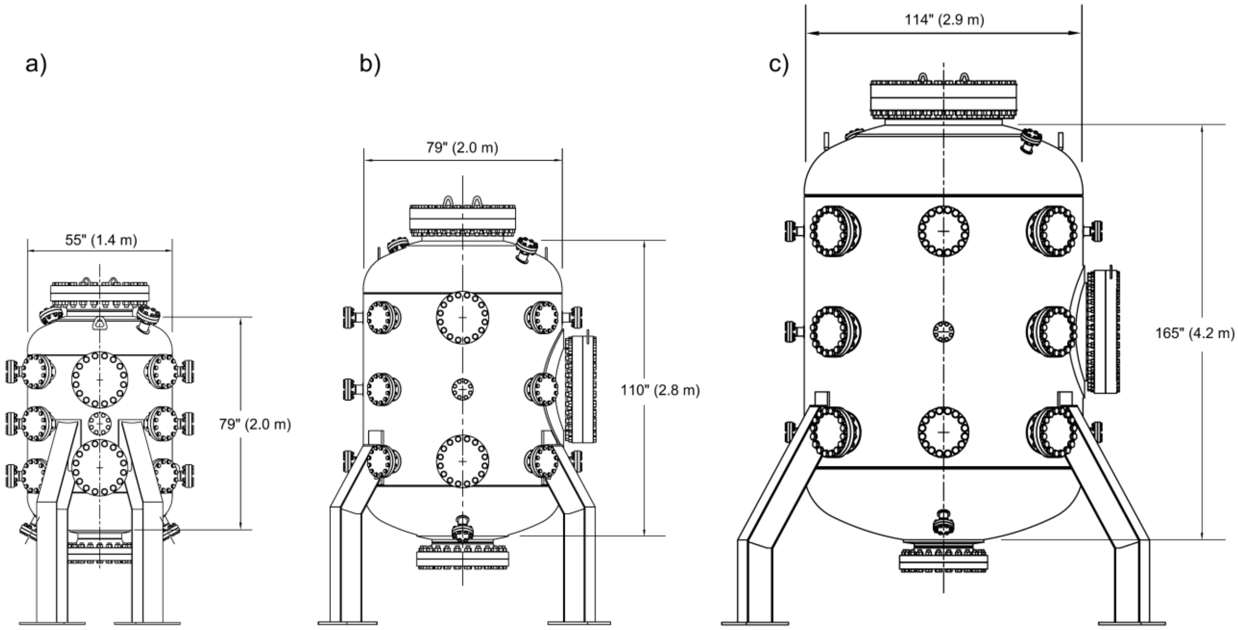


Figure A4: Schematic of FM Global's a) 2.5, b) 8, and c) 25 m^3 explosion vessels.

12" Class 300 ANSI 16.5 B Flange
Bolts: 1.125"-7

6" Class 300 ANSI 16.5 B Flange
(Only on 2.5 m^3 and 8 m^3 vessels)
Bolts: 0.75"-10

3" Class 300 ANSI 16.5 B Flange
Bolts: 0.75"-10

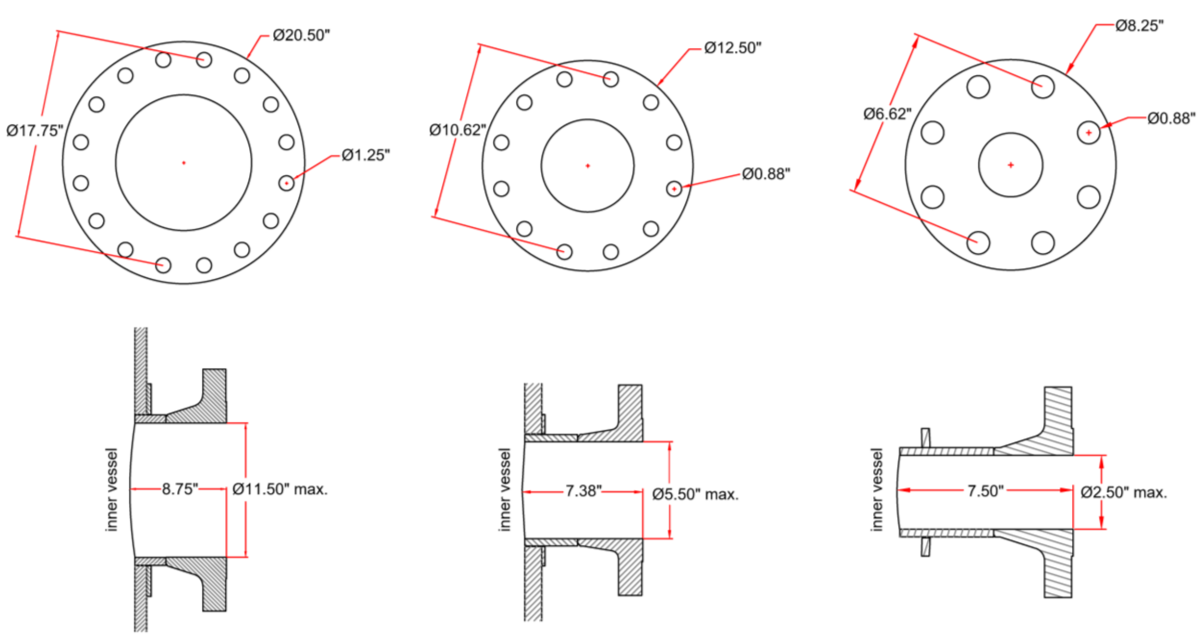


Figure A5: Flange connections at FM Global's explosion vessels used to mount explosion suppressors and detectors.

The 12 in. flange connection shown in Figure A5 is used to mount the explosion suppressor. Smaller flange connections are generally used to mount detectors. Suppressor and detector mounting adapters shall be supplied by the customer.

The suppressor adapter flange shall position the suppressant dispersion nozzle such that its base aligns with the inner vessel wall and the nozzle protrudes fully into the vessel.

Adapter flanges shall be constructed to a minimum pressure rating of 300 psi.

Each inner diameter given for the vessel openings in Figure A5 includes a negative tolerance and is the appropriate maximum outer diameter dimension for any adapter parts that protrude into the opening.