ENERGETIC MATERIALS

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1.0 SCOPE

This data sheet provides recommendations to addresses the hazards of energetic materials (EM) in storage and processing operations.

1.1 Hazards

Energetic materials (EM) are materials capable of releasing large amounts of chemical energy upon external stimulation. The potential for a detonation, deflagration, or intense fire is always present in facilities where EM are stored, handled or processed. An unwanted energy release can destroy buildings, equipment, and the surrounding area if changes in such things as confinement, temperature, and pressure occur.

Many of the hazards presented at EM processing operations are addressed by FM property loss prevention data sheets for fire, natural hazards, and equipment. Use these other data sheets as minimum recommendations, as applicable, with the additional protection recommended in this data sheet for the EM operations.

1.2 Changes

January 2021. This document has been completely revised. The following major changes were made:

A. Reorganized the document to provide a format that is consistent with other data sheets.

B. Updated recommendations to align with current codes, standards and industry practices.

C. Revised recommendations for sprinkler protection to only consider cases in which ordinary combustibles can be involved.

D. Updated loss history.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Knowledge of the types of energetic materials and their properties is critical to the establishment of proper hazard controls that ensure safety during processing. Understanding the minimum concentration and initiation thresholds of EM to impact, friction, heat, and electrostatic discharge during specific processes and handling situations is essential to any hazard analysis. Consider the response of the materials in terms of energy input, sensitivity, and magnitude of energy release when evaluating and applying these recommendations. Test data are essential for determining the chemical, physical, and explosive properties and hazards of raw materials, intermediate compositions, and EM.

All the recommendations in this data sheet require the exercise of good engineering judgment to balance the demands of property loss prevention and economic practicality. For example, in a new installation it may be practical to provide damage-limiting construction for small processes. In an existing facility, with similar subdivided isolated operations, it may not. Other recommendations, such as process and material hazard evaluations, are always appropriate.

TNT Equivalence is the typical method used to evaluate the effects of energetic materials explosions and is still a common practice in widespread use in industry. The loss expectancy guidelines in this data sheet were developed in accordance with this practice.

2.2 Construction and Location

Separation distance between EM operations and exposed areas is the key to protection. Separation distance is needed to limit damage from a fire or explosion. This separation distance is known as the quantity-distance (QD). The QD is defined as the relationship of quantity of EM expected to explode (net explosive weight [NEW]) and the distance between it and other exposed buildings, operations, etc. QD is based on known effects of explosions for a combination of the energetic material hazard classification, the amount, and the construction of both the exposing and exposed location/building.

2.2.1 General

2.2.1.1 Construct buildings handling or storing EM (roofs, walls, ceilings) using noncombustible materials or FM Approved Class 1 materials.

2.2.1.2 Design buildings for the expected blast overpressure from nearby explosions or provide adequate separation distance between buildings to prevent explosion propagation or damage caused by firebrands and projected fragments.

2.2.1.3 Construct buildings containing EM with the potential of generate gas and overpressure during decomposition with a weak section to permit the relief of internal pressure. The roof or an exterior wall may be used to permit this pressure release. Do not use interior walls that cover beams and columns when exterior walls are used as relieving panels.

2.2.1.4 In areas exposed to wildland fires, follow the guidance in Data Sheet 9-19, *Wildland Fire*.

2.2.1.5 Provide direct-strike lightning protection for all buildings that store or handle EM. Combine the building's static ground bonding system with the lightning protection to ensure all components of the building, lightning bonding, and grounding system are at the same electrical potential. See Data Sheet 5-11, *Lightning and Surge Protection*.

2.2.1.6 Design all drain lines, sumps, and basins handling explosive wastes with sufficient capacity for the removal of settled explosives. Inspect and clean out drains periodically to prevent the buildup of explosives.

2.2.1.6.1 Provide drains of adequate capacity; ensure they are free of pockets and have slopes of at least one-quarter inch per foot (10 mm/m) to prevent explosives from settling out in the drain line before reaching the collection point in the sump or settling basin. Use troughs where possible and keep drainpipes to lengths of less than 6 ft (1.8 m) to facilitate cleaning.

2.2.1.6.2 Design sumps to prevent suspended and solid EM material that could settle out from being carried beyond the sumps in the wash waters, and so overflow does not disturb any floating solids. (Weirs in the sumps can be used to increase the flow distance to ensure removal of EM).

2.2.1.6.3 Provide rounded bottoms and removable ventilated covers for troughs and drains between the source of EM and the sump to facilitate inspection for accumulation of EM.

2.2.1.6.4 Do not connect drains and sewers containing waste EM to the normal sewage systems. Do not run waste liquids into closed drains and sewers.

2.2.2 Process Areas

2.2.2.1 Prevent loose or finely divided EM from accumulating in operation buildings by ensuring walls, floors, ceilings and work surfaces are sealed and smooth, with no cracks or crevices. Seal all wall joints and openings for wiring, plumbing, and other utilities to prevent the entry of EM vapor and dust.

2.2.3 Storage Areas

2.2.3.1 Provide storage areas with natural ventilation. Ensure the ventilation system is designed to prevent air blast, fragments, fire or thermal radiation from entering to the storage area.

2.2.3.2 If a heating system is required it should be provided by either a hot water radiant heating system or by indirect warm air heating. Ensure there is no direct hot-air discharge on the explosives.

2.2.4 On-Site Testing/Destruction Areas

2.2.4.1 Conduct operational testing of EM in specially designed buildings with dedicated equipment, located in remote areas where no other operation or storage area could be affected if testing failures occurred.

Tests are conducted to ensure the EM operates properly. Failures regularly occur during testing and can result in major fires and explosions, with EM projecting over wide areas. Normal operations should not be exposed to testing areas for this reason.

2.2.4.2 Perform on-site destruction operations of expired or unused EM or ammunitions, in properly selected and designated areas located at a safe distance from storage or process buildings. Determine separation distances based on the maximum amounts and types of EMs or ammunitions that could be destroyed at the site. If necessary, provide strengthened construction or barricades to isolate and protect other buildings and operations.

2.2.4.2.1 Maintain destruction areas with a minimum of 200 ft (60 m) of clear zone, free of trees and dry grass, to prevent fire spread.

2.3 Process Safety

2.3.1 Establish a formal process safety program in accordance with Data Sheet 7-43, *Process Safety*. Include a detailed evaluation of all process and storage areas and ensure a thorough process is followed for implementation.

2.3.2 Determine EM in-process hazard classifications for raw ingredients, intermediate compositions, and EM formulations (cured and uncured) using appropriate tests. Use caution when interpreting test results, as small-scale tests may not accurately reflect the in-process hazard classification when quantities or confinement are increased.

2.4 Occupancy

2.4.1 General

2.4.1.1 Provide a formal documented housekeeping/cleaning program to maintain safe conditions. As a minimum, include in the program the following activities:

A. Prevent EM (condensates and dusts), from accumulating on structural members, radiators, heating coils, steam, gas, air or water supply pipes, or electrical fixtures.

B. Check for migration of EM in hidden areas during processing and cleaning operations (behind seals, in gear boxes, lubrication systems, etc.).

C. Do not perform general cleaning concurrently with hazardous operations.

D. Promptly remove spillage of EM and hazardous materials following proper cleaning and disposal procedures.

E. Use floor-cleaning methods that do not create ignition hazards in buildings containing EM. Safer alternatives include hot water and steam.

F. Design equipment surfaces for cleaning and accessibility.

G. Ensure cleaning agents are compatible with the EM in the area.

2.4.1.2 Minimize accumulation of explosive waste and empty containers with EM residues in process areas. Ensure any explosive waste/empty containers are removed at the end of each shift and prior to idle periods.

2.4.1.2.1 Use inert compatible liquids in waste containers to desensitize any initiating explosives.

2.4.1.3 If hand tools are used in process or maintenance operations involving EM, do the following:

A. Use non-sparking tools compatible with the operation.

B. Have a method to account for all tools used in any operation; for example, a checklist or shadow boards labeled for each device to be accounted for at the end of each operation.

2.4.1.4 When ignitable liquids with a flashpoint lower than 100F (38C) are used for operations, such as cleaning of equipment or tooling, conduct the operation in a different room where no EM are exposed or at least at a distance of 50 ft (15 m) from any EM. When over 6.5 gal (25 L) of ignitable liquid are present, ensure adequate safeguards are provided in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

2.4.1.5 Establish a maximum intended inventory of EM in all process areas.

2.4.1.6 Use always closed or covered containers designed to handle and store EM and pyrotechnic composition, except during processing.

2.4.1.7 Conduct black powder (and similar sensitive material) handling, grinding, sifting, etc. in a wet state (i.e., mixed with water or other appropriate compatible diluents).

2.4.1.8 Institute a general policy for an empty pockets program for all personnel entering operating areas where foreign material could result in impact ignition of the material, including mixing, casting, powder processing and pressing areas.

2.4.1.9 Establish an inspection procedure for incoming goods to ensure they do not present any contamination or foreign objects.

2.4.1.10 Use only compatible chemicals inside processing or storage areas. Check the compatibility of chemicals used in the facility prior to their receipt or use.

2.4.1.10.1 Include compatibility checks for lubrication oils and greases, hydraulic fluids, plastic bags, gaskets, electrical wiring, and other material that could come in contact with EMs or their components.

2.4.1.10.2 Do not change the designated use of space and equipment without a thorough cleaning and inspection to prevent incompatible material contact.

2.4.1.10.3 Isolate preparation operations such as weighing oxidizers and fuels (metallic powders) from each other and from other incompatible or EM.

2.4.2 Storage

2.4.2.1 Ensure EM quantities do not exceed the approved magazine capacity for the specific class of explosives.

2.4.2.2 Store materials according to compatibility groups.

2.4.2.3 Locate EM within a magazine to prevent direct contact with walls or obstruct ventilation.

2.4.2.4 Store only closed containers and ensure unpacking or repacking operations are only performed with a minimum of 50 ft (15 m) from the magazine or other explosives.

2.4.3 Storage and Display of Commercial Explosives

“Commercial explosives” as used in this data sheet means materials that contain small amounts of explosives and that could be found at commercial or retail stores (e.g., fireworks, flares, model rocket motors, automobile airbag gas generator assemblies, small ammunitions, explosive cartridges for fire nail guns).

2.4.3.1 Store commercial explosives in approved magazines according to their hazards and the total amount of explosives permitted. Do not store them in general warehouses or retail facilities.

2.4.3.2 Store materials only in containers or packages approved for transportation and storage by USDOT or UN.

2.4.3.3 Limit the amount to what is needed for the shelf or rack display and protect them in accordance with 2.5.2.

2.5 Protection

2.5.1 General

The recommendations in this section only consider sprinkler protection for cases where ordinary combustibles can be involved in a fire where EM are processed or temporary stored (in-process storage). These types of fires represent a source of ignition for EM and could be controlled by sprinkler systems before EM becomes involved.

2.5.1.1 Provide automatic sprinkler protection for in-process storage areas or EM process areas where ordinary combustibles may be present. Install a deluged sprinkler system designed to provide a minimum of 0.30 gpm/ft^2 (12 mm/min) density for the entire area.

2.5.1.2 Protect fire protection systems against damage in areas where explosion hazards are present. Refer to Data Sheet 7-14, *Fire Protection for Chemical Plants*, for additional information.

2.5.1.3 Provide sway bracing in accordance with Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*, in adjacent areas that may be exposed to the explosion effects.

2.5.1.4 Ensure all manual shutoff valves and automatic sprinkler control valves (alarm check, deluge, etc.) can be activated from a location outside of the expected blast ring (e.g., control room).

2.5.1.5 For open-head deluge systems, include inspection of the internal piping for fugitive EM.

2.5.1.6 Protect all areas NOT handling EM materials in accordance with the applicable FM data sheets.

2.5.2 Commercial Explosives

2.5.2.1 Provide sprinkler protection for commercial explosives in retail occupancies (e.g., fireworks, road flares, small ammunition) in accordance with Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*, as cartoned expanded plastic (CEP).

2.6 Equipment and Processes

2.6.1 General

2.6.1.1 Treat all equipment that handles EM, as well as any rooms or buildings in which these can be present, as having an explosion hazard.

2.6.1.2 Use compatible FM Approved industrial fluids in all equipment and vehicles where EM are handled in all new operations and when modifications are made to existing ones. See Data Sheets 7-40, *Heavy Duty Mobile Equipment*, and 7-98, *Hydraulic Fluids*, for additional guidance.

2.6.1.3 Design valves through which EM flows to prevent EM from being pinched or compressed between metal surfaces (e.g., use compatible rubber diaphragm-type valves).

2.6.1.4 Physically or electrically disconnect casting vessels from lifting devices during cast operations.

2.6.1.5 If operating temperatures can affect the EM operations being conducted, do the following:

A. Know the critical operating temperatures for the EM through testing or accepted practice.

B. Use indirect heating methods.

C. Provide nonadjustable high-temperature limit devices to shut down operations and sound an alarm in the control room when temperatures reach 50°F (28°C) below the critical temperature of the EM.

D. Regularly test the limit devices, preferably at the start of each startup of the operation.

2.6.1.6 When coolant is required to prevent EM from igniting during various operations (mixing, reacting, grinding, machining, sawing or drilling, etc.), do the following:

A. Use coolant compatible with the EM composition.

B. Provide positive automatic interlocking devices to prevent the machine from starting until the coolant is flowing. Set these controls to stop the machine if the flow of coolant is interrupted. See Data Sheet 7-45, *Safety Controls, Alarms and Interlocks*, for additional information.

2.6.1.7 Provide EM processing equipment (mixers, grinders, saws, drills, reactors, etc.) with the following:

A. Sensors capable of detecting equipment malfunctions or other potentially hazardous abnormalities particularly for remote-controlled operations, (e.g., machine tool power consumption monitors, over torque sensors, tool force gages, acoustic monitors, temperature indicators such as thermocouples or thermistors, and infrared sensors) that can alert the operator to unusual conditions that require corrective action.

B. Video monitoring systems to provide real-time visual monitoring of remote-controlled operations and to record visual evidence at the time of an accidental initiation.

C. Limit the linear and rotational speeds of equipment to the value, determined from a hazard analysis, that will prevent ignition of the EM.

2.6.1.8 Install screens and metal detectors in the feed and exit streams from all grinding, mixing, pressing, and extruding operations involving oxidizers and EM.

2.6.1.9 Equip mixer blade shafts with seals or packing glands that prevent migration of liquids or solvent vapors into bearings. Avoid submerged bearings and packing glands. If used, test and clean the bearings as needed to prevent contamination.

2.6.1.10 Provide a mechanism that ensures enough space separation between the EM-loaded parts to prevent sympathetic detonations on any conveyors.

2.6.1.11 Provide interlocks to pumps and valves of explosive operations set to automatic shut down the pump when the flow of material stops.

2.6.1.12 Design equipment to prevent metal-to-metal contact.

2.6.1.13 Design and construct equipment to exclude and eliminate moisture from metal-powder operations.

2.6.1.14 Design equipment to prevent the heat generation from getting within 50°F (28°C) of the autoignition temperature of the EM.

2.6.1.15 Design vacuum systems with flanged connections and external clamp fittings to facilitate disassembly and cleaning.

2.6.1.16 Provide vacuum piping systems with high-efficiency filters to prevent explosive dusts from getting into vacuum piping.

2.6.1.17 Construct equipment that processes or transfers EM to contain or safely vent an explosion.

2.6.1.18 Design pressure-relieving vent pipes and blast chimneys for storage bins and hoppers based on testing, considering critical heights and diameters to prevent transition to detonation events. Arrange them to vent to safe areas where no EM or combustible materials are exposed. Ensure the release pressure is not compromising the integrity of any building or structure.

2.6.2 Dust/Vapor Collection Systems

2.6.2.1 Use wet collectors to remove dust and vapor from equipment exhausting air. Use separated systems for dust and vapors. Ensure wetting agents are compatible with the exhausted material.

2.6.2.2 Do not recirculate wetting agents in the wet collector unless the system removes hazardous suspensions.

2.6.2.3 Discharge wetting agents retaining EM into a containment unit designed to keep the EM wet.

2.6.2.4 Inspect the exhaust and collecting equipment at a frequency determined by the site conditions/accumulation history. Remove any EM accumulation within the collection system, including pipes, tubing or ducts.

2.6.2.5 If protective construction prevents propagation of a detonation between equipment, provide each piece of equipment with a complete and separate dust and vapor collection system to prevent propagation through the collection system.

2.6.3 Inerting and Purging Systems

2.6.3.1 Protect processes or equipment that require an inert gas purge system to prevent explosion hazards in accordance with Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.

2.6.3.2 Check inert gas purge systems for operable conditions at regular intervals, but not less than monthly.

2.6.3.3 Check inert gas purge systems that are supplied by tanks before the start of any operation to ensure supply is available for the total duration.

2.6.3.4 Provide alarms on loss of inert gas pressure.

2.6.4 Mixers

2.6.4.1 Design the electrical components of all mixers to meet the appropriate electrical hazard classification, to be remotely located, or to be shrouded and purged with inert gas.

2.6.4.2 Interlock the lowering mechanism to prevent blade-to-bowl contact during all failure modes.

2.6.4.3 Power interruption to the mixer blades in the event of excessive loads or drive mechanism malfunction.

2.6.4.4 Provide safety controls for catalyst additions to limit the rate of introduction of catalyst into the mix to ensure the catalyst is incorporated homogenously to prevent exothermic reactions from igniting the mix.

2.6.4.5 Mount all bearings and drive assemblies outside the mixer and protect against EM and dust accumulation.

2.6.5 Pressing Equipment

2.6.5.1 Provide safety interlocks for equipment used for EM pressing to avoid adiabatic compression.

2.6.5.2 Inspect pressing equipment before operation to ensure pressing surfaces are smooth and free of metal debris to prevent explosions due to friction.

2.6.6 Melt Kettles

2.6.6.1 Provide melt kettles with an indirect heating system (e.g., hot water or steam jacket vessel heating) to keep the temperature of the mixture below its decomposition temperature.

2.6.6.2 Provide the kettle with appropriately designed pressure relief venting. See Data Sheet 7-49, *Emergency Venting of Vessels*, for additional information.

2.7 Operation and Maintenance

2.7.1 Operation

2.7.1.1 General

2.7.1.1.1 Arrange EM operations, piping, bins, hoppers and storage areas to prevent internal fires involving EM from transitioning to detonations by doing the following:

A. Keep the material below the critical height or pile size.

B. Maintain piping below the critical diameter of material being transferred.

C. Maintain operations below critical pressures and temperatures.

D. Provide low-pressure piping set to vent before critical pressures are reached.

E. Provide hoppers with pressure-relieving vent pipes.

F. Design buildings of light-weight construction.

2.7.1.1.2 Check equipment for loose objects and tightness before any operations begin. Secure overhead bolts, screws, and nuts. This can be accomplished with lock wires or epoxy coatings. Use shadow boards for all tools.

2.7.1.1.3 Consider the use of diluents or stabilizers in EM whenever possible in a process.

2.7.1.2 Painting Operations

2.7.1.2.1 Do not use electrostatic spray painting on live ammunition and rocket motors. If this must be done, implement the following minimum safeguards:

A. Limit the energy of the spray gun below the amount needed to ignite EM.

B. Provide high-speed flame detectors in the painting area to shut down paint spray operations in the event of a fire.

C. Cover EM during all painting operations.

D. Comply with the additional requirements of Data Sheet 7-27, *Spray Application of Ignitable and Combustible Materials*, as appropriate.

2.7.1.3 Arms-Loading Operations

2.7.1.3.1 Design shell primer manufacturing equipment, transportation, and operations to protect loose primers or primers in components from accidental impact or pressure. Provide a protective cap when feasible to cover the primer.

2.7.1.3.2 Transfer and store primers in packs designed to prevent sympathetic detonation.

2.7.1.3.3 Ensure primer storage and hoppers on and around primer-loading machines are designed to withstand a detonation of 150% maximum primer quantity.

2.7.1.3.4 Ensure ammunition-loading machines have smokeless propellant storage bins and hoppers designed and tested to withstand a normal low-level ignition of 150% of the amount of propellant.

2.7.2 Maintenance

2.7.2.1 General

2.7.2.1.1 Establish an asset integrity program for systems and equipment in accordance with Data Sheet 9-0, *Asset Integrity*. Base these programs on manufacturer's recommendations, operating history, and any items identified in the hazard analysis for the particular equipment that may become a high-energy hazard or for equipment failures that could initiate a fire or explosion during processing. Ensure the following equipment and activities are included:

A. Check for warping, cracks, crevices, corners, pockets, and any internal equipment configurations that could subject the high-energy material to ignition due to impact, friction or compression.

B. Check for clearances (e.g., blade-to-bowl), bent mixer blades or any other damage that may create friction points.

C. Inspect all process equipment that applies energy to in-process EM for wear and misalignment.

D. Continually identify and eliminate fugitive EM sources.

E. Check belts and rotating equipment for alignment to prevent these from becoming a source of friction heating.

F. Lubricate bearings and rotating equipment (fans, blowers, size-reduction equipment, etc.) in accordance with manufacturers' guidelines.

G. Inspect and test proper function of operating subsystems such as bowl handling and lifting mechanisms.

H. Disassemble, clean, and inspect vacuum system components and piping at regular intervals to prevent EM accumulation. Determine the frequency based on site conditions and accumulation history.

I. Perform non-destructive examination on high stress components per OEM/industry practices guidelines, this includes mixer blades on high torque mixers.

J. Perform testing to determine thickness and integrity of metal walls for steam jackets in melting operations, to prevent contact between fluids.

2.7.2.1.2 Inspect, test, and maintain safety controls, alarms, and interlocks in accordance with Data Sheet 7-45, *Safety Controls, Alarms and Interlocks*.

2.7.2.1.3 Conduct an inspection of clearances and operating systems after any major maintenance or unusual events such as severe weather exposure, earthquakes, mishandling, or a long idle period.

2.7.2.1.4 Perform a pre-safety starting review after each major maintenance outages.

2.7.2.1.5 Check extrusion ram heads for alignment with the press bore to preclude metal-to-metal contact.

2.7.2.1.6 Match punches and dies used in explosives pressing operations in sets that have been inspected and calibrated prior to use to verify dimensional fit and finish characteristics. Conduct nondestructive examination on punches and dies before use and at locally determined intervals to detect hairline cracks and verify structural integrity on all punch and die sets.

2.7.2.2 Lightning, Grounding, and Surge Protection

2.7.2.2.1 Perform visual inspections of the lightning and grounding protection systems for evidence of corrosion or physical damage at intervals not greater than 7 months. Correct and report any deficiencies immediately.

2.7.2.2.2 Test electrically lightning and ground systems after installation, repairs, and at least every 14 months for continuity of the metal components and security of any bonding connections. Ensure the resistance of the electrode to earth does not exceed 25 ohms, and the electrical resistance from any point on the conductor to the electrode does not exceed 1 ohm. Remove all exposed explosives or exposed hazardous materials from the room or area before testing.

2.7.2.2.3 Perform surge protection inspections in accordance with manufacturer's recommendations, without exceeding a 7-month interval and after any suspected lightning strike. Correct and report any deficiencies immediately.

2.8 Training

2.8.1 Train operators on the functions and required actions associated with the storage, processing, and handling of EM in accordance with Data Sheet 10-8, *Operators*. At a minimum, include the following in the training:

- Specific hazards associated with EM
- Handling and storage procedures
- Normal and emergency procedures including shutdown
- Safe work practices
- Cleanup and disposal procedures

2.9 Ignition-Source Control

EM initiation systems often use the controlled input of electrical energy to initiate explosive mixtures and compounds, which start an explosive chain reaction. The uncontrolled release of electrical energy in explosive atmospheres or near explosives and explosive-loaded articles can result in unintended initiation and serious incidents. Electrical energy manifests itself in many forms (e.g., standard electrical installations, lightning, electrostatic discharge, electrical testing) and with various intensities that require special precautions. This section contains minimum electrical safety recommendations for existing, new, or modified explosives facilities and equipment.

2.9.1 Strictly control potential ignition sources where EM may be present. Prohibit smoking and open flames. Do not allow personnel to carry matches, cigarette lighters, or other flame-producing devices into EM areas without an authorized hot work permit.

2.9.2 Ensure all electrical equipment used in areas where EMs are processed or stored, is rated in accordance with NFPA 70, the National Electric Code, Article 500 and appropriate sub articles, or the international equivalent. Refer to Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*, for additional details regarding area classification and equipment selection.

2.9.3 Provide surge protection at all power service entrances, communication systems, electrical or electronic equipment and controls. See Data Sheet 5-11, *Lightning and Surge Protection*, for additional information.

2.9.4 Provide grounding and bonding of metal components in areas where ignitable liquids and/or EM are stored or handled. See Data Sheet 5-8, *Static Electricity*, for additional information.

2.9.5 Conduct a static electricity hazards evaluation if materials sensitive to electrostatic ignition are handled to identify anything (e.g., building structural steel, permanently installed equipment, even personnel), that can accumulate and store electrostatic charges, and any materials that could insulate and interfere with proper bonding and grounding. Steps that can reduce the electrostatic hazard include:

A. Use conductive tabletops, floors, and shoes for grounding personnel.

B. Connect bonding wires or straps between conductive fixed equipment, the tabletops, and floors to the static ground system.

C. Provide grounding straps for employees handling sensitive EM.

D. Use ionizers around the area of static buildup. The ionizers should be open to the air and not blocked or protected by metal grids or shields.

E. Humidify the area (60% minimum).

F. Use non-static-producing clothing (cotton).

2.9.6 Establish a system for monitoring the approach of electrical storms that provides for the timely shutdown of operations.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Loss History

By their nature, energetic materials are frequently involved in unplanned fires and explosions, but if handled properly, they can be kept safe.

In the period of 2009-2019, FM clients reported 9 losses involving energetic materials, for a gross loss of US$63 million (indexed to 2019 values). Of those losses, 4 occurred at facilities in which pyrotechnics and flare devices were manufactured and represented almost 72% of the gross loss in that 10-year period. Artillery manufacturing facilities had 3 losses, representing almost 23% of the gross loss cost.

3.2 Illustrative Losses

3.2.1 Gap Between Components in Explosives Dryer Results in Explosion

A total of 4800 lb (2175 kg) of HMX was being dried in a 6 ft (1.8 m) long, 4 ft (1.2 m) diameter tumble dryer.

The building construction was damage limiting (fiberglass insulated steel panel walls on steel frame).

Shortly after beginning the cool-down cycle, the dryer exploded. The explosion was probably caused by HMX deposited inside a crack in the dryer. As the dryer cooled and contracted, it exerted pressure on the HMX in the crack, which ignited and, with confinement, detonated.

The building and equipment were completely destroyed, with parts thrown up to a mile (1.6 km) away. Remaining dryer pieces were less than 1 in. (2.5 cm) square.

The cracks were likely caused by metals with different expansion coefficients being used in the dryer. This potential was found during the HAZOP of the equipment, but it was installed anyway. The dryer and components did not have any nondestructive testing performed on them, which would have found the cracks from the cyclic thermal cracking. Standard operating procedures were also changed without following management of change programs.

3.2.2 Spilled Propellant Ignites Large Rocket Motor in Casting Building

The casting building is a rail-mounted, corrugated, iron-on-steel frame structure that moves over 20 by 20 by 40 ft (6 by 6 by 12 m) pits used for casting and curing large rocket motor segments. The casting building is one of a number distributed about this plant. A 600 gal (2,300 L) mixer containing propellant slurry is moved over charge hoppers to dump the slurry, which then is discharged into the pits. The mixers are on an elevated dump station that moves on steel wheels on steel rails.

During the casting process, while moving the dump station, popping was heard and sparks were noted near the wheels and sparks were seen falling into the hoppers. The crew evacuated the building. A number of explosions occurred and parts as well as propellant were blown throughout the site.

A small piece of propellant that was spilled on a dump station rail in a casting building ignited when a bridge wheel rolled over the spill. The resultant sparks ignited several hoppers and a mix bowl full of propellant. The fire in this equipment resulted in a subsurface ignition of a 340,000 lb (154 tonnes) rocket motor segment. The entire amount of propellant was jettisoned from the motor and immediately ignited above the ground. The explosion damaged parts of the plant up to one mile (1.6 km) away and was equivalent to 15 tons (13.6 tonnes) of TNT.

Burning propellant was thrown several thousand feet (m) from the initial incident, igniting other rocket segments and buildings and causing additional fires and explosions.

Sparks from propellant spilled on the rail had been identified in prior near-miss investigations, but HAZOPs did not identify this hazard before the loss. During the rebuild, the design was modified to improve inherent housekeeping and remove all possible pinch points. Operating procedures were also changed to reduce the chance of spillage.

Total property damage, including government-owned property, was estimated at over US$24 million with reconstruction lasting over 6 months.

3.2.3 Improper Design of Equipment Results in Ignition of Energetic Materials

A 1600 ft^2 (150 m^2) building of lightweight plastic and metal panel on steel frame construction, except for a 500 ft^2 (45 m^2) blast resistant reinforced concrete control room, was used for mixing and drying of a Division 1.3 (Class B) material involving sodium azide and sulfur compounds. A slurry was formed of several components, spray dried, and collected in a dust collector.

A spontaneous ignition in the spray dryer resulted when poorly mixed material dried on its walls. Ignition was caused by the hot air from the indirect electric heater igniting the dried material. The resultant mixture had autoignition temperatures below the heater outlet temperature.

The resulting explosion resulted in severe damage to the dryer. All dust-collecting equipment was destroyed and the lightweight metal building walls around the dryer were blown off.

Proper testing of equipment and materials through a good HAZOP system could have prevented this loss from occurring.

The Division 1.3 material was a mix being developed as an airbag gas generator. Sodium azide alone is not a Class 1 (explosive) material.

3.2.4 Foreign Material in a Mixer Causes an Explosion

A 1200 ft^2 (110 m^2) building had concrete walls to 8 ft (2.4 m) and mixed concrete block and fiberglass panel on wood frame construction above. The 21 ft (6.4 m) high roof was boards-on-joist construction. The building had a 600 gal (2.3 m^3) vertical pyrotechnic mixer for blending rocket and flare ingredients.

Foreign material in the mixer resulted in a subsurface ignition of the propellant and complete demolition of the mixer and building. A few parts were found as far as 400 ft (120 m) away. Several buildings at the plant, but remote from this operation, had minor damage as well.

Provisions of adequate inlet screens on the mixer would have prevented the foreign material from entering the mixer.

The ultra-high-speed deluge protection for the mixer was shut off.

3.2.5 A Lightning Induced Electrical Surge Resulted in Maloperation of a Propellant Mixer

A 600 gal (2.3 m^3) vertical propellant mixer was located in a 1200 ft^2 (110 m^2) building of mixed concrete and lightweight, damage-limiting construction. Protection included a UV actuated, open head deluge system for the building, and a high-speed system for outside the mixer. The building is provided with properly designed lightning protection. The operation was conducted remotely from a control room about 300 ft (91 m) away. Operation during lightning storms is permitted by procedures in place at the facility.

On the day of the incident, lightning storms passed through the area, and nearby strikes were witnessed by employees.

During operations, the programmable controller for the process experienced failures. Maintenance was contacted and several fixes to the system were completed. During later operations, video showed the mix bowl (positioned by a hydraulic system) dropping unexpectedly. Operators could not stop the operation and an explosion occurred.

An investigation determined a lightning surge damaged control equipment and resulted in the mix bowl being dropped and the mixer turning on, causing the mixer blades to contact the mixer bowl and ignite the propellant. The subsurface ignition of the propellant resulted in the mixing equipment and building being destroyed. Other buildings within 1,000 ft (305 m) had metal panel walls bent and windows broken.

In addition, it was later discovered that damage from a previous lightning storm resulted in lightning protection equipment being removed by maintenance. A properly functioning management-of-change program could have prevented this occurrence.

The second lightning storm damaged the circuit boards, resulting in a short circuit that turned on the mixer when maintenance personnel were removing the mixer control board. Hardback lifting devices were not provided, which allowed the hydraulic equipment to release pressure unevenly on the mix bowl during the repair shutdown. This tilting allowed the mixer blades to contact the mix bowl, resulting in ignition of the propellant during startup.

3.2.6 Explosion at a Flare Manufacturing Facility

An explosion occurred at a flare manufacturing facility in 2018, during the manufacturing of an energetic grain. The interior of the production area was subjected to high temperatures, damaging critical tooling equipment and the building walls/floors. The provided high-speed deluge system in the area actuated to cool the area; however, sprinkler piping was also partially damaged in the initial explosion. Site-wide production was halted as the result of several ongoing investigations.

3.2.7 Explosion and Fire at a Storage Magazine

An explosion occurred inside of a storage magazine at a plant that manufactures artillery systems and mortars, along with their associated ammunitions, causing a fire that spread over 160 ft (50 m) away to dry vegetation and trees and also damaged storage sheds located outside of the magazine.

The site stored explosive raw materials and finished products in magazines constructed over natural valleys, using natural topography to provide separation between individual explosive storage and processing areas. Each magazine had a man-made earth mound, constructed with reinforced concrete, steel doors, and explosion venting installed at the roof level.

A possible cause of the explosion was self-ignition of the propellant charges in the magazine, due to heat generation caused by material degradation.

The fire consumed the propellants stored inside the magazine, and some structural damage was also visible.

3.3 Process Safety

Process safety for facilities in which EM are handled or processed is critical for the prevention of explosions or intense fires. EM may detonate or deflagrate when sufficient energy is provided, thus prevention of accidental ignition is paramount. Other important aspects for the safe handling of EM are understanding the inherent hazards of EM as well as the incompatible materials and operational conditions that may initiate an undesired event.

Process safety programs require detailed evaluations of all process and storage areas, with a thorough process for implementation.

3.4 Ignition Source Control

Ignition sources that may occur during EM processing operations should be identified, controlled or eliminated to prevent explosions. Some of the most common sources are electrical equipment, static electricity, foreign material, equipment impact, high temperature, etc.

Many energetic materials are static sensitive and nonconductive, which means they can develop large electrical charges during processing. The discharge of this static buildup can increase the chances of unplanned explosions. All equipment and vessels handling EM should be grounded to limit the static buildup potential.

Housekeeping should be kept up to the highest standards in the manufacture of energetic materials. Dirt will increase the friction in manufacturing areas, which has resulted in friction ignition of EM materials.

Equipment should be continually examined to prevent unwanted cracks and loose connections. EM may be ignited by compression when the material contaminates cracks and these cracks contract thermally. This situation also occurs when contaminated threads of bolts and screws are turned during equipment adjustments.

Loose machinery should be avoided, and equipment and tooling should be closely controlled and designed to prevent metal-to-metal contact. Losses continue to show sparks and heat produced from metal-to-metal and metal-to-EM impact has resulted in ignition of EM.

The majority of EM is manufactured by adding an oxidizer to a combustible. Oxidizers with incompatible materials can result in extremely sensitive EMs. Extremely exothermic reactions may also occur when incompatible materials come in contact with oxidizers, propellants, explosives, or pyrotechnic materials. Contamination of materials containing oxidizers and EM should be avoided.

4.0 REFERENCES

4.1 FM

Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*
Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*
Data Sheet 5-8, *Static Electricity*

Data Sheet 5-11, Lightning and Surge Protection
Data Sheet 7-0, *Causes and Effects of Fires and Explosions*
Data Sheet 7-14, *Fire Protection for Chemical Plants*
Data Sheet 7-27, *Spray Application of Ignitable and Combustible Materials*
Data Sheet 7-32, *Ignitable Liquids Operations*
Data Sheet 7-40, *Heavy Duty Mobile Equipment*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-45, *Safety Controls, Alarms and Interlocks*
Data Sheet 7-49, *Emergency Venting of Vessels*
Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 9-19, *Wildland Fires*
Data Sheet 10-8, *Operators*

APPENDIX A GLOSSARY OF TERMS

Demilitarization: Any operation involving disassembly, deactivation, or destruction of energetic materials often related to military ordnance, large rocket motors, etc.

Decomposition temperature: Is the temperature at which exothermic and endothermic reactions occur in an explosive when heated. The temperature at which the maximum differential between the sample and the reference temperature occurs before self-heating is the reported decomposition temperature value.

Energetic materials (EM): Class of materials capable of release large amount of stored chemical energy upon external energy stimulation, such as impact, friction, shock, electrostatic discharge, etc. Common energetic materials include explosives, propellants, pyrotechnics and some fuel/oxidizer mixtures.

Net explosive weight (NEW): Is the total weight of all the EM exposed in a storage or process area that could be involved in an explosion event.

Quantity-distance (QD): Refers to space separation requirement established for energetic materials and is measured in a straight line unless large topographical features such as hills exist. The QD in the case of large hills should be the separation distance the blast wave will travel around or over these non-moveable obstructions.

Strengthened/reinforced construction: Structures specifically designed to resist blast load occurring during explosion events, prevent propagation effects and provide protection against fire, fragments and projectiles. These structures are commonly designed with a structural strength of 7-Bar or 3-Bar.

Sympathetic detonation: Detonation of a charge by exploding another charge adjacent to it. It is an unintended detonation of an explosive charge by a nearby explosion. It is caused by a shock wave, or impact of primary or secondary blast fragments.

Unconsolidated EM: Material not solidified. Material being processed is usually not contained. The violent burning of unconsolidated material can result in the material being pushed into the air, forming a cloud. The subsequent ignition of this EM cloud will result in an explosive blast wave similar in effect to a detonation of the material.

Unstrengthened/unreinforced construction: Structures not equipped or constructed to resist blast loading effects. During explosions, these buildings are expected to suffer severe structural damage and may be affected by fires, fragments and projectiles.

APPENDIX B – DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

January 2021. This document has been completely revised. The following major changes were made:

A. Reorganized the document to provide a format that is consistent with other data sheets.

B. Updated recommendations to align with current codes, standards and industry practices.

C. Revised recommendations for sprinkler protection to only consider cases in which ordinary combustibles can be involved.

D. Updated loss history.

October 2017. Interim revision. The following changes were made:

A. Data sheet 7-16, *Barricades,* was incorporated into this data sheet

B. Modified references as follows:

1. Replaced references to “Process Safety Management (PSM)” with “process safety” throughout the document.

2. Guidance for Standard Operating procedures references Data Sheet 10-8, *Operators*

3. Management of Change guidance references Data Sheet 7-43, *Process Safety*

January 2016. Interim revision. Minor editorial changes were made.

April 2013. Minor editorial changes and reference changes from Data Sheet 7-42 to Data Sheet 7-0 reflecting use of non-TNT model for vapor cloud explosions evaluations were made.

January 2013. Clarification was provided on the protection changes for fireworks, road flares and model rocket motors mentioned in Appendix B of the prior version.

February 2010. This document has been totally revised.

In the previous version of this document, protection criteria for storage of fireworks, road flares and model rocket motors were based on a Class 4 product classification. NFPA did not address this matter. In this document, bulk storage of these materials in warehouses is limited only to small motors packed with model rockets in section 2.4.11.3.

2000. Added supplemental FM information to the NFPA document on explosive fabrication of parts and small arms ammunition.

1973 DS 7-28N – adopted NFPA 495 – 1973 with comments

1967 Handbook of Industrial Loss Prevention, Chapter 65