NFPA® 69
Standard on
Explosion Prevention
Systems
2008 Edition

NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471
An International Codes and Standards Organization
Permanent deformation of the enclosure cannot be accepted.

\[ P_{\text{mop}} \geq \frac{R(P_i + 14.7) - 14.7}{\left(\frac{2}{3}\right) R_i} \]  \hspace{1cm} (15.2)

where:

- \( P_{\text{mop}} \) = enclosure design pressure (psig) according to ASME Boiler and Pressure Vessel Code
- \( R \) = dimensionless pressure ratio
- \( P_i \) = maximum initial pressure at which combustible atmosphere exists (psig)
- \( F_u \) = ratio of ultimate stress of the enclosure to the allowable stress of the enclosure according to ASME Boiler and Pressure Vessel Code
- \( F_j \) = ratio of the yield stress of the enclosure to the allowable stress of the materials of construction of the enclosure according to ASME Boiler and Pressure Vessel Code

13.3.4.1* The dimensionless ratio, \( R \), is the ratio of the maximum deflagration pressure, in absolute pressure units, to the maximum initial pressure, in consistent absolute pressure units.

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

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

13.3.4.3 A value for \( R \) other than the values specified in 13.3.4.2 shall be permitted to be used if such value can be substantiated by test data or calculations.

13.3.4.4 For operating temperatures below 25°C (77°F), the value of \( R \) shall be calculated for use in Equation 13.1 and Equation 13.2:

\[ \hat{R} = R \left( \frac{298}{273 + T_i} \right) \]  \hspace{1cm} (13.3)

where:

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

13.3.5 The presence of any pressure relief device on the system shall not cause the design pressure calculated by the methods of 13.3.4 to be reduced.

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

1. For positive pressure systems that handle gases and liquids, the maximum initial pressure, \( P_i \), shall be the maximum initial pressure at which a combustible atmosphere is able to exist, but a pressure not higher than the setting of the pressure relief device plus its accumulation.
2. For positive pressure systems that handle dusts, the maximum initial pressure shall be the greater of the following two pressure values:

(a) Maximum possible discharge pressure of the compressor or blower that is suspending or transporting the material
(b) Setting of the pressure relief device on the vessel being protected plus its accumulation

For gravity discharge of dusts, the maximum initial pressure shall be the atmospheric gauge pressure (0.0 bar or 0.0 psi).

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

13.3.8 Auxiliary equipment such as vent systems, manways, fittings, and other openings into the enclosure, which could also experience deflagration pressures, shall be designed to ensure integrity of the total system and shall be inspected periodically.

13.4 Maintenance. Any enclosure designed according to the methods of this chapter shall be inspected and maintained in accordance with local jurisdictional practices for registered pressure vessels. In particular, relief devices shall be inspected periodically to ensure that they are not plugged, frozen, or corroded.

13.4.1 If not required by local jurisdiction, inspection and maintenance shall be in accordance with API 510, Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration.

13.4.2 Enclosures shall be inspected at least every 3 years.

13.4.3 Repairs and modifications to the enclosure shall be made consistent with the original design code.

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

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

Chapter 14 Passive Explosion Suppression Using Expanded Metal Mesh or Polymer Foams

14.1* Applications.

14.1.1 The use of expanded metal mesh or reticulated polymer foams manufactured, tested, and installed in accordance with the requirements of this chapter shall be permitted for explosion suppression in unoccupied enclosures containing flammable gas or vapor.

14.1.2 These enclosures shall include, but not be limited to, fuel tanks, flammable liquid storage tanks, portable containers, and flammable liquid cargo tanks.

14.2 Foam and Mesh Requirements.

14.2.1 Expanded metal mesh shall meet the requirements in 14.2.4.

14.2.2 Polymer foams shall meet the requirements in 14.2.5.

14.2.3 Both types of suppression materials described in this chapter shall satisfy the explosion suppression test requirements in Section 14.3.

14.2.4 Expanded Metal Mesh Requirements.
14.2.4.1® Expanded aluminum or other metal mesh shall have a density of 24 to 51 kg/m³ (1.5 to 3.2 lb/ft³) as determined by the average of three samples from the same manufacturing run as the samples used for the other tests in Sections 14.2 and 14.3.

14.2.4.2 The expanded metal mesh shall have sufficient surface area to absorb the heat generated in an incipient deflagration of a flammable gas-air mixture as demonstrated by the tests described in Section 14.3.

14.2.4.2.1 The expanded metal mesh surface area per unit volume shall be measured or calculated for three samples.

14.2.4.2.2 The measurements and associated calculations shall be documented and made available to the authority having jurisdiction.

14.2.4.2.3® Expanded metal mesh intended for the protection of alkane-air mixtures and other flammable vapors with fundamental burning velocities within 15 percent of the fundamental burning velocity of a near-stoichiometric propane-air mixture shall have a surface area-to-volume ratio of at least 0.25 mm⁻¹ (0.1 in⁻¹).

14.2.4.2.4 Expanded metal mesh intended for the protection of flammable gases or vapors with faster burning velocities shall have a minimum area-to-volume ratio determined from explosion suppression tests described in Section 14.3 with that particular flammable gas or vapor.

14.2.4.3® Pore Size.

14.2.4.3.1® Expanded metal mesh shall have a pore (cell) size that is smaller than the quenching distance for the flammable gas or vapor expected in the protected enclosure.

14.2.4.3.2 In the case of alkanes or flammable gases and vapors with fundamental burning velocities within 15 percent of the near-stoichiometric propane-air burning velocity, the fundamental burning velocity of a near-stoichiometric propane-air mixture, at least 0.25 mm⁻¹ (0.1 in⁻¹).

14.2.4.4® The metal alloy composition and the composition and thickness of any coating shall be reported in accordance with the most applicable ASTM, military, or industry standard.

14.2.5® Polymer Foam Requirements. Polyurethane or other polymer foam shall have a density of 19 to 32 kg/m³ (1.2 to 2.0 lb/ft³) as determined by the density test described in ASTM D 3574, Standard Test Methods for Flexible Cellular Materials — Slab, Bonded, and Molded Urethane Foams.

14.2.5.1® The polymer foam number of pores per inch, as determined from the air flow test shown in Figure 1 in MIL-DTL-83054C and in MIL-PRF-87260A, and the corresponding air flow versus pore size correlation in Figure 2 and paragraph 4.6.4 of MIL-DTL-83054C or Figure 2 of MIL-PRF-87260A for conductive polymer foam, shall be a minimum of 6 pores/cm (15 pores/in.) for foams with a density of 19 to 24 kg/m³ (1.2 to 1.5 lb/ft³), and at least 4 pores/cm (10 pores/in.) for foams with a density of 24 to 32 kg/m³ (1.6 to 2.0 lb/ft³).

14.2.5.2 For applications with liquids or gases with fundamental burning velocities greater than 0.5 m/sec (1.6 ft/sec) the minimum number of pores per inch shall be determined by test as described in 14.3.2.

14.2.5.3 The polymer foam shall have a maximum of 50 percent deflection when tested in accordance with the constant deflection compression test described in paragraph 4.8.7 of MIL-DTL-83054C and method B of ASTM D 3574.

14.2.5.4 Tensile Strength Specifications.

14.2.5.4.1 The polymer foam shall have a minimum tensile strength of 103 kPa (15 psi) when tested in accordance with ASTM D 3574 and paragraph 4.6.5 of MIL-DTL-83054C.

14.2.5.4.2 In addition, the foam shall not experience a loss of tensile strength greater than 50 percent when tested at the maximum expected application temperature.

14.2.5.5 Electrical Resistivity.

14.2.5.5.1 The polymer electrical resistivity shall be measured at 24°C (75°F) or other temperature representative of the protected process using the procedure described in ASTM D 257, Standard Test Methods for DC Resistance or Conductance of Insulating Materials, and in Section 14.3.25 of MIL-PRF-87260A (USAF), Foam Material, Explosion Suppression, Inherently Electrically Conductive, for Aircraft Fuel Tank and Dry Bay Areas.

14.2.5.5.2® The polymer resistivity shall be less than 1 x 10¹¹ ohm-cm at 24°C (75°F) or other temperature representative of the protected process and at 55 percent ± 5 percent relative humidity.

14.2.5.6 The polymer ignitability and fire heat release rate shall be measured using an oxygen consumption calorimeter per NFPA 271, Standard Method of Test for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter, at an imposed radiant heat flux of 75 kW/m².

14.2.5.6.1 The polymer time-to-piloted-ignition at this heat flux shall be longer than 5 seconds.

14.2.5.6.2 The heat release rate per unit area shall be documented and made available to the authority having jurisdiction upon request.

14.2.5.7 The polymer foam shall demonstrate the resistance as shown in 14.2.5.7.1 and 14.2.5.7.2 to deterioration after being submerged in the container liquid for a period of 4 weeks.

14.2.5.7.1 After drying the foam, the tensile strength test referenced in 14.2.5.4.1 shall be repeated with no more than a 40 percent reduction in measured strength.

14.2.5.7.2 The electrical resistivity test shall also be repeated, and the measured resistivity shall be less than 1 x 10¹¹ ohm-cm at 24°C (75°F) or other temperature representative of the protected process and at 55 percent ± 5 percent relative humidity.

14.2.6 The foam shall be sufficiently flexible to be inserted into and fill up the protected enclosure, using blocks of foam no smaller than 1 ft (0.3 m) in length or the smallest dimension of the enclosure, whichever is smallest.

14.2.7 The minimum foam block width and height shall be determined from the double void explosion suppression tests described in 14.3.6 and 14.3.7 and the installation requirements in Section 14.4.

14.2.8 Foam packages and shipping documents shall contain the foam make and type, the foam density, the area-to-volume ratio, and the pore size.

14.3 Expanded Metal Mesh and Polymer Foam Explosion Suppression Testing.

14.3.1 Expanded metal mesh and polymer foams shall be subjected to explosion suppression performance testing as described in 14.3.2 through 14.3.5.2.
14.3.2 Test results shall be as specified in 14.3.6 and 14.5.7.

14.3.3* Explosion suppression tests shall be conducted with dry mesh or foam firmly inserted in closed test vessels of at least 140 L (5 ft³) volume, and with a cross-sectional area of at least 0.45 m² (100 in²).

14.3.3.1 The first test shall be conducted with the vessel 80 percent filled with mesh or foam of documented area-to-volume ratio or pore size and percent liquid displacement, and the remaining 20 percent of the vessel empty except for the gas-air mixture described in 14.3.4.

14.3.3.2 The second test shall be conducted with the vessel 90 percent filled with mesh or foam, with a 10 percent void volume.

14.3.4 The tests shall be conducted with a flammable gas-air mixture with a fundamental burning velocity representative of the burning velocities of flammable vapors expected in the intended applications.

14.3.4.1 Propane at a concentration in the range 4.4 to 4.8 volume percent shall be used for applications in which the flammable gas has a fundamental burning velocity in the range 0.5 to 0.6 m/sec (1.5 to 1.9 ft/sec).

14.3.4.2 Suppression tests for applications involving other flammable gases or vapors shall be conducted with a representative gas-air mixture at a concentration in the range 1.1 to 1.2 times the stoichiometric concentration.

14.3.4.3 After the gas mixture has been established uniformly throughout the test vessel, the gas concentration shall be verified by a calibrated gas analyzer or by sampling and subsequent chemical analysis.

14.3.4.4 The pressure in the test vessel prior to ignition shall be representative of the normal operating pressure of the intended application.

14.3.5 The flammable gas-air mixture shall be ignited with an ignition source of at least 10 joule energy triggered in the void volume, and the resulting reduced explosion pressure, \( P_{\text{red}} \), shall be measured and reported.

14.3.5.1 After conducting the second test (with the 10 percent void volume), all the mesh or foam shall be removed and the explosion test repeated with the same gas mixture in the gas-filled closed vessel, or in another test vessel of similar volume.

14.3.5.2 The value of \( P_{\text{red}} \) measured without the mesh or foam shall be measured and reported.

14.3.6 Single Void Explosion Suppression Tests.

14.3.6.1 A particular composition and porosity of expanded metal mesh or polymer foam shall be permitted for explosion suppression applications if the value of \( P_{\text{red}} \) measured in the 10 percent void volume test at initially atmospheric pressure is no greater than 54 kPa (8 psi), and if the pressure measured in the test with the 20 percent void volume is no greater than 89 kPa (12 psi).

14.3.6.2 If the tests and intended application has a pre-ignition pressure, \( P_{\text{ig}} \), of some other value, the maximum allowable values of \( P_{\text{red}} \) shall be determined from the values of \((P_{\text{red}} - P_{\text{ig}})/(P_{\text{max}} - P_{\text{ig}})\) per Table 14.3.6.2.

<table>
<thead>
<tr>
<th>Void Volume Fraction</th>
<th>Maximum Value of ((P_{\text{red}} - P_{\text{ig}})/(P_{\text{max}} - P_{\text{ig}}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.043</td>
</tr>
<tr>
<td>0.20</td>
<td>0.10</td>
</tr>
</tbody>
</table>

14.3.7* Double Void Explosion Suppression Tests.

14.3.7.1 Double void explosion suppression tests shall be conducted with the same vessel, gas mixture, and ignition source as described in 14.3.3 through 14.3.6, but now with two voids separated by varying thicknesses of dry expanded metal mesh or polymer foam.

14.3.7.2 Starting with 5 cm (2 in.), the thickness of mesh or foam shall be increased in 2.5 cm (1 in.) increments until the tests demonstrate that the flame does not propagate across the mesh or foam from the ignition void to the second void, as determined from measured temperature increase or visual records, as well as pressure rise.

14.3.8 The minimum thickness of mesh or foam required to achieve suppression in the double void tests shall be no greater than 127 mm (5 in.).

14.4 Expanded Metal Mesh or Polymer Foam Installations.

14.4.1* Explosion suppression mesh or foams shall be installed only in enclosures with ultimate strengths or yield strengths, as determined by the owner or operator, equal to at least 1.5 times the value of \( P_{\text{red}} \) determined from the 20 percent single void volume explosion suppression tests described in 14.3.3 through 14.3.5.

14.4.2 The mesh or foam shall fill at least 90 percent of the entire enclosure volume as verified by visual inspection during and following the installation.

14.4.2.1 The minimum thickness of any one block of mesh or foam used in the installation shall be the value determined in the double void volume tests described in 14.3.7.

14.4.2.2 Documentation of the installed fill fraction and minimum thicknesses of mesh or foam, as well as the explosion suppression test results, shall be made available to the authority having jurisdiction upon request.

14.5 Expanded Metal Mesh or Polymer Foam Maintenance and Replacement.

14.5.1 Inspection.

14.5.1.1 Mesh or foam installations shall be initially inspected for any evidence of deterioration at intervals of no greater than 6 months. Further guidance on inspection shall be in accordance with Chapter 15.

14.5.1.2 When there is visual evidence of deterioration, the mesh or foam shall be replaced, in accordance with the installation requirements in Section 14.4.

14.5.1.3 Mesh or foam installations shall be inspected following any explosion or fire exposure.

14.5.2 Disposal of used, liquid-contaminated mesh or foam shall be in accordance with local environmental regulations.
A 13.3.4.1 The maximum deflagration pressures for several dusts can be found in Annex F of NFPA 68, Standard on Explosion Protection by Deflagration Venting.

A 13.3.6 The maximum initial pressure depends on the origin of the pressure. In some cases, the maximum initial pressure is determined by the setting of a relief device on the system. In such cases, the maximum initial pressure is the sum of the relief device set pressure and the relief device accumulation pressure. Overpressure due to boiling of the vessel contents (for example, from external fire exposure) might raise the concentration of fuel in the vapor phase above its upper flammable limit and does not constitute a deflagration hazard.

A 14.1 The expanded metal mesh and polymer foams described in this chapter are intended for protection against internal deflagrations and are not intended for boiling liquid expanding vapor explosion (BLEVE) protection of liquidified gas storage tanks nor for emergency relief venting of flammable liquid storage tanks.

A 14.2.1 These requirements are taken from the range of densities in Table 1 of MIL-R-87152A (USAF), "Military Specification: Baffle Material, Explosion Suppression, Expanded Aluminum Mesh, for Aircraft Fuel Tank."

A 14.2.4.2.3 Where the application range is based on the fundamental burning velocity of the protected mixture, the same test method should be used to compare the burning velocity of the subject mixture to that of near stoichiometric propane-air. In the case of a metal mesh made by expanding slit foil and then folding the expanded metal into bats, the area per unit expanded foil volume is equal to

$$\frac{\omega}{W \cdot H} = 2 \left( \frac{w_f \cdot L_p}{W \cdot H} \right)$$

where:

- $w_f$ = slit foil width
- $n$ = number of layers in a bat of height $H$
- $L_p$ = length of unexpanded slit foil required to produce an expanded length $l_f$ between folds
- $W = \text{expanded foil width}$
- $H = \text{height}$
- $l_f = \text{expanded length between folds}$
- $L_p = \text{unexpanded length of foil in a bat}$

(from Szgola, A., Prengy, K., and Appleyard, R., "Evaluation of Explosive Explosion Suppression System for Aircraft Fuel Tank Protection."")

A 14.2.4.3 In the case of metal mesh made from expanded slit foil, the pore size is approximately equal to the full spacing between slits.

A 14.2.4.4 In the case of a perforated aluminum foil mesh, the alloy composition should be specified per Aluminum Association standards (for example, composition designations 3005 or 3010). In the case of chromate coatings, MIL-C-5541, "Chemical Conversion Coatings on Aluminum and Aluminum Alloys," would be applicable.

A 14.2.4.5 This material is taken from the reference for required densities found in Table 1 of MIL-J-82054C, "Detailed Specification Baffle and Inserting Material, Aircraft Fuel Tank."

A 14.2.5.1 The specifications for the minimum number of pores are for applications involving alliances or flammable
gases and vapors with fundamental burning velocities within 15 percent of the near-stoichiometric propane-air burning velocity.

A.14.2.5.5.2 The maximum resistivity value required in 14.2.5.5.2 has been achieved and surpassed using conductive reticulated polyurethane foam described in SAE AIR 4170A, "Reticulated Polyurethane Foam Explosion Suppression Material for Fuel Systems and Dry Bays." This reference also describes the advantages of conductive foam in eliminating electrostatic ignitions that the U.S. Air Force was experiencing in certain aircraft equipped with higher resistivity polymer foams. If electrostatic charge generation mechanisms, such as direct fuel impingement onto the foam, can be avoided, the conductive foams may not be necessary.

A.14.3.3 Figure A.14.3.3 shows a diagram of a test vessel with a void volume, $V_a$, and mesh-or foam-filled (arrestor) volume, $V_v$.

A.14.3.7 A diagram of the double void explosion suppression test setup is shown in Figure A.14.3.7. The ignition void fraction, $V_a/(V_a + V_v)$, is typically 0.29.

![FIGURE A.14.3.3 Single Void Explosion Suppression Test Setup (MIL-PRE-877260A).](image)

![FIGURE A.14.3.7 Double Void Explosion Suppression Test Setup (MIL-F-877260).](image)

A.14.4.1 For example, the value of $P_{max}$ shown in SAE AIR 4170 Rev A for fine pore blue polyether foam at an initial pressure of 3 psia (21 kPa) is about 11 psia (76 kPa) for propane-air explosion testing with a 20 percent single void volume. This foam can be installed only in enclosures with either an ultimate strength or yield pressure of at least 17 psia (117 kPa).

A.14.4.2 The number of mesh or foam blocks used during installation should be minimized. Voids between mesh or foam blocks should not be co-linear in order to avoid the potential for direct flame propagation between multiple blocks. Compression of the mesh or foam during installation should also be minimized.

Installation guidelines for mesh or foam in aircraft fuel tanks and dry bays are given in SAE AIR 4170 Rev A, "Reticulated Polyurethane Foam Explosion Suppression Material for Fuel Systems and Dry Bays."

A.15.4.1 Suppresant storage containers, automatic fast-acting valves, flame front diverters, or flame arresters should be supported by other than the protected process, ductwork, or piping as determined by engineering review. Reinforcing pads, external mounts, or other means to redistribute the reaction forces of the explosion prevention device should be implemented. It is not intended or expected that the protection equipment be supported by the process equipment. External support may be required in order for the explosion prevention system to operate properly. Detection devices should be mounted such that product impingement will be minimized. Suppresant containers should be located such that discharge is not directed toward process openings where employees may be present.

A.15.5.5.1 Safety instrumented system (SIS) design focuses increasingly on the concept of "safety integrity level" (SIL). A process that is to be protected is assigned an SIL level based upon risk analysis. An SIL level of between 1 and 3 is assigned (between 1 and 4 under IEC 61511, Functional Safety — Safety Instrumented Systems for the Process Industry Sector), with 1 being the lowest level. Layers of protection are typically combined to achieve the SIL requirement for a process with individual safety systems often having a lower level than the process. This edition of NFPA 69 does not require the use of SIL levels for explosion prevention systems but recognizes their use. The guidelines for isolating a Safety Instrumented System from the basic process control system are included in ANSI/ISA-84.00.01, Functional Safety, Safety Instrumented Systems for the Process Industry Sector, current edition. IEC 61511 is also appropriate.

A.15.5.5.2 Initiating device circuits, notification appliance circuits, and signaling line circuits shall be permitted to be designated as either Class A or Class B, depending on their performance during non-simultaneous single circuit fault conditions as specified by the following conditions:

1. Initiating device circuits and signaling line circuits that transmit an alarm or supervisor signal, or notification appliance circuits that allow all connected devices to operate during a single open or a non-simultaneous single ground fault on any circuit conductor, should be designated as Class A.

2. Initiating device circuits and signaling line circuits that do not transmit an alarm or supervisory signal, or notification appliance circuits that do not allow connected devices to operate beyond the location of a single open or a non-simultaneous single ground fault on any circuit conductor, should be designated as Class B.

A.15.7.1.3 The frequency depends on the environmental and service conditions to which the device are to be exposed. Process or occupancy changes that can introduce significant changes in condition, such as changes in the severity of corrosive conditions or increases in the accumulation of deposits or debris, can necessitate more frequent inspection. It is recommended that an inspection be conducted after a process maintenance turnaround. Inspections should also be conducted following any natural event that can adversely affect the operation (e.g., hurricanes or snow and ice accumulations).

A.15.7.2.1 Before starting maintenance, always make sure that any process environmental conditions such as gas-air mixtures or vapor-air mixtures are not dangerous to health.

A.15.7.3 See Figure A.15.7.3.