Previous Page

ing both mechanical and manual disposal operations. For example, a serious fire in an outside area injured a laboratory technician when she attempted to puncture a small number of antiperspirant aerosol units without grounding them first.

Due to space limitations, coverage of this interesing subject has been brief. Additional data can be gleaned from the National Protection Association (NFPA) *Fire Code,* 1977 issue, Volume 4, Chapter 56A, as well as Part IV, Sec 46. Also, the BAMA Electrostatics Panel produced a manual titled *General Guidelines for the Safe Handling and Disposal of Powder Containing Aerosols*" (1980); and finally, special reports such as the *Aerosol Age* (March 1979) article titled "Measuring In-plant Electrostatic Charge" by Reusser, R.E., et al of Phillips Petroleum Company should be of interest.

AEROSOL FLAMMABILITY IN PLANTS AND WAREHOUSES

To this point we have discussed only the flammability aspects of single aerosol units. but the scope of aerosol flammability extends also to considerations of safe manufacture and storage. These aspects have become particularly important during the period from about 1977 on, when the industry was forced to rely upon hydrocarbons as the predominant propellent type. The first major testing of aerosol flammability under simulated warehouse conditions was begun by the Factory Mutual Engineering Corporation (FM) in 1979 and led to results, conclusions and recommendations of concern to the industry. As a result, a cooperative program with FM has been funded by industry for further testing, and this may not be concluded until about 1983. These larger-scale flammability aspects are covered here in detail.

Safe Handling of Aerosol Concentrates

The transition from CFC to hydrocarbon propellents has not had a significant effect upon the composition of aerosol concentrates, but the growing industry commitment to overall plant safety, brought on by the increased use of hydrocarbon gas liquids, has acted to improve the manufacturing conditions under which the concentrates are produced. Stated more directly, there was little point in investing up to millions of dollars for the safe utilization of hydrocarbons, if a serious fire in a relatively unsafe liquid compounding operation could burn down the plant.

Of the plant and warehouse fires that have directly affected the aerosol industry during the past ten years or so, hydrocarbon gas liquid types are by far the most common, being perhaps 60% of the total. Aerosol concentrate fires and warehouse storage fires account about equally for the remainder.

The usual cause of a concentrate fire is the ignition of a flammable vapor/air mixture by an electric spark. Two classes of sparks may be involved: those from the commutator area of an electric motor or from an electric switch, and those generated by static electricity. The ignition of flammable powder/air mixtures is very rare (only one small instance known), and ignition from free flames is also very uncommon.

The two substances most commonly involved in aerosol concentrate fires are ethanol and relatively volatile petroleum distillates. Ethanol has a Tagliabue Closed Cup (TCC) flash point of 55°F (12.8°C). A typical, fairly volatile petroleum distillate used in many furniture polishes and other products, consists of a blend of mainly isoheptane and isooctane and has a typical TCC flash point of 39°F (3.9°C). Since these flash point temperatures are usually below ambient, the mere act of striking a match near the top of a tank containing either solvent could result in a disastrous fire. In fact, the situation is made even more critical in that the stirring and possible vortexing of these liquids acts to wet the walls of the tank and create a miasma of vapor and tiny liquid droplets in the head space, making the tank more susceptible to content ignition than might be anticipated from the temperature of the liquid.

Heating ethanol is not recommended except in a completely closed, pressure-tight vessel. The same comment applies to petroleum distillates all the way up to the kerosenes and even mineral seal oils. As a rule, heating ethanol is useful only in speeding up the dissolution of solid hair spray resins and similar additives, which will go into solution at room temperature if given a little more time. But in the case of the isoparaffinic and similar petroleum distillates, it is often necessary to heat the oil-phase to about 170°F (77°C) before combining it with a water-phase to make various emulsion type concentrates. Ideally, this potentially dangerous step should be conducted in a closed tank with two or three intakes of an efficient exhaust system located below the side wall area, and with no electrical equipment within at least 30 feet (9.1 m) unless it is explosion-proof. The tank should not be opened until the completed emulsion has been jacket-cooled to 100°F (37.8°C) and preferably below.

The relatively volatile isoparaffinic solvents, VM&P napthas and similar petroleum distillates are considered more dangerous than ethanol. They have lower flash points as a rule, form flammable vapor/air mixtures with less than 1% vapor (ethanol has an LEL concentration of 3.28%), and have vapor densities of typically 3.5 to 4.0 compared with air. Ethanol is only 1.6 times as heavy as air. A heavy vapor has the capability of traveling a good distance along a floor, drainage channel or other surface — possibly to a remotely located ignition source. A travel distance of over 250 feet (76 m) has been authenticated in the case of a hydrocarbon vapor. When ignited, hydrocarbon vapors produce relatively smoky fires. Burning hydrocarbon liquids are also far more difficult to extinguish than ethanol fires, because they are insoluble in water. They may even form burning layers on the surface of the water, which act to carry the problem into other areas of the facility.

Other flammable chemicals have been implicated in aerosol fires, either in the compounding area or filling area. They include diethyl ether, acetone, methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), methanol and isopropanol (IPA). all these liquids are volatile and have TCC flash points of about 60°F (15.6°C) or below. Several contract fillers have turned down potential business involving these solvents (especially diethyl ether) on the basis that they felt the level of flammablility risk was unacceptable for their production facilities. In one instance, after settling a major claim, an insurance company advised a filler that they would no longer insure his plant if he continued using any volatile liquid petroleum distillates.

The primary defense against concentrate fires is ventilation. Exhaust registers should be located near tanks used for compounding flammable concentrates, preferably below the rim, to suck up any vapors escaping from the top. Larger plants may have very large exhaust systems, with main trunks of sheet metal construction measuring as much as 4 x 4 feet (1.22 x 1.22 m) in cross-section. They remove air to the outside so rapidly that adequate heating of the compounding areas can be very difficult during the cold winter months.

Direct ventilation by the use of explosion-proof fans can be used to diffuse relatively concentrated and possibly flammable vapor/air mixtures so that they become harmless through dilution with more air. This approach is suitable if the mass of generated vapor is relatively small in comparison with the size and air transfer rating of the enclosure. Some fillers leave large doorways open during the summer, to provide cross-ventilation. This may be useful as a back-up precaution, if a good breeze is blowing in the right direction, but only to that extent.

The escape of flammable vapors can be minimized by closing over the tops of compounding and holding tanks, keeping hatches shut when not in use for additions or observations, and monitoring the introduction of chemicals to tanks so that dangerous spill-overs will not happen. In one case, a hair spray concentrate overflowed a 4,000 gallon vertical holding tank, and the alcoholic mixture festooned downward onto a plywood enclosure literally covered with switches on both the inside and outside walls. Fortunately, nothing happened — except that the plywood cubicle was dismantled and the banks of switches mounted in a more remote location. Flammable liquids and gases are unforgiving: if a flammable vapor contacts an ignition source, it will catch fire.

Fortunately for the aerosol industry, very few formulations are prepared by adding finely divided potentially flammable powders to liquids. Many chemical manufacturers deliberately produce flammable or combustible solids in macro forms: prilled, pelleted or coarse granules, for the safety of both their own employees and those of their various customers. Starch powders are often added to hot water to produce starch concentrates, but the humidity helps to moisten the paper bag and drain away any possible charges. An example with far more potential for static-induced flammability would be the addition of powdered pharmaceutical compounds to ethanol, especially if they are contained in polyethylene bags. Plastic bags are notoriously difficult to ground, since they are so non-conductive. For this kind of work, employees should be grounded by means of wrist straps, shoe straps or conductive floor mats. Further protection is afforded by the use of the 3M Company's "907" Ionized Air Source or a similar device. In the "907" (which is really only a nozzle) a circular strip of Polonium 210 ionizes up to 75 CFM (35.4 liters/s) of air. This is sufficient to reduce a static charge of 25 kV to zero in less than one second at a distance of two feet (0.61 m). The polonium is an alpha emitter, but these particles cannot even penetrate the epidermous layer of skin and are thus regarded as harmless. The isotope has an effective life of one year, and the equipment is leased for that period of time. The "907" nozzle must be connected to a suitable air blower system.

Ethanolic concentrates have caused a large number of so-called filler fires over the years, possibly caused by sparking micro-switches, static charge or other ignition sources. Remembering that only vapors burn, many fillers position air-circulating fans near the filling machine to remove flammable vapors and, incidentally, hasten the evaporation of any spilled liquid product.

Safe Handling and Gassing of Hydrocarbons

A great deal of specific information has been amassed by experts into such books as the "CSMA Recommendations for the Safe Handling and Filling of Hydrocarbons in the Plant and Laboratory" and such equivalent volumes as those by the British Aerosol Manufacturers Association (BAMA) and Aerofill, Ltd. In addition, such circumspect firms as Gillette and Unilever have developed safe practice guides, guidelines and checklists for audit and inspection, to make sure their aerosol products are produced in conformance with recognized safety standards in the use of hydrocarbon propellents. Finally, a number of seminars have been held in both the U.S.A. and Europe, under the auspices of trade associations interested in providing aerosol people with information regarding the safe use of these gases. Because of this, our treatment here is limited.

There are two key segments of any installation using hydrocarbon propellents: the unloading, storage, pumping and piping system, and the gassing room. Fires have occurred in both areas, although the ones within the gassing enclosure are almost always the more serious.

Unloading, Storage and Handling System

Since hydrocarbons are delivered in tanktrucks of up to 8,000 gallon (30,280 liter) capacity and in tankcars of up to about 30,000 gallon (113,600 liter) capacity, the minimum tankage for any filling plant will be about 10,000 gallons (37,850 liters). Permanent storage tanks in the 10,000 to 30,000 gallon range must be located not less than 50 feet (15.24 m) from property lines and important buildings. Tank truck and/or tankcar unloading stations should be at least 10 feet (3.05 m) from the tank. Both storage tanks and associated equipment should be maintained in a fenced area with two emergency exits. The land should be kept free of grass and weeds and should have no low spots. Air should move freely across it to disperse any possible vapors.

Shut-off valves at the tank should be accessed readily, even in the unlikely event of a fire at the propellent pump. Safety relief devices on the tank should have the required capacity and venting extensions. The vessel itself should have approved steel or concrete supports. It should meet the 250 psi (1.72 MPa) working pressure and ASME code requirements and must be well grounded.

The storage tank should have a pressure gauge, thermometer and liquid level gauge. Appropriate shut-off valves, emergency shut-off valves, back-flow check valves and excess flow valves should be used in conjunction with the liquid inlet, liquid outlet and vapor line. The tank should be painted in a white or pastel color and marked or placarded as to the contents.

Pipelines should be laid out to allow for expansion and contraction of the metal and for expansion of liquid contents to prevent rupture between shut-off points. The latter is handled by hydrostatic relief valves in each section. All pipes should be painted and placarded as to contents and direction of flow.

Unloading compressors or pumps should be mounted on a concrete base and kept fairly remote from tanks or other pumps, since seals have been known to leak, then fail and cause ignition, producing fire plumes up to an estimated 60 feet (18.3 m) high. In large installations, these pumps have been collected into a pump house fitted with gas detection equipment. All electrical equipment must comply with the National Electrical Code, Class I, Group D and be grounded. The unloading of grounded tanktrucks and tankcars is described in the National Fire Protection Association (NFPA) Pamphlet No. 58 and in other literature. Start-up and shut-down procedures for the entire system should be followed closely, preferably by check-list.

An uncontrolled fire in a tank farm, leading to the overheating of propellent tanks beyond the capability of pressure relief valves to drain off the excess pressure development, will cause eventual tank rupture and a truly awesome burning liquid expanding vapor explosion sometimes called a BLEVE. A large propellent tank might produce a blast-associated fireball up to 500 feet (150 m) in diameter, with upward drafts of up to 400 mph (590 ft/s, or 180 m/s). Steel and aluminum metals within the fireball are known to melt, be carried aloft, and then come down as a red hot rain. Buildings within a quarter mile (402 m) may be set afire from the radiation. Exposed persons some distance away may get mild "sunburns", severe "sunburns", burns, or worse, depending upon proximity.

Tests carried out in England (at the School of Artillery, Larkhill, by Expamet Blevex Ltd.) in April 1979 proved that heavily insulated propellent tanks could survive a one hour heating from a kerosene fire as long and wide as the tank above it. The insulation was composed of about a 2" (50 mm) air space, then 4" (100 mm) of coated, expanded aluminum foil (15 layers, supported on Hi-Rib struts off the tank), a second 2" (50 mm) of coated, expanded aluminum foil (15 layers, supported on Hi-Rib struts off the tank), a second 2" (55 mm) air space, and then the whole encased in sheet metal.

At least one major U.S.A. filler reviewed this option for tank protection and decided against it, due to cost and other reasons. Instead, the firm protected their many propellent tanks with a monitor gun (or "water cannon") fire suppression system. Several cannons are mounted at widely separated points, such as roof edges or towers, near the tank farm. They are activated by temperature rate-of-rise detectors located throughout the tank installation. Supplied by either city water or private reservoirs, each water cannon can spray more than 600 g/m (2,300 liters/m) into the tank farm.

The Gassing Room

Installations for the gassing of hydrocarbon propellents into aerosol containers come in a diversity of designs, sizes, levels of relative safety and costs. A preferred system includes a gashouse physically separated from the main plant buildings by at least five feet (1.5 m). A number of fires and explosions have been caused by placement of gassing enclosures within plant buildings; however, in some cases this alternate is unavoidable.

The gas house should be constructed with three rather substantial walls, preferably of concrete, plus a fourth wall that contains large "blow-out" panels. Since a hydrocarbon gas/air explosion can theoretically generate up to about 120 psig (827 kPa) — except that any gashouse would rupture first — it is necessary to protect operators from dangerous pressure build-ups by providing light-weight panels, sheer-bolted to wall frames so that they can blow outward at internal pressures of about 0.08 to 0.13 psig (0.55 to 0.86 kPa). The panels also serve to protect the gashouse from serious structual damage.

Ventilation is the key to explosion prevention under normal operating circumstances, but its limitations must be clearly understood. For a typical gashouse with an air volume of 2,000 cu. ft. (56,600 liters) as little as 1.25 gallons (2.7 kg) of isobutane can bring the entire area to the lower explosive limit (LEL). Much less is needed to reach the LEL or beyond in specific areas, such as near the gassing machines. Considering that high-speed gassing operations often require as much as 15 g/m (56.8 liters/m) of liquefied propellent gas, it is easy to show that a serious rupture in an unprotected gas inlet line could bring the gashouse to a potentially explosive condition in a matter of a few seconds.

The usual ventilation system changes the air in a gashouse once every minute, which would not have any significant ameliorating effect on the consequences of a serious rupture in an unprotected gas line. If the hydrocarbon sensing device detects a rise to 20% of the LEL value (about 0.4v% gas) an alarm is normally triggered and an interlock system causes the ventilation rate to be tripled — to an air change every 20 seconds.

Finally, when the hydrocarbon detector system senses a rise to 40% of the LEL value, or about 0.8v% gas, a different alarm is sounded, the gasser is shut down automatically and the hydrocarbon inlet line is automatically closed by a solenoid-operated valve. In any event an inlet line would be protected by one or two excess flow valves, so that, even if a serious rupture occurred, the flow increase would act to shut off the gas supply.

In the course of operations, various propellent leaks take place at the U-t-C or T-t-V gassers. The propellent liquestatic pressure in these machines and the inlet lines ranges from 550 to 800 psig (3.80 to 5.52 MPa). If certain metal components in the heads fracture, or if a pulsing flexible hose ruptures, the leakage rate can be intense. For safety purposes the closest excess flow valve should be located quite near the machine, without any accumulators, large diameter pipes or other high capacity line components in between. This will act to minimize gas entry into the room as a result of the sudden leak.

Various sensing devices are available to detect the build up of propellent vapors in the gassing enclosure. The most foolproof type draws the vapor/air mixture from 3/16" (4.7 mm) copper tubing terminals placed in two or three strategic locations, passing the mixture across a continuous infra-red sensor that determines absorption at a specific waveband where the hydrocarbon gases are relatively opaque. The degree of absorption indicates the concentration of propellent in the mixture. If concentrations beyond the 20% LEL level are encountered, an interlock system acts to increase ventilation, sound an alarm and perhaps light up warning annunciator signals elsewhere in the plant. At 40% LEL levels the equipment is shut down and the gas supply closes automatically, as mentioned earlier. Some set-ups perform these functions at 25% LEL and 50% LEL, respectively. The equipment can be pre-set as desired.

The system is made fail-safe so that in the event one or more of the "sniffer" intakes becomes inoperative — kinked tubing, vacuum pump failure, belt failure, etc. — the equipment will be shut down and the gas line shut off until the problem is remedied. One shortcoming of the equipment is that it takes a number of seconds for the gas/air mixture to travel through the copper or aluminum tube and finally reach the remotely located sensing unit.

Infra-red systems are supplied by the Mine Safety Appliances Company (Pittsburgh, PA), Davis Instruments Division (North Charlottesvile, VA), Scott Aviation Company (Lancaster, NY) and the Bacharach Instrument Company (Pittsburgh, PA).

A far less costly system is also available, which uses a thermal conductivity sensor at the site to pick up the presence of hydrocarbon vapors. Response time is thus almost instantaneous. The sensors can be inactivated by vapors or mists that can form a coating on the metal detection surfaces. Methylene chloride, silicones, varnishes and several other substances can act to breech the integrity or poison the sensors in this way. A few installations use only this type of system; some use both the infra-red and thermal systems together. Firms such as Bacharach and Mine Safety Appliances produce the thermal conductivity system.

A lot of controversy still exists concerning other equipment that may be placed in the gashouses. It is not uncommon for them to also contain hi-pressure propellent booster pumps, check-weighers, button tippers, vacuum equipment and so forth. In one case, a gassing room contains a hot tank. Industry engineers appear to be about evenly divided on whether gashouses should only contain gassers, or also several pieces of other production-related equipment. In any event, all gas house electrical gear must be Class 1, Group D, Division 1 (explosion proof), and electrical equipment outside the gashouse, but within 30 feet (9.15 m) should be Division 2.

It is very desirable to maintain the gassing room humidity at 70% RH or higher, generally by the use of steam jets. These jets can also be used to de-ice the gasser heads, provided a strictly anhydrous product is not being produced. The humidity acts to reduce the possibility of static sparking. A number of fires have occurred in gassing rooms. Most had an unexplained origin, but were probably initiated by triboelectric sparking at energy levels of 0.2 mJ or above.

Very costly copper-beryllium wrenches, hammers and other tools are often found in gas houses. The metal is soft, compared with hardened steel, so wear and damage can be a problem. The theory is that this alloy is only about 2% as spark-prone as steel, when it strikes a steel surface, thus it is safer to use. Two arguments with this theory are that the LEL or flammable level should never be reached in the first place, and even if it were, mechanical sparks are not sufficiently energetic to ignite a hydrocarbon/air mixture.

Nearly all gashouses have a system for extinguishing fires. They depend upon pressure, heat, or ultra-violet detection devices positioned on the ceiling or upper wall areas and react to fires by activating water deluge equipment (typically delivering 350 to 400 g/m (1,325 to 1,514 liters/m) or a ceiling-mounted cylinder or "egg" of Halon 1301 ($CBrF_3$). The Halon type equipment is available from Walter Kidde & Company (Belleville, NJ), Fenwal, Inc. (Ashland, MA) and other firms.

For the usual Halon 1301 fire suppression system, a pair of ultra-violet wide-range detectors are installed on the ceiling and a pair of back-up pressure-increase detectors are mounted on upper wall areas opposite each other. The UV system will pick up fire radiation in the 170 to 260 nanometer (nm) range, with peak sensitivity at 2150 nm. Detection and reaction time is about 5 milliseconds (ms). The detector unit sends an electrical signal to the solenoid striker between the Halon 1301 egg and spreader assembly, rupturing the prescored bursting disc and letting the Halon fly out at injection speeds averaging about 200 ft/s (61 m/s). At the same time, the ventilation system is shut off, so that no Halon is wasted to the outside.

The hydrocarbon/air flame front has a velocity of about 1.44 ft/s (0.44 m/s) at LEL. If a fireball of about 1 ft (305 mm) in diameter has been produced by the time detection is accomplished in the 6 ms before the Halon 1301 strikes it and total suppression is effected, the fireball will have grown to about 2.73 ft (0.83 m) in diameter. This scenario assumes a 15 ft (4.5 m) travel distance from spreader assembly to the core of the fire, and zero growth from the instant of contact. Actual results are more serious. In one example, the fireball was described as one quarter as large as the gassing room and momentarily engulfing the lone operator. In another case no dimension was given, but three persons in the room were engulfed. In both, the internal pressure rose by about 2.5 psi (17 kPa) and the people were somewhat dazed and had mild burns on exposed skin surfaces. Their cotton clothing did not burn. About 5 v% of Halon 1301 is necessary for explosion suppression.

Halons have been discussed in the propellent chapter. In the case of Halon 1301 there are no human effects up to the 7 v% level in air, after 4 minutes of exposure. Above this, people were subject to light-headedness and had a problem with mental concentration. It was non-lethal, even at very high levels. No cardiac arrhythmias were detected. The thermal decomposition products included hydrogen fluoride (HF) at 200 to 300 ppm, hydrogen bromide (HBr) at 40 to 50 ppm, plus bromine (Br_2), carbonyl fluoride (COF_2), carbonyl bromofluoride (COBrF) and carbonyl bromide ($COBr_2$) at concentrations too low to measure and probably less than a few ppm.

The major problem with Halon 1301 installations is economics. For example, a system in the Chicago area was set off by a person welding about 60 ft (18 m) away. About $5,000 of extinguishant was released into the gas house and the production line was down for the rest of the day, while arrangements were made to have the egg recharged and the system reset. These situations are now quite rare, since firms with this equipment have learned how to accommodate to its ideosyncrasies. Suppression systems are used principally to prevent or mimimize employee injuries. With blow-out panels and shut off systems, the protection of the gashouse and its equipment is a secondary function.

Warehouse Storage of Aerosols

Industry interest in the possible flammable hazard of stored aerosol products extends back to at least 1955, when large amounts of flammable or combustible substances were first introduced into formulations. Several isolated experiments were made where one to five 12-pack cases were placed in a bonfire. Two series of experiments were conducted in this manner near Jones' Beach, Long Island, NY, where photographs of rupturing cans were taken to help determine the optimum ethanol concentration in a hair spray. In one informal study, about 25,000 cans of a predominantly kerosene product were ignited, producing a fire averaging 50 ft (15 m) across, plus large amounts of dense black smoke. In one photograph, a flying can was clearly outlined at a height of about 170 ft (52 m).

During the early 1960s a palletload of aerosol varnish was set afire by the Factory Mutual Engineering Corporation in their testing center at West Glocester, RI. A vigorous fire resulted which could not be controlled by the standard sprinkler system and had to be extinguished using fire hose. A film of the fire was taken, and the research results informally reported to the National Fire Protection Association (NFPA) and other organizations.

The NFPA, which often sets recommended standards that are later enacted into national or local regulations, is an organization composed primarily of fire marshalls, insurance company engineers and industry in general. Among their diverse interests is the safe storage of flammable and combustible liquids, including aerosols. They have defined these liquids as follows:

Class 1A	Liquids having TCC flashpoints below 73°F (22.8°C) and having a boiling point below 100°F (37.8°C). Examples: isopentane, diethyl ether and aerosols defined as "Flammable" (or "Extremely Flammable") by the Federal Hazardous Substances Act of 1960.
Class IB	Liquids having TCC flashpoints below 73°F (22.8°C) and having a boiling point at or above 100°F (37.8°C). Examples: acetone, hexanes and ethanol.
Class IC	Liquids having TCC flashpoints at or above 73°F (22.8°C) and below 100°F (37.8°C). Examples: turpentine, n-butanol and n-nonane.

Class II	Liquids having TCC flashpoints at or above 100°F (37.8°C) and below 140°F (60°C). Examples: many kerosenes, butylene glycol and Cellosolve Solvent.
Class III	Liquids with TCC flashpoints at or above 140°F (60°C) and below 200°F (93.3°C). Examples: less volatile kerosenes and pine oil.
Class IIIA	Liquids with TCC flashpoints at or above 200°F (93.3°C). Examples: propylene glycol, corn oil and mineral oil.
Note:	Class I liquids are considered as ''Flammable'' liquids and the others are considered ''Combustible''.

The NFPA 30 recommendations stipulated storage restrictions for these liquids, which were most stringent for Class IA, and thus ''Flammable'' aerosols, as defined by the FHSA. Sanctions included maximum pile size in terms of gallonage and height, aisle placement and widths and the prohibition of basement storage for Class I liquids. At one time, Class IA liquids were recommended only for storage at heights up to 3 ft (0.91 m), but this was later raised to 5 ft (1.52 m). Even this was considered extremely oppressive and unwarranted for ''Flammable'' aerosols and the industry was greatly troubled by the recommendation, and often unable to comply with it for economic reasons.

When the Occupational Safety and Health Administration (OSHA) was formed in 1970 they planned to engage in widespread standard-setting activities, and began adopting many voluntary consensus standards as regulations. The NFPA definitions were encoded into Chapter XVII, Sec. 1910.106 (13, 18 and 19) of the Code of Federal Regulations, and the recommended restrictions for storage were likewise adapted with no changes. The restrictions remained as OSHA regulations from about 1972 to 1978, at which time the agency, reacting to public and Congressional opinion, deleted about 1100 individual regulations, including all those that related to aerosols, with the exception of one that stipulated maximum gallonage per pile.

Unfortunately though, during the 1970s several states and numerous local authorities adopted the NFPA/OSHA concepts into their own regulations. There is a great deal of inertia at these levels, and even now at least two states have regulations banning the stacking of ''Flammable'' aerosols over 3 ft (0.91 m) high. Fortunately, they are not enforcing them. In 1979 an attempt was made to get the NFPA to delete their definition of a ''Flammable'' aerosol as a Class IA liquid, or, failing in that, at least have such aerosols equated with Class 1B liquids, so that stacking could be 10 ft (3.04 m) high in harmony with their recommendations. The attempt was initially unsuccessful and was not pursued in 1980 because of developments within the Factory Mutual Insurance group that impacted on this area.*

The Factory Mutual Initiative**

The Factory Mutual Research and Engineering Corporation (Norwood, MA) is part of the Factory Mutual Insurance Group, which is jointly owned and operated by four major insurance firms: Allendale, Arkwright-Boston, Philadelphia Manufacturers and Protection Mutual. The company engages in loss analysis, risk analysis, training and other activities, making periodic recommendations to their associated commercial carriers regarding risk reduction and loss prevention. Factory Mutual (FM) has about 740 loss protection engineers who frequently accompany sales personnel on field trips, assessing the safety of warehouses and plants, and make recommendations for the reduction of risk to what may be termed an acceptable level. In some instances, retrofitment is necessary as continuing research uncovers new problems, or if the establishment is used for the storage of new, more hazardous goods than before. Once compliance with engineering standards is reached, the carriers will insure it or provide re-insurance, as the case may be. As a rule, the carriers provide their insureds with sufficient time to upgrade their warehouses, continuing their insurance coverage for periods up to two years or more if the firm promises to make the needed improvements. In most cases, the semi-annual or annual FM engineering ''spec'' of warehouses results in anywhere from one to ten recommendations for improvement. In many cases, the owners can respond in writing, stating that they feel they are applying safe storage conditions and

*One interesting legal analysis suggests that the NFPA definition of a ''Flammable'' aerosol is tied to the FHSA definition in laws now administered by the CPSC. As such, it only relates to household products — not to pesticidal, food, drug or cosmetic aerosols. Consequently, at least 40% of all aerosol products would not be subject to the NFPA Class IA liquid definition, or regulations by various authorities based upon the NFPA liquid classifications. In any event, the NFPA Code 30 is scheduled for a total review in the near future, and it is hoped that the industry can insert some beneficial changes into the wording on aerosols at that time based on test data still being collected.

**This section is written with some reluctance, since the complex situation is still developing and the end results may be quite different than what is visualized at this time. No standards or recommendations are proposed or implied.

no actions are contemplated. This often ends the matter, unless serious deficiencies are involved.

The carriers associated with FM are known as HPR (Highly Protected Risk) insurers. Their rates are very low, since the risk has been reduced to a practical minimum in the establishments they insure. IRI (Industrial Risk Insurers), Kemper, IRM (Improved Risk Mutual) and other carriers offer the same type of coverage, and there are also many other insurers that adjust their premiums on the basis of perceived risk level. These latter companies, however, usually have rates which are significantly more than that of HPR insurance.

The FM carriers may form the largest property insurance unit in the world. Through Factory Mutual International they operate in a number of countries and are said to insure over 20,000 business establishments worldwide. Most are plants and warehouses, but some are large retail outlets as well. The FM research facilities are the most sophisticated available for large-scale warehouse fire testing. As a result, their technical recommendations are treated with respect. They are looked at both by recommending bodies (Underwriters Laboratories and NFPA) and standard-setting organizations (BOCA and UBC) as the acknowledged technical leader in the field of fire control. For example, the UBC is the United Building Code Organization, which operates in the thirteen western states. Within the UBC a committee of fire chiefs and persons with similar interests are now developing what is called the United Fire Code (UFC); a document that will affect the construction and fire protection requirements of commercial buildings for years to come. They are using the published FM loss prevention data in their decision-making activities. Regulatory bodies and other insurance carriers often accept or are at least influenced by the various FM recommendations. Consequently, although there may be a lag time of (say) six months to six years for these large organizations to develop or change their codes, the pronouncements made by FM have a very large long-term effect, influencing many other aspects of fire control, safety and risk assessment outside the company.

FM's interest in aerosols was sharpened during 1978 and early 1979 when three warehouses had fires which caused over $250 million in damage. They were insured in part by the FM carrier companies. The investigations that followed showed that both warehouse structures and the goods they contained had changed greatly during the 1970s, to the extent that the standard protection systems could no longer effectively cope with the new hazards. Many warehouses had grown taller; some were now over 100 ft (30.5 m) in height, with racks from floor to ceiling and often supporting the roof. Pallets were moved in and out by computer-controlled stacker cranes or automatic track and lift operations. Any fires that started in these high-rise structures could readily grow to heights of 60 to 80 ft (18.3 to 24.4 m) within several minutes, prior to activating the ceiling sprinkler system. By that time control might be extremely difficult or impossible.

Very large warehouses had also come into vogue. One section of the huge Ford warehouse that burned during 1978 in Merkenich, West Germany had an area of over 18 acres (7.2 ha or 7.6 million ft^2). Numerous warehouses in excess of a million ft^2 (0.95 ha) are now operated in the U.S.A. One of these burned in the Edison, NJ area during 1978 and aerosols are alleged to have been involved in spreading the initial fire.

The other factor was that the nature of the stored goods had changed. The most significant change was the greatly increased use of plastics, replacing metal, wood, paper and other traditional materials in both products and packaging. Probably the most flammable form of plastic is polystyrene foam and similar foam structures, used for paper cups, meat trays, mattresses, cushion-packaging and so forth. Finally, it was recognized that some aerosol products now had higher contents of flammable ingredients and might be more hazardous.

In 1979 FM engineers designed a series of fire tests to reevaluate their guidelines for protecting warehouses. The program was divided into two sections; one was related to rack storage of ordinary and mixed combustibles and plastics. The other involved aerosols.

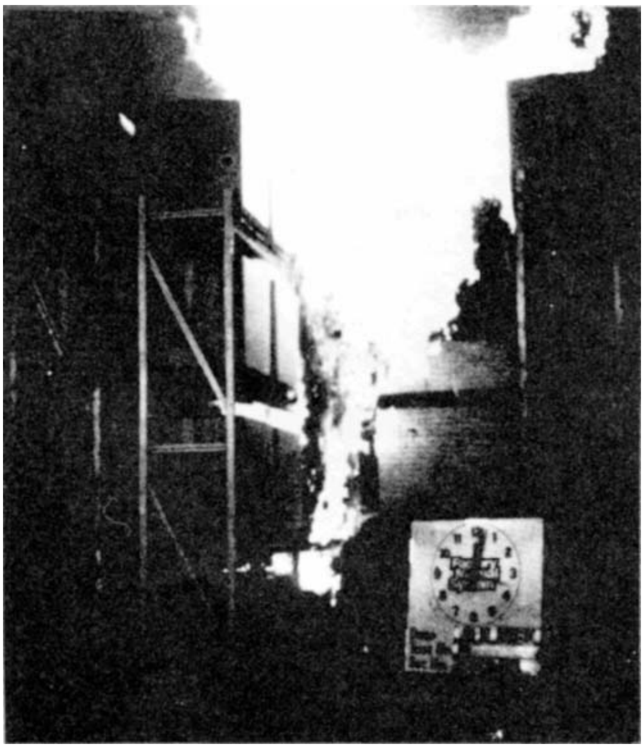
The aerosol program, funded at about $200,000, consisted primarily of the evaluation of FM's three classes of products: water-based, alcohol-based and liquid petroleum based. Large numbers of aerosol cans were purchased from a local filler. They were of the 211 × 604 (65 × 158 mm) size and had either 9 or 10 Av. oz (255 or 284 g) fills. The water-based prototype product consisted of 65% water and 35% of hydrocarbon propellent A-70, the alcohol-based type contained 65% isopropanol and 35% hydrocarbon, and the liquid petroleum based formula was composed of 65% toluene and 35% hydrocarbon. These formulations were supposed to represent the full range of aerosol formulations and packaging variations.

The results of the FM tests have been published in *Fire Record,* (pg 10, Sept/Oct-1980) and other journals. The water-based formula was tested first. A single palletload, consisting of 72 12-pack cases of aerosols, was ignited at the bottom using a cotton ball saturated with 4 oz (113.4 g) of n-heptane. As the corrugate fire grew, some cans ruptured, but the 0.3 gpm (12.3 liter/m) sprinkler system controlled it easily. Other storage arrays were tested with the same results. The test team concluded that these products could be protected effectively by sprinkler systems recommended for ordinary combustibles. The fires were related to the Class A types, generated by paper and cardboard commodities.

These tests were conducted at the FM Research Center at West Glocester, RI, where two test pads are available and can be set up to duplicate most warehouse configurations. The sprinkler system has nearly 1000 sprinkler positions. Various horizontal spacings, sprinkler head sizes, water pressures and other variables can be handled. The ceiling system in the main test area is 30 ft (9.14 m) above the floor, but platforms can be erected to reduce this distance if desired.

Figure 11. Warehouse Fire Involving Aerosols
Photo of early stage of warehouse fire, involving aerosols formulated with 65% isopropanol and 35% A-70. Ceiling sprinklers rated at 0.3 gpm (12.3 liter/m/m²) with 286°F (141°C) linkages were inadequate for control.

A partly dispersed fireball accounts for the enlargement of the upper reaches of the fire. Only a small amount of smoke has been formed.



The usual sprinkler system for a general purpose warehouse consists of a "Christmas tree" or more modern grid type piping arrangement, starting with 6 to 8" (152 to 203 mm) mains that connect to the water tower, reservoir or city water supply. As the system spreads across the warehouse ceiling area, the pipe size gets progressively smaller, down to a 1" (25 mm) end-pipe size (as a rule) to accommodate the usual ½" (13 mm) threaded connection to the 30 gpm (114 liter/m) individual sprinkler heads. The heads may be fitted with fusible lead-alloy activators that melt at 286° or 160°F (141° or 71°C). Fusible linkages are available at other temperature ratings, but are much less popular. The 286°F (141°C) heads are used most commonly for ceiling sprinkler systems, since for most fires they were found to provide an optimum response: actuating fairly promptly, and yet not melting the linkage so readily that the system is compromised by the operation of an excessive number of heads, some of them not over the actual fire.

The 160°F (71°C) heads have been preferred for in-rack storage protection, where they are often back-mounted on each storage tier at 8 ft (2.44 m) intervals, as an extension of the basic ceiling system. Recent data suggests that for use over aerosol products, these low-melting heads may be better than the 286°F (141°C) type for ceiling sprinklers. The ceiling systems generally contain sprinkler heads at 10 ft (3.05 m) intervals, so that every head controls an area of 100 ft² (9.29m²). Thus, if the head is rated to spray 30 gpm (114 liter/m) at standard water pressure (generally 25 to 30 psig or 172 to 207 kPa), the sprinkler density is rated as 0.3 g/m/ft² (12.3 liter/m/m²). In abbreviated form, the density is simply mentioned as a number, or as a number identified as "gpm" to indicate that the English system is being used.

The FM test team then began the evaluation of alcohol-based aerosols, thought to represent a medium-range hazard. They set up a 20 ft (6.1 m) high row of racks, two pallets deep, four pallets high and six pallets wide. In the center they placed eight pallets of actual aerosols (four high and two wide). The rest of the pallets contained corrugate boxes with metal liners. Also, on the other side of an 8 ft (2.44 m) aisle they placed a target rack filled with more dummy cases. The only fire control in this test was a 0.3 gpm (12.3 liter/m/m²) ceiling sprinkler system.

The FM engineers ignited the aerosols at floor level, using the standard cotton/n-heptane wad. In about 1:50 minutes the fire had reached a height of about 20 ft (6.1 m) and cans started to rupture. Some rocket propulsion also took place. When the individual cans exploded under a pressure of about 225 psig (1.55 MPa) and equivalent equilibrium temperature of about 160°F (71.1°C), the 35% of hydrocarbon A-70 blend propelled the flaming contents outward in all directions, resulting in a fireball of approximately 9 ft (2.74 m) in diameter, lasting for about a second.

The characteristics of the fire in its early stages is shown in Figure 11. The fire got out of control very quickly and had to be extinguished by using a combination of greatly increased water pressure in the sprinkler system (about 90 psig or 621 kPa) and manually operated fire hoses.

The next test was a repetition of the previous one, except that in-rack sprinklers were used in addition to the ceiling system. In this case the fire was controlled, although some cans did rupture. The flames did not spread across the 8 ft (2.44 m) aisle. When a fire is listed as "controlled", this does not mean that it has been extinguished; only that it has been reduced to proportions that are not expected to enlarge as long as sprinkling continues. For example, fires deep within the framework of oak pallets cannot be reached by sprinkler water and will continue to burn until extinguished by fire hoses operated manually.

The third test was similar to the second, but with the number of palletloads of product escalated from 8 (1 × 2 × 4 high) to 24 (2 × 3 × 4 high). The fire was more intense than before, but was eventually controlled by the combination of ceiling and in-rack sprinklers.

The fourth test was the only one involving floor storage. Twelve pallets were assembled into a 3 × 4 × 1 high array, about 12" (305 mm) apart. A 0.3 gpm (12.3 liter/m/m^2) ceiling system was used. After ignition between the palletloads, many cans ruptured and the fire was intense, but the sprinklers were able to control the fire, with less than half the cans becoming involved. The results left open the question of what would happen in the event of storage of two and three palletloads high, if ignition occurred.

The final test for the alcohol-based product series involved a small in-rack storage array of pallets, 2 × 2 × 2 high. Only ceiling sprinklers were provided. An ignition at the center caused a rapid fire development which grew out of control. The test had to be aborted.

The conclusions reached by the FM engineers at the end of this test series were that aerosols with alcohol-based contents can be protected with ceiling sprinklers if they are stored in solid piles about one palletload high, but if stored in racks, both ceiling and in-rack sprinkling must be used if the fire is to be controlled.

The last product to be tested was the toluene/hydrocarbon prototype. This was expected to give the sprinkling system its most severe test, since the BTU (kcal/g) content was about 20% higher than the isopropanol/hydrocarbon blend. Furthermore, the toluene is also water-insoluble and tends to create floating, burning layers upon water. Smoke generation was also expected to be a problem.

In the first sequence, the FM engineers set up a rack storage of eight pallets with a 2 × 2 × 2 high configuration. A target row of dummy cases was set up across an 8 ft (2.44 m) aisle. Both ceiling and in-rack sprinkler systems were used, with the heads rated at 0.3 gpm (12.3 liters/m/m^2). The fire spread quickly, generating fireballs and spread across the aisle quite easily. It was soon aborted because the sprinklers could not effect control.

The second test was limited-height solid floor pile study, involving an array 3 × 4 × 1 high. Ceiling sprinklers rated at 0.3 gpm (12.3 liters/m/m^2). Shortly after ignition, flames engulfed the entire pile and the test had to be aborted. In a subsequent study only a single palletload was ignited. Within four or five minutes, even this small amount of storage got completely out of control and the test had to be aborted. Nearly every can had ruptured and all flammable contents had been consumed when the fire was finally extinguished. These three tests convinced the FM engineers that standard 0.3 gpm (12.3 liters/m/m^2) sprinkler systems were inadequate for this type of aerosol formulation.

In the next three tests with the toluene/A-70 prototype product, the FM engineers used special sprinkler heads with larger orifices rated at 0.6 gpm (24.6 liter/m/m^2). These heads had orifices of 17/32" (13.5 mm) diameter instead of the ½" (12.7 mm) diameter used previously on the 0.3 gpm (12.3 liter/m/m^2) heads. Despite the cross-sectional enlargement of only 13%, these new heads could deliver twice as much water to the fire with the same water pressure (30 psig or 207 KPa).

In the first test a rack storage was set up using a 2 × 2 × 2 high pallet configuration, along with a target row of palletloads across an 8 ft (2.44 m) aisle. Cans began to rupture about 2½ minutes after ignition, but the combination of high-density ceiling sprinkler heads and standard density in-rack sprinklers controlled the fire.

A floor-standing array 3 × 4 × 1 high was then set up and ignited. Although there were fireballs and heavy smoke, the 0.6 gpm (24.6 liter/m/m²) sprinklers controlled the conflagration.

In a final, larger test an array of 24 palletloads (2 × 3 × 4 high) was placed in racks, with a target row of 1 × 2 × high aerosol palletloads directly across an 8 ft (2.44 m) aisle. Fireballs and dense black smoke were produced a little over two minutes after ignition, and about a minute later the fourth (top) tier of the target row caught fire. Despite the intensity of the fire, the high-density ceiling sprinklers and regular 0.3 gpm (12.3 liters/m/m²) in-rack sprinklers controlled the blaze.

The results of the many FM tests are summarized in Table XV. They showed that aerosol products can be stored safely in warehouses, provided sufficient sprinkler water is provided. For water-based items the standard 0.3 gpm (12.3 liter/m/m²) ceiling sprinklers were found sufficient under all storage conditions. For alcohol-based formulas, the standard ceiling sprinkler system was found to control one-high floor storages, and in rack storage, standard in-rack sprinklers must also be used. Finally, for liquid petroleum distillate types, the FM tests indicated a need for high-density, 0.6 gpm (24.6 liter/m/m²) ceiling sprinklers to control one-high floor storages, while for in-rack storage, both these and standard 0.3 gpm (12.3 liter/m/m²) rack sprinklers were needed. There were also concerns about smoke generation and flying, flaming cans in the case of the liquid petroleum distillate formulas. It was thought that the flying cans might ignite satellite fires, possibly putting an intolerable strain upon the overall sprinkling system.

The aerosol industry was made aware of the FM test results at about the beginning of 1980. CSMA immediately assumed a lead role for response, forming an Aerosol Storage Task Force and later a Protocol Development Task Group to design and execute further tests. The industry disagreed with the FM position that their aerosol testing was about 95% complete. Several experts considered that it was more like 35% complete and that more testing was necessary to provide sufficient cost effective alternatives, especially for bulk pallet storage, as opposed to in-rack storage. It would be premature to try to get thousands of warehouses — plants, distribution centers, supermarket storage areas and so forth — to upgrade their fire protection facilities for the storage of flammable aerosols.

Typical questions that circulated throughout the industry at the time can be illustrated as follows:

a. Which of the three FM categories (water-based, alcohol-based or liquid petroleum based) fits my products? For example, antiperspirants, hydroalcoholic products, emulsion types and products

TABLE XV

Summary of FM† Test Results of 1979/80 on Aerosol Prototypes

Class	Aerosol Concentrate	Pallet Array	Stacking: Floor	Stacking: Rack	Sprinkler Size: Ceiling	Sprinkler Size: Rack	Result
Water-based	65% Water	1 × 1 × 1	x		0.3*		Controlled
Water-based	65% Water	2 × 2 × 2		x	0.3	0.3	Controlled
Water-based	65% Water	2 × 2 × 2		x	0.3	—	Controlled
Alcohol-based	65% Isopropanol	1 × 2 × 4		x	0.3	—	Not Controlled
Alcohol-based	65% Isopropanol	1 × 2 × 4		x	0.3	0.3	Controlled
Alcohol-based	65% Isopropanol	2 × 3 × 4		x	0.3	0.3	Controlled
Alcohol-based	65% Isopropanol	3 × 4 × 1	x		0.3		Controlled
Alcohol-based	65% Isopropanol	2 × 2 × 2		x	0.3		Not Controlled
Liq. P.D.-based	65% Toluene	1 × 2 × 4		x	0.3	0.3	Not Controlled
Liq. P.D.-based	65% Toluene	3 × 4 × 1	x		0.3		Not Controlled
Liq. P.D.-based	65% Toluene	1 × 1 × 1	x		0.3		Not Controlled
Liq. P.D.-based	65% Toluene	1 × 2 × 4		x	0.6**	0.3	Controlled
Liq. P.D.-based	65% Toluene	3 × 4 × 1	x		0.6		Controlled
Liq. P.D.-based	65% Toluene	2 × 3 × 4		x	0.6	0.3	Controlled

*0.3 gpm (12.3 liter/m/m²) standard (General Purpose Warehouse) sprinkler heads, with ½" (12.7 mm) orifice and 286°F (141°C) linkage.

**0.6 gpm (24.6 liter/m/m²) high-challenge sprinkler heads, with 17/32" (13.5 mm) orifice and 286°F (141°C) linkage.

†FM = Factory Mutual Research & Engineering Corp.

with very high levels of non-flammable chlorocarbons were impossible to categorize.

b. Are all liquid petroleum based products equivalently dangerous? For example, it was recognized that the 65% toluene prototype caused the activation of 36 0.3 gpm (12.3 liter/m/m^2) sprinkler heads when a single pallet was ignited, but other tests, involving paint products with 70% of a toluene-based concentrate, only opened 4 sprinkler heads of identical design and capacity.

c. Why was so little emphasis given to floor standing palletloads in the FM program (only five tests) and why was no testing done in the case of floor standing aerosols over one pallet (5 ft or 1.52 m) high? For example, possibly 90% of warehoused aerosols are stored on the floor in multi-pallet heights not tested by FM.

d. Could improvements in storage design reduce flammability hazard? For example, the floor standing FM tests were conducted with sprinkler heads about 25 ft (7.62 m) above the stock, which gave the fires a chance to develop more fully before the system was actuated. Tests at Southwestern Research Institute, Texas have indicated an optimum distance of from 3 to 8 ft (0.91 to 2.44 m).

e. Could improvements in package design reduce flammability hazard? For example, the use of flame retardant cases and/or dividers, highly water absorbant cases and/or liners, or specially designed cases to enhance content wettability.

f. If the four insurance carriers associated with FM insist upon cost-intensive retrofitment of warehouses containing flammable aerosols as a condition for continuing HPR coverage, is there any merit in transferring to non-HPR forms of insurance coverage?

Additional testing was necessary in order to answer these and a myriad of other serious questions. About \$250,000 was subsequently raised by the CSMA, in terms of collections and pledges from firms in both the U.S.A. and abroad, to fund a program of further testing. Protocols were developed by the industry and then technically reviewed with FM engineers before each phase of the testing was done at the FM Research Center at West Glocester, RI. At the time of this writing (June 1, 1982) CSMA is beginning to seek further funds to continue the program.

During July, 1981, after a year or so of review and approvals, FM published their "Loss Prevention Data 7-29S" titled "Storage of Aerosol Products". This ten-page document had been developed prior to the initiation of the first CSMA tests (Nov. 24, 1980), and thus took no cognizance of CSMA's test results. Many of the statements surprised the industry, particularly since the conclusions and recommendations were all based upon prototype products quite different than the real ones they were designed to represent. The aerosol industry would have preferred that FM refrain from issuing any datasheet until the results of CSMA's program could be developed and evaluated.

In their datasheet, FM stated that 10 to 80% of the contents of an aerosol is the propellent, such as isobutane and propane. They felt that their testing suggested that the propellent adds little to the overall hazard (at least up to 35%), so that the flammability of the base product is the major consideration. If the product (concentrate) contains more than 80% water it should be classified as a water-based product and treated the same as ordinary combustible goods for warehousing purposes; e.g. Class III commodities.

Alcohol-base products were not otherwise identified. The FM recommendation was that they be stored without restraints anywhere in the warehouse, but floor storage should be limited to one palletload or 5 ft (1.5 m) high. Ceiling sprinklers should be designed to provide 0.30 gpm (12 liters/m/m^2) over 2,500 ft^2 (230 m^2) using 286°F (141°C) heads. Pile sizes should be limited to a total of 25 palletloads and separated by a minimum of 5 ft (1.5 m) from other storage piles. For in-rack storage, in addition to the ceiling system just mentioned, rack sprinklers should be installed every 8 ft (2.44 m) using 165°F (73.9°C) heads. One line for every tier except the top tier. Hose stream demand was suggested as 750 gpm (2.8 m^2/m), if cut-off rooms are not used.

From these recommendations the total water requirement can be calculated. In the case of a floor storage area of 2,500 ft^2 (230 m^2) the maximum ceiling sprinkler demand would be 750 gpm. Adding this to the 750 gpm demand (for three 2.50" (64 mm) fire hoses) the total becomes 1,500 gpm (5.6 m^2/m). this amount of water can usually be supplied by a reliable city water main system. If not, either a water tower or reservoir would be required. The capacity of these water storages would have to be at least 180,000 gallons (672 m^2) — enough to supply the maximum for at least two hours.

It should be emphasized that this "maximum scenario" assumes that every sprinkler in the 2,500 ft^2 (230 m^2) minimum controlled area will be activated. This would amount to 25 sprinklers. To put this in perspective, a fire that is well controlled may actuate 4 sprinklers or less. Those that set off over about 12 sprinklers are regarded as serious.

The FM datasheet then gave recommendations for petroleum-liquid based aerosols, where their concerns were greatest. Because of rocketing cans and potential exposure of other commodities, they recommended that these aerosols be stored in a one hour fire-resistant cut-off area. (A wall with this level of fire resistance can be constructed with a surface of ½" (12.3 mm) thick plaster-board or sheetrock.) Floor storage should be limited to one palletload or 5 ft (1.5 m) high. Ceiling sprinklers should provide a density of 0.60 gpm (24 liters/m/m^2) over 2,500 ft^2 (230 m^2) with 17/32" (14 mm) orifice 286°F (141°C) rated heads. For in-rack storage, in addition to the ceiling sprinkler system, rack sprinklers should be installed every 8 ft (2.44 m) using 165°F (73.9°C) heads rated at 0.30 gpm (12 liters/m/m^2). One sprinkler line should be used for each tier except the top tier. For this overall method of protection, storage heights are limited to 20 ft (6.1 m), but another sprinkler configuration, not listed here, is available for still taller constructions. Finally, if the distance between the top of the storage and ceiling sprinklers exceeds 15 ft (4.57 m) a barrier should be installed over the top tier of storage and in-rack sprinklers provided beneath.

Considering the suggested hose stream demand of 750 gpm (2.8 m^2/m) and the maximum ceiling sprinkler demand over the minimum 2,500 ft^2 (230 m^2) floor storage area, the total water requirment for floor storage can be calculated as 2,250 gpm (8.4 m^2/m). This is beyond the average capacity of many city water main systems. The alternate would be to use either a water tower or reservoir. The capacity of these storage systems would have to be at least 270,000 gallons (1009 m^2), or enough to supply the maximum requirement for at least two hours. With cut-off rooms of less than 6,000 ft^2 (560 m^2), reductions of the fire hose demand are permitted.

In the case of rack storage areas used for petroleum-liquid based aerosols, the total water requirement would be still higher, depending upon the extra demand for the rack sprinkler heads, with the exact amount subject to in-rack storage provided.

If a reservoir is contemplated, a suitable pumping system will have to be provided. The capacity will depend on the type and quantity of aerosols in storage under maximum foreseeable conditions. Some city water systems get down to pressures as low as about 5 psig (34 kPa) at times of peak demand: those below 30 psig (207 kPa) will need pressure upgrading by means of a pumping station. The average water tower will provide the 30 psig (207 kPa) minimum pressure requirement listed in the FM datasheet, assuming the vertical head or distance between the bottom of the tank and the 6 to 8 highest (and most remote) sprinkler heads is sufficient. Considering a modern grid system, where the pressure is essentially flat, a head of 69.2 ft (21.1 m) is then needed.

Literature available for some newer sprinkler heads suggest that density, water pressure and head design are all important for fire control. Pressures in the area of 50 psig (345 kPa) appear to be minimum for some of these sprinklers, giving a combination of small water drops for evaporative cooling near the ceiling (to avoid setting off more heads than really needed), and larger water drops to go into the fire plume and into the seat of the fire to fight it directly. Any need for these higher pressures must be considered against the backdrop of limitations that apply to existing water supply and sprinkler systems.

The industry hoped to achieve a reduction of the stated FM 2,500 ft^2 (230 m^2) minimum control area, based upon the good results of recent tests. (Note: in 1982 the Viking head was informally rated for 1,500 ft^2 (138 m^2) minimum. City water mains will then probably be able to continue to supply the anticipated needs of most warehouses and distribution centers.

Any firms contemplating adjustments to their fire control systems should consider what has been reported here only as a general guide, necessarily incomplete in the interest of brevity and confidentiality, and subject to revisions as the art of aerosol fire-fighting develops further. Competent fire engineers should always be consulted, as well as local fire codes.

Product Reformulation

A great deal of confusion exists as to how to fit existing aerosol formulations into the three categories (water-based, alcohol-based and liquid-petroleum based) in the FM recommendations. It is probable, however, that about one-third of U.S.A. aerosol formulas can be fitted into each class as they apparently were meant to be defined. Many products must be considered borderline. For example, many furniture polishes contain about 20% petroleum distillate in the overall formula, and this would mean that the concentrate portion would have to contain less than 80% water. They would then be classified as petroleum-liquid based products and made subject to the fire control requirements just mentioned, according to the FM datasheet. On the other hand, actual test results have demonstrated that these formulas are no more hazardous than products containing more water, and should be included in the water-based category. Reformulation might be considered as an option, but it is hard to justify the derogation of a fine product in order to force it into an artificial storage category.

On the other hand, many aerosol products can be reformulated with the addition of water, or more water, as a goal. In some cases this may result in a change of category. Paint products can now be prepared with about 35% water, and some of these commercial formulations use dimethyl ether instead of the usual hydrocarbon A-70 blend. (Dimethyl ether has 69% of the BTU value of the hydrocarbons.) In any event, it is very doubtful if paints can ever be formulated with sufficient water to fit into the FM water-based category. Ultimately, it may be practical to have certain formulations specifically tested by FM to determine if they are sufficiently safe to be exempted from their liquid petroleum based class and placed in a less hazardous one.

On a more positive note, such products as anhydrous bug killers, mothproofers and engine cleaners can be reformulated using sufficient water (80% in the concentrate) to be fitted into the FM water-based category. The addition of water to ethanol-based products has been looked at. For example, hair sprays are on the market with up to 9% water and the technology exists to raise this amount to at least 30%, while still maintaining a single-phase liquid. For some formulas, however, there are questions of wetness and (in general) consumer acceptance. In the 1960s hair sprays with 30 to 35% water were marketed, but they were two-phase liquids and never did well. Such brandnamed hair sprays as Cindy and French Touch were discontinued by about 1965. Personal deodorant sprays can be formulated with 5 to 8% of water before phase separation occurs, but they are then perceived as wetter than before, so this approach is generally contraindicated. Disinfectant/deodorant sprays usually contain modest amounts of water, which has been shown to make them more effective against many microorganisms. In no case has it been possible to reformulate a so-called alcohol-base product into a product fitting the FM definition of a water-based formula.

As merely one way of looking at the way flammable hazard increases with flammable content, we can suggest the approach illustrated in Figure 12.

About 70% of all warehouse fires are caused by human error. Some 14% are caused by incendiarism. The arsonist quite often sets two or three separate fires, putting a severe and often intolerable strain on the sprinkler system. Equipment failure, lightning bolts and other random causes account for a minority of warehouse fires.

Static sparking of damaged aerosol cans was the probable cause of a $515,000 loss in California. A spark from the electric motor of a fork lift truck ignited an area containing reject and often leaking butane lighter fuel containers in a warehouse in Stoke-on-Trent, Staffordshire, England. The building contained 2.5 million aerosols, including air fresheners, furniture polish and other items. The loss was about $3.5 million and occured in Feb., 1980. A third fire was caused by stacking paint cans too close to a radiator, so that the exces-

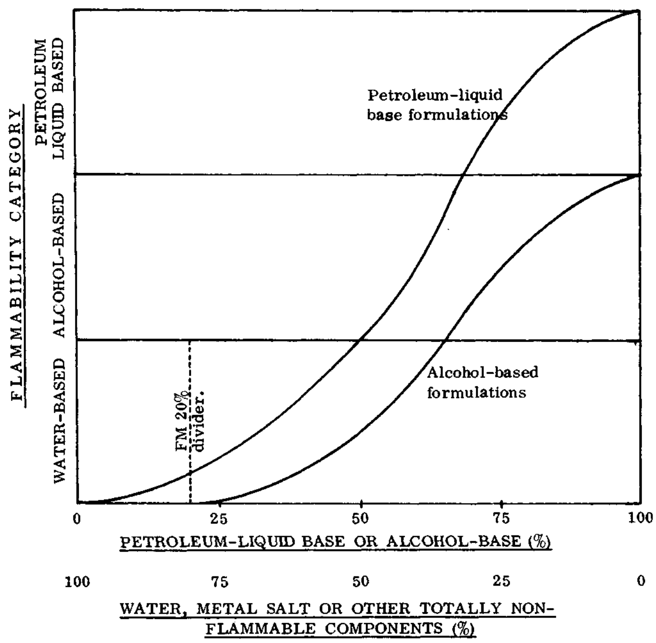


Figure 12. Graph Charting Flammable Storage Hazard
Increase of flammable storage hazard with flammable content of aerosol concentrates (As estimated by the author). Assumptions: that the hydrocarbon propellent, if used, is 35% or less; and that chlorocarbon ingredients are absent.

sive heat ruptured them, after which they ignited. And a fourth was started by flames or sparks from the exhaust of a lift truck, parked near palletloads of hair spray, so that the corrugate ignited. Warehouses associated with manufacturing facilities are probably more susceptible to fire than buildings used solely for storage purposes. In England, two plants burned as a result of the release of hydrocarbon gas in one case and the spillage of a drum of flammable solvent in another. Details on these and other major fires have been published in the *Fire Prevention Journal,* Dec., 1980, in a U.K. Insurance Technical Bureau publication titled "Aerosols — the hazards of manufacture, storage and use in the United Kingdom, (1980)" and in other periodicals.

A key to success in controlling aerosol fires is quick sprinkler response. The initial test series conducted by FM indicated response times of not less than about 2 minutes after ignition, and often shortly following rupture of the first aerosol cans of alcohol-based and liquid petroleum based products. Depending upon the aerosol contents, distance to the sprinklers and similar aspects, 10 minutes may elapse between ignition and sprinkler actuation. Modest reductions in these latency periods may be effected by the use of 160°F (71°C) bismuth-alloy linkage heads, by differently designed heads and so forth.

An improvement in response time may be provided by specific detection units. They can range from highly simplistic smoke or heat sensor units with audible alarm, to a highly sophisticated system of electrically connected combinations of smoke, fixed temperature and rate-of-rise (in temperature) detector units. In the ideal system, these sentinel stations will cause an audible alarm to sound at one or more fire alarm control panels, where quick reference to the specifically illuminated zone of annunciation on the panel will show the plant or warehouse area in trouble. As a guard against malfunction of a particular sensor, many systems require the actuation of two units for a full-alert response mode, often including the automatic operation of an alarm in a nearby fire station. The best heat detectors are the combination rate-of-rise and fixed temperature type. The best smoke detectors are of the solid-state photoelectric type, operating on the light-scattering photodiode principle. These detectors are typically factory set to detect smoke at a nominal 15% light obscuration per foot, regardless of the rate of combustion, the distance between the detector and the fire source, the combustible material, the temperature or velocity of the smoke and whether the fire is in a confined or open area. They are designed also to ignore invisible airborne particles or smoke densities below the factory set point.

Combinations of these detector units are normally ceiling mounted on a 15 x 15 ft (4.57 x 4.57 m) grid. Individual zones comprise anywhere from 3 to 40 detectors and are usually identifiable areas within the plant or warehouse, such as the staging area, or the north warehouse addition. In one example, a 345,000 ft^2 (32,100 m^2) plant required 18 zones. Smoke detectors are generally preferred for areas where storage density is high and people density is low; temperature detection units are usually suggested for the reverse, such as laboratories, maintenance shops and cafeterias. If desired, the automatic actuation of sprinklers can be effected in hazardous areas, using sprinkler supervisory devices. In 1982 the installation of a complete smoke/temperature/rate-of-rise detection system with 120V-AC conduited power, control units and so forth cost about $14,000 for 100,000 ft^2 (27,870 m^2) filled stock warehouse.

Such systems are installed to greatly reduce detection time in case of fire. Detection is often accomplished in less than a minute after a reasonably large-scale ignition. Although automatically calling the local fire department is sometimes the only response, most plants and warehouses place some reliance upon their own people to converge upon the fire and try to either contain it or extinguish it while it is still quite small — and has not yet had time to start rupturing aerosol cans. Many states have regulations concerning the organization, training and other aspects of a fire brigade. If such a formal response activity is contemplated, state and local regulations should be reviewed.

Suppliers of these fire control systems include the Autocall Division of the Federal Signal Corporation (Shelby, OH), the B&A Division of George E. Miller, Inc. (Terre Haute, IN) and other firms. They will assist in designing custom engineered systems to match the individual needs of warehouses and filling plants.

Warehouse Storage of Aerosols - International

Concerns relating to the safe storage of flammable aerosols are not limited to fire prevention organizations in the U.S.A. Conflagrations involving multi-million unit aerosol storages have occurred recently in England, West Germany, Nigeria and South Africa. In fact, the disaster in South Africa, which destroyed the facilities of Alupac (Pty.) Ltd., is reported to be the most serious aerosol plant fire in history, with several deaths and over a hundred persons hospitalized. The firm was South Africa's largest contract filler. The fire took place in Feb., 1982.

For purposes of brevity, the warehouse storage situation in only one other country is reviewed here. In the U.K., there are several overlapping regulations, plus others in progress, that deal with aerosol storage. The general "Petroleum Regulations" define volatile petroleum mixtures as those containing ingredients directly derived from petroleum with a flash point below 73°F (22.8°C). To store more than 3.6 (U.S.A.) gallons (13.6 liters) of such materials requires that the premises carry a petroleum license. CFC aerosols do not pose a problem, but for kerosene-based products that are hydrocarbon propelled this restriction can be very real.

Such products fall under the definition of "Highly Flammable" in the Highly Flammable Liquids and Liquified Petroleum Gases regulations, which control the storage and labeling of aerosols containing more than 500 ml of product, where the contents include over 45% or over 250 g of flammables — substances with a flash point equal or less than 212°F (100°C).

In addition, the Health and Safety Executive (Committee) (HSE), under the Health and Safety at Work Act and the Sixth Amendment of the Substances Directive, is drawing up three sets of regulations covering the storage of hazardous commodities (including aerosols) at all places of work. The first is directed at flammable gas storage. The general proposals have been approved by the Advisory Committee on Dangerous Substances and a draft of the regulations could well be published for public comment during 1982. But, as yet, the contents are not known with any accuracy. There is some likelihood of a modest quantity exemption for aerosols, but not for enough to cover a typical supermarket situation. The second covers flammable liquids. Fortunately, it contains an exemption for most aerosol products. The third is more general, and would appear to divide aerosols into two or three classes of flammability, which would affect how they must be stored in a warehouse. If only good housekeeping principles are required, then there will be few problems; but if segregated storage, fire resistant structures or other restrictions are involved, then the regulations will be extremely serious for business at both the wholesale and retail levels and could badly damage the marketing of aerosols. At this point, it looks like segregated storage and similar sanctions may be proposed.

The European industry has followed the FM activity as closely as possible. Their sprinkler heads and other aspects of the control system are different than the American standards and this has been of some concern. Because of the role of a fork lift truck in the reported initiation of the very large Permaflex warehouse fire, the British Aerosol Manufacturers Association (BAMA) is planning some studies of such factors as the crushing of a single can of highly flammable product in a warehouse under a variety of conditions.

Across the world there seems to be a growing awareness of the flammability of hydrocarbon based and CO_2 based anhydrous aerosol products. What it portends in terms of warehouse requirements is difficult to assess at this time, but it seems logical that improvements in fire control systems and structures will be required, first by several insurance firms and later by various authorities.

Safe Disposal of Aerosol Containers

During the late 1970s, and particularly starting about 1980 both safety and regulatory concerns caused the industry to focus on methods available for the safe disposal of their defective aerosol units. Although there are wide variations from filler to filler, about 0.5% of filled aerosol cans are now considered as non-salvageable rejects. The percentage is higher for drug and cosmetic products because of FDA Current Good Manufacturing Practices (CGMP) and tigher quality assurance requirements; and lower for household products which are less stringently controlled. For example, in past years millions upon millions of aerosols, inadvertantly filled to slightly less than the prescribed net weight range, were simply "short-shotted' with a few grams of additional propellent to bring them up to the specification weight. Many marketers no longer permit this latitude. In fact, certain marketers no longer allow the dispensing of a few grams from aerosol products filled with a net weight slightly over the specified range.

During production, reject cans collect at various points along the filling line: at the hot tank, the gassers, inspection stations near the end of the line, and so forth. Some of these cans will be recognized as leakers, others will be misfills, defective lithos, units with crushed valves and cans with pressure-induced deformations such as buckling. Where a rash of leaking cans is encountered, the potential for serious risk increases. Productions have been made where well over a thousand welded side seam leakers have been detected in the hot tank during one eight-hour shift. The rate of rejection (hour to hour) can vary widely in such instances, and the rate of leakage can vary from cans that produce a gas bubble every ten or twenty seconds to those best described as "gushers". Where rapid leakers are encountered, every effort should be made to remove them promptly to an outside area in order to prevent fires. Ventilation of the filling area (and obviously the gassing area) is also a vital attribute.

Cans discarded after the gasser sometimes include leakers. In many cases, cans with misplaced valves will leak to emptiness in a few seconds. Some gassing rooms also house checkweighers, button tippers and other equipment.

Rejects from these operations are generally non-leakers. Normally they are tossed into the reject barrel along with the gasser rejects. The use of a regular 30 to 55 gallon (110 to 200 liter) steel drum is commonplace, but ideally these receptacles should be pierced near the bottom with a number of 1" to 2" (25 to 51 mm) diameter holes in order to get any escaping hydrocarbon or dimethyl ether vapors out of the drum and into the ventilation system where they can be swept out of the area on a continuous basis. If powder-type or other electrostatically sensitive aerosols are being produced, it is a good idea to ground the drum with alligator clips.

Once these drums of reject cans are taken to the outside for disposal, the question of the best disposal method must be addressed. In the past, such cans were often simply loaded into a parked dumpster and periodically hauled away to the nearest dumping site. For smaller operations, cans were often pierced by hand, using a hammer-like tool having a hardened steel pointed cone. Both of these options are now considered obsolete in today's more highly regulated society. Considerably more expensive methods must be employed.

In the U.S.A. disposal procedures for aerosols must follow the EPA regulations under the Resource Conservation and Recovery Act of 1976 (RCRA), which were issued May 19, 1980. State and possibly local regulations must also be considered. The language of the federal regulations supports a legal opinion that fillers may puncture, crush, incinerate or otherwise "unseal" an aerosol container in a pre-disposal activity without the need to register with the EPA as a treater of hazardous waste.

Aerosols are not listed by the EPA as hazardous wastes. Therefore, they may be considered as such only if they meet the characteristics of hazardous wastes identified in 40 CFR Part 161 (45 *Fed. Reg.* 33084). Four such general characteristics are listed. In addition, if the waste contains any of approximately 400 chemicals regarded as toxic, reactive or otherwise dangerous, then the waste will qualify as hazardous and persons who dispose of such materials must comply with the applicable hazardous waste management and permitting regulations or be subject to EPA enforcement action.

The subject of reactivity of an aerosol dispenser has been studied. While aerosols do rupture if heated under confinement (as do cans of various beverages, packed vegetables and so forth), it has been determined that the apparent intent of Congress and the exact wording of the reactivity definition makes it impractical and unreasonable to interpret the reactivity characteristic to cover aerosol cans and other sealed containers. During late 1980, persons at the EPA concurred informally with this interpretation.

While aerosol cans, in and of themselves, are considered as not subject to regulation as hazardous solid wastes, the contents of such cans must now be addressed. If they exhibit any of the characteristics of hazardous waste or are specifically listed as hazardous wastes, then those contents are subject to regulation. The flammability or explosivity of the contents must be considered, as well as the toxicity and acidity/alkalinity. As a general rule, it is thought that aerosols considered as non-flammable under the Federal Hazardous Substances Act of 1960 (FHSA) are not candidates for hazardous waste under the flammability or explosivity category. Aerosol oven cleaners that contain sodium hydroxide or potassium hydroxide are probably hazardous wastes from an alkalinity and corrosivity standpoint.

If aerosol cans containing materials identified as hazardous waste are punctured or otherwise "unsealed" and the contents collected and subsequently shipped off-site for treatment or disposal, the facility "unsealing" the cans would be a generator of hazardous waste and subject to the requirements of 40 CFR Part 262 (45 *Fed. Reg.* 33140). On the other hand, if, after the cans are "unsealed" the contents are treated or disposed of on-site, the facility "unsealing" the cans would be a "treater" of hazardous waste (the contents) and be subject to the requirements of 40 CFR Parts 264 and 265 (45 *Fed. Reg.* 33154). While these statements are based upon legal opinions current at the time of writing, firms having questions in this area should consult expert counsel for additional advice.

A number of equipment options are available for the disposal of reject aerosol containers. They include can shredding (high and low speed), can piercing, can crushing, catalytic burning, incineration and so forth. A sophisticated can shredder called a Pulvermatic System is available from the Metal Box Engineering Division (Cheshire WA14 1TA, England) in the form of a turnkey operation. Cans are fed into the shredder via a special conveyor belt. The shredded solids then pass into a container below, while the liquid materials go into a companion drum. Any explosive gas is greatly diluted with ambient air using a ventilation system, after which it is discharged to the atmosphere. A second version of the device, which is quite a bit larger, handles 54 gallon (200 liter) drums which can be loaded with aerosol cans, boxes of tablets, or other items. The drums are tipped into the machine and the operation is then as just described. Both versions have been installed and are operating successfully.

Similar devices are offered by the Hoveringham, Ltd. firm also of England. One is now in New Jersey and another in the Chicago area, in addition to devices in use within the U.K. The firm has arranged to pick up filled 54 gallon (200 liter) drums of aerosol waste, remove them to the disposal site, process them and invoice the filler on the basis of the number of drums submitted each time. A disposal unit under development by Kartidg Pak, Inc. (Davenport, IO) is reported to function on similar principles.

At least one major U.S.A. filler/marketer uses a can crushing device, consisting of a heavy stone millwheel rolling against a track. The unit crushes areosol cans easily and the liquid portion of the product is then directed into a holding vessel nearby. Since the tank contents are saturated with hydrocarbon gases and have a boiling point of essentially the ambient temperature, there have been concerns regarding safe disposal. The device stands in a relatively remote outdoor location and should ignition occur in the crusher no damage would result.

Can piercing is a fairly common disposal method. For example in the Cloud Manufacturing Company device, which is quite inexpensive, cans are fed down a metal tube, where they encounter a starwheel with sharp, penetrating points. The gases and liquids are drawn further downward and diluted with air. The ventilating system then emits the gas/air mixture to the atmosphere, while the liquid passes through a coarse screen and into a drum. The perforated cans are deflected by the screen and are collected into a second drum or bin. A can flattening device may be used to eliminate much of the bulkiness of the emptied units, after which they can often be sold as scrap for about $60 per ton ($66 per metric ton).

In some piercing models cans enter a slot and are positioned for piercing. A ground bar swings into position on the row of cans. The piercing mechanism is hollow and contains inlet holes to enable the can contents to be withdrawn while the device is in the can up to the circular seal. The contents pass through the piercer under their own pressure and enter a vacuum exhausting chamber which is also heated to prevent chilling of the liquid, so that the propellent portion can be vaporized more completely and ventilated away. Sometimes nitrogen is introduced into the baffled chamber until the released propellent gases exceed the upper explosive limit (UEL), as monitored by a detection device. As before, the trapped liquids will contain some hydrocarbon gases and be extremely flammable.

Two types of devices seem to be preferred for paints and coatings, which of course can be very messy when the can is breeched. The first is incineration. A heavy-duty furnace is available, where cans may explode from the heat without damaging the equipment. Conveyors are used to bring filled cans to the furnace and to periodically withdraw ruptured cans from the firebox. Depending upon air availability, these furnaces may produce heavy smoke from the combustion of solvents such as toluene and xylenes. Since heavy smoke can pose problems from the standpoint of the Clean Air Act and other regulations at both the federal and state levels, a few firms have considered the addition of catalytic converters to furnance exhaust systems.

Catalytic converters are now used by one or two firms in New Jersey (a state with unusually severe environmental regulations) to convert exhausting hydrocarbon vapors into heat. The heat is then used for energy recovery. This type of system can be used for gas house vents as well as for the stack vents of can shredders, piercers and crushers.

The second system considered for paint type products involves a pressure type crusher to be located in a safety disposal room similar to a gassing room. High forces and velocities are used at the crushing level to fully flatten the dispenser while jetting the contents downward into a collection vessel. This device has been designed by a major paint filler/marketer and may be in operation shortly.

The Can Disposal Committee within the Aerosol Division of CSMA has collected a large amount of specific data on methods for aerosol can disposal. They will be written and published by CSMA as an adjunct to their book titled "Recommendations for the Safe Use of Hydrocarbon Propellents in the Plant and Laboratory".