

**MONTREAL PROTOCOL
ON SUBSTANCES THAT DEplete
THE OZONE LAYER**

**REPORT OF THE
HALONS TECHNICAL OPTIONS COMMITTEE
DECEMBER 2018**

**TECHNICAL NOTE #3 – REVISION 3
EXPLOSION PROTECTION – HALON USE AND ALTERNATIVES**



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on Substances that Deplete the Ozone Layer**

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Preface

Technical Note #3, *Explosion Protection - Halon Use and Alternatives*, replaces the chapters on this subject that were part of early Assessment Reports of the UNEP Halon Technical Options Committee (HTOC). Future reports may contain an abbreviated chapter that briefly introduces the subject and refers the interested reader to this document. The HTOC elected to take this approach as much of the information that, while important to understand when developing strategies for explosion protection, has been largely reported before. As such, it was deemed by the HTOC to make the *Explosion Protection* subject a stand-alone document that may be referenced by future Assessment Reports. By this approach those having particular interest in the technical aspects of the *Explosion Protection* subject can access a self-contained document. The following is the most recent update to this technical note.

Revision 3 note. This Technical Note was last revised in 2014 as Revision 2 of the original document. Practices related to use of alternatives to halons in industrial explosion protection remain substantially unchanged, to the best understanding of the authors. Production of new systems using halons ceased in the early 1990s. Most, but not all, explosion protection systems that used halons have since been decommissioned or replaced with systems using alternative agents, usually dry chemicals or water, or with systems using alternative technologies such as explosion vents, fast-acting isolation valves, or similar mechanical systems. The text below differs from Revision 2 only in minor editorial adjustments.

1.0 Introduction

Working spaces, whether manned or not, which may contain dispersed mixtures of fuel and air are at risk of severe loss of property or life should ignition occur. The propagation of flames through such spaces occurs so rapidly that evacuation of personnel is generally not possible. Enclosed spaces are subject to extremely rapid rates of pressure increase leading possibly to explosion of the enclosure. Explosions may lead to fatalities in the immediate area or in areas adjacent to the risk areas. Explosions may cause catastrophic failure of plant components leading to major fires, toxic releases, or environmental damage. The subject of this technical note is the protection of life and property from such explosive events.

2.0 Definitions

Deflagration: A combustion process propagated at sub-sonic velocity through a fuel-oxidizer mixture usually consisting of air and a dispersed fuel component which may be a flammable vapour, mist, or dust. Energy release rates are usually limited by the fundamental burning velocity (thermal and reaction kinetic feedback mechanisms) of the mixture and the extent of the surface area of the flame sheet. Deflagration flame velocities begin at about 0.5 m/s and will rapidly accelerate in the presence of turbulence. Transition to detonation is possible under some conditions. Rates of energy release are typically several orders of magnitude higher than for diffusion flame processes.

Detonation: A combustion process propagated at sonic or super-sonic velocity through a fuel oxidizer mixture. The speed of the combustion wave then becomes supersonic relative to the unreacted medium. Flame velocities in excess of 1000 m/s prevail.

Explosion: The damage or injury-producing event which may result from a deflagration or detonation or other pressure-elevating process.

Fire A combustion process most often characterized by diffusion flame behaviour where the rate of energy release is limited by the molecular scale mixing of fuel and oxidant species.

Inerting: The prevention of the initiation of combustion of an otherwise flammable atmosphere by means of the addition of an inhibiting or diluting agent.

Suppression: The termination of combustion processes through inerting, chemical inhibition, or thermal quenching effects of extinguishing agents, or some combination thereof.

3.0 Explosion Protection Methods

Spaces at risk of a potential explosion may be protected in the following ways:

3.1 Prevention

1. Through application of appropriate principles of safe engineering design, construction, operation, and maintenance of process systems.
2. Through application of inerting agents to atmospheres which are, or may become, flammable.

3. Through high-rate mechanical ventilation of atmospheres which are, or may become, flammable to eliminate combustible conditions.

3.2 Mitigation

Mitigation may be achieved by designing spaces at risk for:

1. Containment of the pressure developed.
2. Pressure relief venting, i.e., release of gas through relieving panels to avoid attainment of pressures which would cause the process enclosure to fail.
3. Combustion isolation, i.e., prevention of the transmission of the combustion process to associated equipment spaces.
4. Deflagration suppression, i.e., detection and extinguishment of the deflagration front prior to attainment of a condition resulting in equipment damage or personal injury.

Several extinguishing agents including halons, dry chemicals, and water have been or are currently used, where appropriate, in deflagration suppression, inerting and, in chemical isolation of duct systems.

4.0 Fundamentals of Deflagration Suppression

Deflagration suppression is a special case of fire suppression characterized by very early detection of the onset of combustion followed by the rapid delivery of an appropriate extinguishing agent. Situations in which application of deflagration suppression is generally appropriate are of two types:

- a. Type A Presents the risk of development of a rise in pressure sufficient to cause failure of a confining enclosure i.e. a general explosion risk to property, or
- b. Type B Poses a direct threat to people in the vicinity of a deflagrating cloud of combustible gases, mists, or dusts.

The mechanisms of deflagration suppression include chemical effects ("inhibition", or interference in flame chemistry by free radical mechanisms) and physical effects (thermal quenching of the advancing flame front and dilution of fuel and air by agent vapours, e.g., steam dilution upon evaporation of water droplets). The relative importance of chemical inhibition in addition to thermal effects to achieve flame extinction depends on the nature of the agent employed. When water is employed as an agent the extinguishing mechanism is entirely thermal. Significant chemical inhibition comes into play in addition to thermal effects when the agents employed are halons or dry chemicals.

An important feature of a deflagration suppression agent is its ability to prevent re-ignition of the combustible atmosphere due to the continued presence of an ignition source such as heated surfaces, flying sparks, embers, electrical shorts, or electrostatic hazards. Water has little or no effectiveness in this regard when the combustible is a gas. Dry chemical agents offer significant short-term re-ignition protection against combustible gases. This protection is lost when the agent dust settles out. Halons, and other gaseous agents, offer sustained re-ignition protection due to the persistence of agent vapours in the protected space.

In order to extinguish a deflagration in progress, deflagration suppression systems deliver much larger amounts of agent in much shorter times than do fire extinguishing systems. In fire protection applications the quantity of halon 1301 delivered is generally sufficient to achieve an agent vapour concentration in the vicinity of 5 to 6 vol%, which includes a significant safety margin. In contrast with fire suppression, deflagration suppression requires much higher effective concentrations of agent in order to achieve successful extinguishment of a growing fire ball. These systems, therefore, generally deliver much larger amounts of agent, often to achieve halon 1301 concentrations of up to 15 vol%.

The elapsed time for agent delivery in fire protection is quite varied depending on the application. Halon total flooding systems typically discharge in 10 s. Water sprinkler systems can be designed to operate in very short time scales, tens of seconds, to long time scales, tens of minutes. In contrast, deflagration suppression must be accomplished in extremely short time frames and total agent discharge is typically achieved in 100 milliseconds or less. Deflagration suppression systems are always operated by automatic sensing and actuation due to the short time scales in which these systems must function in order to achieve successful suppression.

5.0 Applications of Deflagration Suppression

Examples of Type A situations (property damage) include protection of industrial process spaces such as dust collectors, silos, grinding and milling equipment, solvent storage rooms, crude oil pump rooms, solvent vapour ullage spaces and pneumatic dust transfer ducts, and municipal waste shredders.

Examples of Type B situations (personal injury) include commercial aerosol filling operations, solvent storage or pump rooms, oil and gas processing facilities, aircraft dry bays, crew bays of military vehicles, naval machinery spaces, and any application in which personnel may reasonably be expected to be present at the time of a catastrophic system failure with a subsequent risk of initiation of a deflagration. Material or structural damage in Type A incidents may also lead to personal injury.

Prevention of flame propagation in pipes and ducts is often achieved by chemical isolation, i.e., by dispersing an agent into a pipe system. Protection in pipes and ducts and in many other Type A situations (above) may be achieved by halons or other agents, which may be delivered rapidly to achieve extinguishing concentrations. The toxicity of the agent at its extinguishing concentration is not usually an important factor in these applications. Toxic agents, or agents that decompose in a flame to form toxic compounds, may, in some Type A situations, pose significant health risks to personnel involved in necessary service, maintenance, or post-fire activities.

Agent toxicity is generally a major consideration in Type B situations. Such applications are routinely manned or may be manned at the time of actuation of the suppression system. The agent of choice in such situations has been halon 1301 due to its low toxicity, extinguishing effectiveness, and protection against re-ignition. High-rate-discharge systems using water have been employed for deflagration suppression protection in some spaces processing flammable gases (e.g. aerosol propellants). Inerting of spaces where flammable gases may be present is particularly challenging where people could be present. Halon 1301 has been used for this purpose. HFC-23, having very low toxicity and high volatility, has served as a substitute for

halon 1301 in some inerting applications. Refer to Table 2 in UNEP HTOC Technical Note #1 for more information on HFC-23. Technical Note #1 may be found here: https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note1_2018.pdf

6.0 Replacing Halons in Deflagration Suppression Systems

6.1 Industrial Applications

Subsequent to passage of the Copenhagen Amendments to the Montreal Protocol, actions have been taken by providers of halon industrial deflagration suppression systems to both offer non-halon based systems in new sales and to also urge owners of existing halon suppression systems to retrofit them with extinguishers using environmentally acceptable agents. Either dry chemical or water, with or without additives, can serve as a satisfactory, or even superior, agent to halon 1301 or halon 2402 in many dust explosion or hydrocarbon vapour explosion protection applications. There remain certain applications where a "clean" extinguishing agent (i.e. one that evaporates leaving no residue) is important. In these cases, studies¹ have shown that suppression of vapour cloud (propane) deflagrations can be achieved using high concentrations of HFCs with results related closely to the heat absorbing capability of the agent (specific heat and latent heat of vaporization). HFCs have been shown to be very effective in creating inert flame barriers in duct systems and are specified in one system protecting bucket elevators.

6.2 Commercial Applications

The principal application of deflagration suppression systems is in protection of aerosol can filling rooms, and hydrocarbon pump and transfer stations of moderate size, i.e., of the order 100 m³ in volume. Protection of aerosol fill operations constitutes an important use of halon 1301 among Type B situations. This special protection need arose due to the phase-out of the use of non-flammable CFCs as propellants in aerosol products. This transition in propellant technology took place in 1975 as an early outgrowth of the discovery of the catalytic role of chlorine in ozone depletion. Most CFC based propellants were replaced by hydrocarbon formulations which were typically mixtures of propane and isobutane. The advent of combustible propellants coupled with, in many cases, the combustible products being delivered presented an extreme potential hazard in the manufacturing environment. This new hazard gave rise to the use of halon 1301 based suppression systems. Research has shown² that in some applications water (without additives) appears to offer effective personnel protection against localized hydrocarbon vapour deflagrations involving less than a 0.5 kg of propane in air. One provider of deflagration suppression systems does offer water as an alternative to halon 1301 in these applications.

¹ Senecal, J.A. "New Clean Agent Comparison in Deflagration Suppression," International CFC & Halon Alternatives Conference, Washington, D.C., October 23-26, 1995.

² Senecal, J.A., Ball, D.N. & Chattaway A. "Explosion Suppression in Occupied Spaces" Halon Options Technical Working Conference, Albuquerque, N.M., May 3-5, 1994.

6.3 Military Vehicles

The crew bays of military vehicles face a potential mist cloud deflagration threat should one of the vehicle's fuel tanks be penetrated by armour piercing rounds. Naval machinery spaces face a hazard from deflagrations of combustible machinery fluids in both peace time and war time. These occupied spaces continue to require halon 1301 for protection. Research has been conducted on alternatives. Water is not acceptable due to freezing at low temperatures. Water with non-toxic additives, which depress the freezing point, has been shown by one supplier of military vehicle systems to offer suppression effectiveness nearly similar to halon 1301. However, there are still performance issues such as the fire/deflagration re-igniting once the application of water has ceased. Further work is still needed to confirm that water can be an acceptable solution for use in vehicle systems.

Another product that has been used in military vehicles employs an agent consisting of HFC-227ea together with a sodium bicarbonate-based powder. A high-pressure extinguisher dispenses agent from a bottom-mounted valve. The initial discharge from the suppressor is high in powder concentration and effects primary flame suppression, while the trailing halogenated fire extinguishing agent discharge creates, in conjunction with the suspended powder cloud, an inert atmosphere of sufficient persistence to allow appropriate personnel response.

HFC-236fa has also been used in military vehicles. This agent has superior toxicological properties compared with HFC-227ea, and in this instance it is not necessary to use the sodium bicarbonate-based powder.

There have been numerous attempts to use the fluoroketone FK-5-1-12 in military vehicles, both as a neat agent and with the sodium bicarbonate-based powder. In all cases, although the deflagration was successfully suppressed, the level of hazardous composition products was unacceptable. For more information on this specific topic, and military vehicle fire & explosion suppression in general, please refer to the HTOC 2018 Assessment Report, which may be accessed here:

https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/HTOC_assessment_2018.pdf

7.0 Conclusions

Halons have been widely used to suppress deflagrations, a class of combustion events characterized by rapid flame-ball growth and high rates of energy release. Explosions are events resulting in personal injury or destruction of property. Explosion protection is achieved through methods to prevent or mitigate deflagrations. Effective protection of systems and personnel at risk from such events requires suppression systems that:

1. Create inert atmospheres, or
2. Respond automatically to the incipient event and achieve extinguishing agent concentrations to suppress a deflagration in time scales of the order of 100 milliseconds, and which require agent concentrations much higher than typically employed in total flooding fire suppression applications.

Halons have been specified in industrial, commercial, and military explosion protection applications where either "clean" or people-safe agents were essential. Replacement of halon 1301 in such applications presents a significant challenge in fire or explosion protection situations involving human life safety. Industrial studies have shown that HFCs can be used to good effect in some deflagration suppression or duct isolation applications, but further work is required to establish a basis for broader acceptance of the use of other fire extinguishing agents in industrial and military applications.