

**CONTROL OF UNCONFINED VAPOR CLOUDS BY
FIRE DEPARTMENT WATER SPRAY HANDLINES**

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INTRODUCTION

Fire departments are called more and more frequently to deal with incidents involving the release of hazardous materials. It is natural then that the tools and tactics used in fire fighting have come to be applied to hazardous material situations which are not yet involved in fire. One such situation is the release of a hazardous material with the subsequent formation of an unconfined vapor cloud or plume.

Hazardous material responders therefore often consider the use of water, particularly in the form of water spray or "fog" streams produced by handlines, as at least one element of a control strategy. This derives from several factors:

- traditional use of water by fire fighters to extinguish fires
- belief that water sprays may provide ventilation or disperse vapor clouds
- ready availability and relative ease of application of water sprays, and
- effectiveness of water sprays in controlling some of the hazards of these materials

Much research has been carried out on fixed water spray systems and sprinkler systems which has general application to the use of water on hazardous materials.* Additives such as foam, "light water," (TM) and "slick water" are available to enhance the performance of water in controlling vapor cloud formation. Much has recently been learned in both the laboratory and in the field about the uses and limitations of these chemicals. The many issues involved in the selection and safe use of these techniques and additives have been discussed in scattered technical presentations or in recondite learned journals. However, little of this vital information has been directed at those fire officers and haz mat team leaders who must daily cope with hazardous materials incidents.

Therefore, this brief article is written to serve two purposes:

- To gather together a bibliography of some of the major relevant technical articles, and,
- To discuss briefly the findings and issues involved in the use of water on hazardous materials.

This article will probably dissatisfy some at either end of the continuum of fire protection practitioners. For the technically trained, the fire protection engineer, the physical chemist, the researcher in combustion theory, it will offer an overly simplified view of their

real world. For them we direct their attention to excellent reviews by Pikaar, Strehlow, or Guggan or research reports by McQuaid, Van Doorn and a host of others. To the fire fighters who believe that structural fire fighting tactics are adequate for any haz mat situation, a series of quotations from fire service leaders in haz mat are offered.

In order to handle a hazardous materials incident a set of special skills is necessary. These skills are over and above that which is taught to fire fighters in structural fire fighting classes. As a result, those without the necessary knowledge and expertise have problems in deciding how to handle these incidents. Mistakes are made, which cause injury to emergency response personnel or the general public, additional property damage occurs, and there can be significant environmental damage.

Warren Isman (1983)

The few communities that do have contingency plans specifically addressing hazardous substances accidents have usually been influenced by the presence of a substantial risk (a large chemical manufacturing complex) or a past event. But for the most part, plans found in the field today are not realistically applicable to chemical events. This is not to say that the emergency forces found locally are inappropriate; the function of the firefighter, the sheriff, and the civil defense official is an absolutely vital part of the cleanup and mitigation effort. It is the application of these functions that can be at times a problem.

Let us use the firefighter as an example. No group in this country is better trained and equipped to fight fires, but that is part of the problem. Training and planning mostly concern how to apply water to a fire, rearrange debris, isolate hot spots, remove and tend to injured, and protect personnel from smoke and fire. There are, however, a growing number of fires and potential explosions that need no application of water — where water, in fact, may well contribute to a major disaster. This involvement with chemicals is a whole new ball game.

Al Smith (1981)

Emergency response to hazardous materials incidents is unlike traditional firefighting in that response personnel must identify the specific chemical haz-

*See Exclusions cited on page 2.

ards facing them before approaching an accident or attempting a rescue mission.

Charles Wright, [In]
Office of Technology,
Assessment (1986)

An inappropriate response to an accident involving unfamiliar chemical products can endanger individuals, the surrounding community, and the environment. Local fire or police department personnel are usually the first to respond to a hazardous materials accident during transportation, and even in a plant, hence their training is of primary importance. Of the approximately 2 million people in the emergency response network, OTA estimates that a maximum of 25 percent have received adequate training to meet a hazardous materials emergency.

Office of Technology
Assessment (1986)

The Fire Services must learn to accept the fact that the training received and reinforced in fighting structural fires is, in most cases, *totally inadequate* to handle hazardous materials incidents safely. In many tragic instances, it has been dead wrong, [emphasis in original].

Frank Fire (1986)

The complexity of the subject chosen, control of hazardous materials by water, indicates that some subdivision of the data is required.

We have chosen four categories for discussion:

- Preventing vapor cloud formation
- Reducing vapor clouds
- Controlling vapor clouds
- Preventing or controlling vapor cloud ignition.

Although several topics could be discussed under more than one category, we have placed them in particular categories for ease of discussion, not to imply that other uses may not exist.

The reader is cautioned to carefully consider the entire document and urged to consult the references as available. In order to reduce the size of the article, we have usually stated a major point only once; therefore, skipping portions or using portions out of context may mislead the reader.

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EXCLUSIONS

• Fixed Systems—Sprinkler or Water Spray

Fixed systems used in control of hazardous materials in which water is the extinguishant, suppressant or other active agent are not covered by the discussion of this paper.

The National Fire Protection Association (NFPA) has developed a series of standards which may be studied for the particular limitations of each type of fixed system.

Sprinkler systems (NFPA 13), water spray fixed systems (NFPA 15) and explosion prevention systems (NFPA 69) possess many of the attributes of handlines but the need for brevity precludes their discussion.

Many of the studies cited however, are based on such systems since much information is available for fixed installations but not usually for handlines.

• Explosion Suppression Systems

Specialized explosion suppression systems engineered in accordance with the precepts of NFPA 69 can be effective in controlling and extinguishing incipient and developed explosions. Similarly, fixed tub systems have demonstrated adequate performance in test and field use for control of underground coal, methane or coal-methane explosions.

For information on these systems, the reader is directed to a few selected articles in the bibliography.

• Fire Fighting

While many of the principles outlined in this paper may apply to fire fighting (extinguishment) no attempt has been made to research or discuss this area. Readers may want to consult articles by Rasbash et al. (1954) (1960), by Haessler (1974) (1986), or by Drysdale (1986).

VAPOR CLOUD PRODUCTION

Fire fighters have traditionally not been concerned with the dispersion of products of combustion, "smoke," released into the atmosphere by free burning fires. Yet when hazardous materials are involved in a fire or a non-fire incident, airborne dispersion as "smoke," unburned vapor clouds or plumes, may pose the major threat to public safety — even more than the threat generated by the fire or release incident.

In many fire incidents, the "smoke" plume is buoyed upward on the hot thermal column to disperse in the atmosphere. In many non-fire incidents no such convenient buoyant mechanism is available and the plume or cloud follows

along the ground where it may contact a source of ignition (if it is flammable) giving rise to an unconfined vapor cloud explosion (Flixborough, 1974, 28 dead) or expose concentrations of people to toxic hazards (Bhopal, 1984, 2000 + dead).

Even some substances whose vapor densities are less than that of air, may, in some releases, form non-buoyant or "dense" vapor clouds.

Ammonia (vapor density of gas about 17/29 (0.59) that of air) may form dense vapor clouds depending upon how it is stored and the mode of container failure. Similarly methane stored as LNG or hydrogen fluoride or oxygen stored as liquid oxygen may not be as easily dispersed as simple chemistry may predict.

Therefore prevention or control of non-buoyant or dense vapor clouds is of prime importance in haz mat incidents.

I. CONTROLLING VAPOR CLOUD FORMATION

The first line of defense against exposure to vapor clouds is to prevent their formation. Useful tools and techniques are commonly available for controlling release of a hazardous material and for minimizing vaporization. Among the former are the plugs, valves, patches, clays, and tapes familiar to all haz mat responders. They are not discussed here but should always be used if feasible to keep the hazardous material contained.

Minimizing vaporization after a substance is released, or controlling the rate of release are usually accomplished with the traditional tools of the firefighter — water and sometimes water additives. These should be supplemented as appropriate by diking, damming (amount of vapor evolved is proportional to exposed area), neutralization, or other recognized techniques.

In each of the following uses of water spray, the importance of technical information about the specific hazardous material released is apparent.

CAUTION

**SOME HAZARDOUS MATERIALS REACT
SO DANGEROUSLY TO WATER THAT
NONE OF THESE PROCEDURES ARE
ALWAYS SAFE.**

Cooling

Cooling a pool of spilled hazardous material by water ice has been investigated by Greer, et

al. (1981, 1979) who found no significant cooling effect. Direct cooling of containers by water spray is an effective means of reducing the temperature of the contents and therefore retarding vaporization only when the relationships of exposed surface area of the container, the container volume, cooling water temperature and volume, vapor pressure of the material and specific and latent heats of evaporation are favorable. For example, spraying a nonexposed leaking propane tank car would probably not significantly reduce the leakage. The vapor pressure of propane at 100°F is about 185 psia, reducing the temperature to 75°F will still leave a vapor pressure of 130 psia. (The boiling point of propane is -44°F.)

Water reactivity of the material may also limit the use of cooling. Under the conditions described above, for instance, the vapor pressure of chlorine could be reduced from 152 psia to 107 psia by applying water spray. However, the resultant acid formation and corrosion of tank or fittings may *increase* the size of the leak and increase leakage. This, of course, does *not* mean that we should not directly cool containers exposed to a fire or radiant heating. Cool containers that are significantly above normal temperatures (fire exposures) or when you have specific knowledge that cooling will be effective.

Heating

Water spray is discharged at the approximate temperature of the water supply. While we normally consider water as a cooling agent for fires whose kindling or ignition temperatures are in the hundreds of degrees F and whose flame temperatures may be in the thousands of degrees F, 70°F may be quite warm in comparison to the temperatures that pools of some hazardous materials such as the cryogenics might reach. For example, liquid oxygen is stored at temperatures below minus 300°F or some 370°F colder than our 70°F water. If discharged on the ground by a leak, the liquid oxygen can only obtain heat to boil or evaporate from its surrounding air or the ground upon which it lies. Moisture in the surrounding ground is rapidly frozen partially insulating the pool of liquid oxygen and retarding its evaporation. Application of water spray can provide sufficient heat to increase the boiling of the liquid oxygen and create dense clouds of oxygen and frozen water spray. Tactical considerations will dictate whether or not this rapid vaporization is desirable.

Some non-cryogenic liquefied gases such as the low vapor pressure butane and chlorine may pool as will anhydrous ammonia which requires a comparatively high heat to vaporize (high latent heat of vaporization — 590 BTU/lb at its boiling point of 28°F.). Even propane with its

high vapor pressure and low latent heat of vaporization may pool in winter weather.

'The hydration of ammonia with water is exothermic. The contact of liquid ammonia with water will increase the evaporation rate as a result, whereas the natural evaporation of ammonia is endothermic, causing the remaining liquid to cool and spontaneously reduce the rate of evaporation further. First contact emergency response personnel, typically a local fire department, use water liberally to wash spilled materials away from the point of leakage. As with LPG, this can be hazardous. Emergency response personnel should attempt to avoid contact between water and liquid ammonia pools with the objective of reducing vapor generation rates.'

Destese and Rhoads (1982)

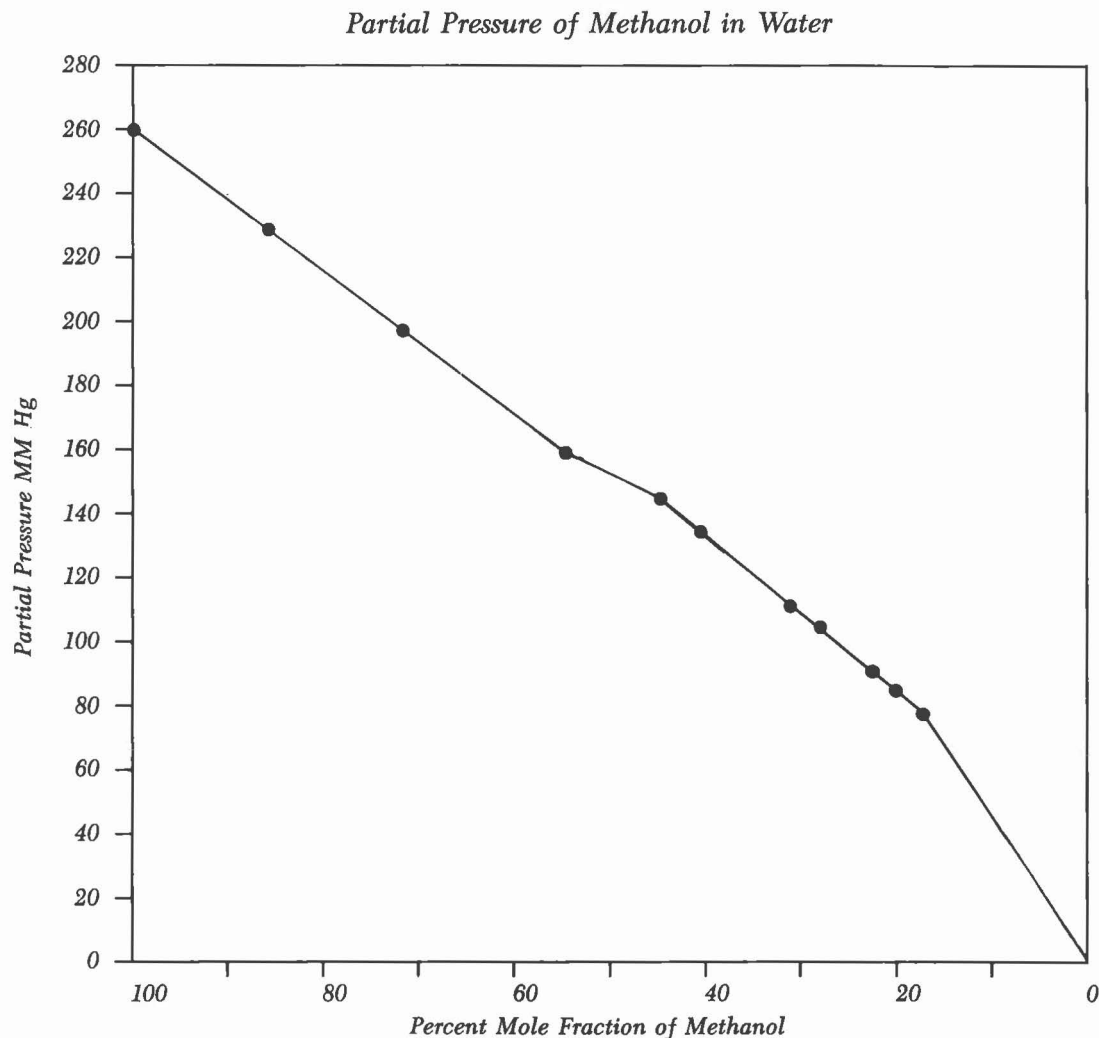
Decisions to heat a pool of hazardous material must be based on a realistic appraisal of the ability to safely control the resultant vapor cloud.

Dilution

Water miscible solvents such as acetone, methanol or ethanol can be diluted by application of water to form non-flammable mixtures. Large quantities of water are required in relationship to the size of the spill or tank since dilution to ratios of 4 to 5:1 (water to alcohol) may be required to prevent ignition.

As the concentration of water increases, the partial pressure of the solvent and hence its ability to vaporize decreases. Eventually not enough vapor can be evolved to burn and the fire goes out or cannot be ignited.

This is illustrated in the following graph which shows the vapor pressure (or the ability



to vaporize) decreasing as the concentration of methanol decreases with the addition of water.

Reducing vapor pressure by dilution will not decrease vaporization in every case. If the water adds significantly to the temperature of the material, vaporization may increase.

Knowledge of the thermodynamic properties of both water and the hazardous material are required to use dilution safely for other than simple solvents such as methanol (Thorne, 1977/78).

Covering

Not all hazardous liquids are lighter than water. Carbon disulfide for instance, has a density or specific gravity of 1.26 (about 25 percent heavier than water) and is insoluble in water. Vaporization of carbon disulfide has been controlled by gently applying a layer of water to float on the surface of the tank or spill. (Cases 309 and 558 in MCA, 'Case Histories of Accidents in the Chemical Industry.')

Low velocity water spray from an applicator may be required to minimize mixing.

Emulsification

Water discharged on the surface of some viscous liquid materials may form an emulsion which can froth into a foam-like blanket. This may serve to seal the surface of the hazardous material and retard evaporation. This method of vaporization control is seldom used and then usually only in a fixed system with specially designed coarse water spray nozzles. Caution must be exercised since in liquids of appreciable depth, frothing may cause the material to overflow the container, spreading contamination.

Attempts to use handlines, especially with straight streams or narrow spray patterns may cause violent frothing and slop-over if the temperature of the liquid is above the boiling point of water (212°F) and the material is sufficiently viscous. (API, 1980)

Special emulsifying agents may be applied by handlines using mechanical foam equipment. The effectiveness of this technique has not been adequately demonstrated.

Phase Separation

Gasohol, a mixture of gasoline and one of the light alcohols (usually ethanol) has the foam-destroying properties associated with the alcohols or other polar solvents.

Applications of non-alcohol resistant foams on gasohol will not form stable foam blankets and therefore it is difficult to retard vaporization. Alcohols which are equally miscible in both water and gasoline are subject to

phase separation if the water tolerance of the fuel is exceeded. (Phase separation means that the gasoline will separate from the alcohol and float to the top of the container and the alcohol and water will sink to the bottom.) The concentration of water required to exceed the water tolerance is about 2 percent by volume for common gasohol mixtures. DiMaio (1980 (a), 1980 (b)) has proposed the application of water to a gasohol tank or spill to separate and isolate the alcohol leaving the upper (exposed) gasoline layer suitable for the application of non-alcohol foams. While this has not been tested to our knowledge, Noll (1986) advises, '...the use of the phase separation technique is not recognized as a viable tactic when dealing with large quantities of alcohol containing fuels.'

Plant operating personnel may be aware of the water tolerance of other separable materials and could advise trying a phase separation.

Water Additives

The properties of water which make it an attractive agent for control may sometimes be enhanced by the use of water additives.

The most commonly used water additives are the various "foam" liquids which are designed to lower the specific gravity of water, to lower its surface tension, or to change other physical properties.

The first may be done through traditional mechanical foams, either at high or low expansion ratios, the second through use of newer aqueous film forming foams which may be applied with or without mechanical expansion, and the third by addition of other special chemical additives.

Other additive functions may include:

1. "Wet" water to decrease surface tension;
2. "Slick" water to modify flow characteristics;
3. "Thickened" water to increase viscosity;
4. "Dry" water to form a powder covering on the liquid surface; and
5. Emulsifiers or dispersants.

None of these other additives have found widespread use in controlling vaporization of hazardous materials.

The literature of foam application to hazardous materials is quite large and inappropriate to discuss in this paper. However, mention should be made of work by DiMaio et. al. (1984) and by Cousin and Briggs (1986) which indicate the low effectiveness of nonaspirated (unfoamed) AFFF and the possibility that it may enhance ignition of a flammable liquid.

We have included some selected references in the bibliography.

II. REDUCING VAPOR CLOUDS

Direct attack on a vapor cloud using waterspray may remove vapor from the atmosphere by combining the hazardous material with the water.

One available mechanism is through solution of the hazardous material in the water. A second is physically binding the material to the water particle which then rains out. Chemical reactions may also take place which change the hazardous material. In some instances, these water reactions may result in a less harmful or easier to handle substance. In other instances, a more severe problem could be created.

The only widespread use of vapor reduction by fire departments has been in controlling anhydrous ammonia releases through sorption. Other uses are not common.

Sorption

Some gases dissolve readily in water and from relatively harmless compounds. Ammonia, for example, is soluble in water to about 43 percent by weight (Braker and Mossman, 1971) allowing ammonia vapors to be easily dissolved by water spray. This results in the formation of a solution of ammonium hydroxide.

Greiner (1984) has demonstrated the effectiveness of this technique in more than 300 demonstrations throughout North America. Studies by Eggleston, Herrera and Pish (1975) with vinyl chloride (solubility 0.11 percent by weight), and with ethylene (solubility 0.01 percent by weight) indicated that sorption of these gases by water spray was insignificant. Chlorine is more soluble in water than either vinyl chloride or ethylene (7.3 percent by weight), but the production of hypochlorous and hydrochloric acid solutions which are highly corrosive limits the usefulness of waterspray (Kelly 1977).

Where both high solubility in water and relatively harmless reactions and reaction products will occur, waterspray sorption may be tried. However, Whiting and Shaffer (1978) feel that air entrainment which "dilutes" the water may be a limiting factor in widespread use of sorption.

Scrubbing

Reduction or removal of aerosols (dusts and mists) may sometime be accomplished by scrubbing the plume with water spray. This technique has been shown to be effective for

the removal of coal dust (Tomb, et al. — 1972 Nagy, et al. 1974) and for industrial dust control (McCoy et al. 1983, Jayaraman et al. 1981).

Effectiveness of water-spray protection for mists of heat transfer agent (HTA) was established by Vincent, et al. (1976 (a)). They pointed out 3 cautions in the design of such systems:

1. "Vapor-air or gas mixtures such as methane, ethylene, ether, etc. are not scrubbed by water fog; and this system should not be depended upon to protect against these hazards,"
2. "Water fog is believed to be generally applicable to mist and dust type explosions..." but they only tested against one HTA; and,
3. "The space immediately surrounding a large HTA vapor leak will have vapors and mist in combustible concentrations even with water fog nozzles operating. An ignition source very near a large leak can start a fire which the water fog will not extinguish."

Scrubbing with handlines has not been adequately investigated for its use to be recommended.

III. CONTROLLING VAPOR CLOUDS

Vapor clouds may drift with the winds following local terrain and structures, or they may initially be propelled with some force such as occurs when a compressed gas is released from its container. In either case, vapor clouds are subject to control or dissipation by the impact of water sprays or of air entrained by water sprays. In a given situation, it may be difficult to determine which factor of air entrainment, mixing, dilution or a combination of these factors are operating.

As will be noted later, uses of water spray for maximum air entrainment tend to minimize the effect of water spray impact and vice versa.

The factor of selection seems to be based on the driving force behind the vapor cloud. If strong, such as a compressed gas release, then impact of water spray (the barrier effect) may be more effective. For a drifting cloud, ventilation or dilution may be the method of choice depending upon cloud size. Ventilation or dilution of massive clouds is impractical due to quantities of water required.

Ventilation

Water sprays may contain large quantities of air which can be used for dilution or redirection of vapor clouds. Eggleston, et al. (1976) point out the high degree of variability of air flow produced by water spray and the

fact that air velocities developed are quite low. They recorded flows from downward directed nozzles of 87-226 cfm/gpm depending upon nozzle type and height above the ground. Other studies cited in Eggleston, et al. (1976) which were evaluated by Factory Mutual found entrainment at rates as high as 1,080 cfm/gpm in tiered water-spray systems. Teele (1981) gives values of 6,500 cfm for a 1½-inch spray nozzle and 8,700 cfm for a 2½-inch. Using average flows of 100 gpm and 250 gpm, respectively this gives an entrainment rate of 35-65 cfm/gpm. Haessler (1986) writing in the 16th Edition of the Fire Protection Handbook gives a value of about 30 cfm/gpm for handlines while Rosenham (1986) in the same volume, gives a value nearly 6 times higher or 170 cfm/gpm. Neither article cites a source.

Fitzgerald (1958) using a 2½-inch fog nozzle achieved flows of 50,000 to 96,000 cfm in a tunnel (ducted flow) at nozzle pressures of 100 psi and 70,000 to 131,000 cfm at nozzle pressure of 150 psi. Nozzle type or waterflow were not given but based on common water-spray nozzles, we could estimate entrainment rates at 100 psi of 200 to 384 cfm/gpm (ducted). Note the increase in entrainment with increased nozzle pressures.

Whiting and Shaffer (1978) using a 250 gpm nozzle and a 750 gpm deluge set estimated entrainment rates of 338 cfm/gpm. They estimated that the experimental oil smoke was diluted by a factor of greater than 10. They pointed out that, 'large spills of very toxic and highly volatile chemicals would be difficult to dilute below the toxicity limit, however, the flammability limits are about three to four orders of magnitude higher which indicates that even large spills of flammable chemicals would be ameliorated using this system.'

Heskestad, et al. (1976) found that for a given nozzle size, spray angle and distance from the nozzle, entrainment flows tended to be proportional to the water flows. Spray angle was found to be critical with a 90 degree pattern entraining 5 times as much air for a given water flow than did a nearly 30 degree pattern. Of course, using a wide pattern reduces the effective horizontal reach of a 1½-inch handline about 30 percent (from about 54 feet to 38 feet) thereby requiring a much closer approach to a vapor cloud.

Therefore, we could expect the most effective ventilation (air entrainment) from a high flow, high pressure, wide angled pattern. Safety considerations of maneuverability and reach limit these parameters to common handline values (for 1½-inch 100 to 150 gpm at 100 psig at <90°). Assuming an entrainment rate of 50 cfm/gpm then a "standard" 1½ hand-

line could be expected to entrain about 5,000 cfm.

In comparison with usual fire department smoke ejectors, a 1½-inch handline approximates the air flow of a 16 inch diameter ejector and a 2½-inch approximates a 20 to 24 inch diameter ejector. (Super Vacuum Manufacturing Co., undated)

To relate this entrainment to a cloud of vapor, assume a hemispherical cloud 100 feet in diameter. It has a volume of 260,000 cubic feet. To reduce this vapor cloud to a concentration of one percent will require 26,000,000 cubic feet of air. Moving 5,000 cfm it will take nearly 87 hours for this dilution assuming perfect mixing, no cloud drift, or dispersion.

Watts (1976) using a downward pointing nozzle that entrained 24,000 cfm of air found that a vapor cloud of 50 percent ethylene fed by a 600 cfm ethylene source could be reduced to the lower flammable limit (LFL) (3.1 percent by volume in air) in less than 11 seconds.

Beresford (1981) describes the use of a combination of two 200-500 gpm flat fan sprays and two 300-1500 gpm (1000-3500 gpm, total) wide angle monitors to raise and disperse gas leakages from pipelines and storage containers. "Two monitors set to operate on a wide-angled spray are placed approximately 30 feet apart and arranged so that the water will discharge in the form of an inverted vee 40 to 50 feet above ground level. The water spray feathers at this point and the resultant droplets fall to the ground like heavy rain. Two flat-fan sprays are set up at right angles to the monitors and they discharge a fan shaped vertical curtain of water some 40 feet wide and 40 feet high. The overall effect is to surround the leaking gas with an upward moving screen of water to create the desired chimney effect. To ensure that the gas is not passing through the sides of the chimney, one or more gas testers patrol the periphery testing continuously. If a breakthrough of gas is detected, an extra flat fan spray is quickly placed in position to seal off the gap. If correctly set upon initially, there has been no necessity to augment the initial layout.

The reason for this combination of spray methods is that the flat fan sprays have been found to effectively stop the lateral spread of gas and the monitors to provide the massive air movement essential for dilution and dispersion."

Included in this study are the following case histories and his evaluation of the method.

"• Propylene discharging from a 2-inch diameter drain line at 400-psig and at atmospheric temperature at a rate of approximately 100-tons per hour which could not be isolated for several hours.

- Methane at 60-PSIG and at atmospheric pressure leaked at a rate of 50-tons per hour for thirty minutes from a fracture at a bend in a 6-inch diameter pipeline.
- Ethylene gas at 500-PSIG leaked from the flanged joint of a 14-inch diameter pipe for some fifty minutes, impinging on steelwork at high velocity.
- Ethylene gas leaking from pipelines and spheres at varying temperatures and pressures has been successfully contained and safely dispersed on a number of occasions.
- The vapors from leakages of Ethylene Oxide, LPG, Gasoline, Naphtha, Benzene and Hydrocarbon Solvents have also been safely contained using the methods described.

Such methods are not capable of dealing with catastrophic failure of equipment, the result of which should be carefully considered at the design stage and steps taken for secondary containment where considered necessary. However, these procedures are suitable for serious gas leaks which could escalate into a major incident if not quickly controlled.

The drawback of this method of containment is the time taken to set up the equipment currently available. Study of gas leakage incidents where explosions have taken place has shown that ignition of the gas/air mixture has often taken place in between three and five minutes of the leak commencing. This leaves little time for equipment to be set up so automatic detection and protection would appear to be the only feasible solution to this kind of problem."

Barrier

One traditional use of water spray which seems to be well supported by research is forming a water curtain or barrier to *vapor*, (not *flame*), travel with multiple handlines. This is illustrated in Figure 3-4.8(a) of the NFPA "Manual on Aircraft Rescue and Fire Fighting Techniques for Fire Departments Using Structural Fire Apparatus and Equipment" (NFPA-1975). Air entrainment by water sprays depends upon transfer of momentum from the water drops to molecules of air thus causing the air to move (Smith and Van Doorn 1981). Similarly, momentum transfer to vapor or gas molecules or to aerosols also occurs causing this movement. Advantage can be taken of this imparted momentum to control the travel of a vapor cloud or to redirect it away from sources of ignition or other areas of danger. Smith and van Doorn, (1981) report that the effectiveness of a water spray in inducing velocity to air (or vapor) is droplet size dependent:

"Momentum transfer between the rain of droplets and the ambient air induces

large scale movement: fine droplets lose their momentum rapidly and so tend to move large volumes relatively slowly. Coarse droplets penetrate much further and although entraining less air, the induced velocities are generally higher."

Momentum of the water spray varies with the spray pattern. We see this in the increase in nozzle reaction as the spray cone is narrowed into a straight stream from a wide pattern spray. Likewise, we know that a straight stream or narrow spray pattern has better reach against the wind than does a wide pattern spray (it is better able to overcome the momentum of the air; i.e., wind). Increased nozzle pressure also increases the momentum available to transfer to the vapor of air.

Escaping hazardous materials may have a high momentum caused by tank pressures, temperature, static pressure, wind or a combination of any or all of these factors. If we want to oppose the vapor travel, we must supply momentum in another direction which will stop or redirect this flow.

As a general rule, control of materials escaping under pressure will require higher nozzle pressure, narrower spray patterns and coarser spray droplets than would be required for control of a vapor cloud.

Numerous other studies of ventilation and barrier production are contained in the bibliography.

IV. PREVENTING OR CONTROLLING VAPOR CLOUD IGNITION

Much research has been conducted on the effects of water spray on the energy required to initiate a fire in a flammable vapor cloud, the effectiveness of water as an inerting material for flammable vapor clouds, the quenching of a flame by water spray, and the attenuation of infrared radiation by water curtains.

Each of these issues will be discussed in turn but a few cautions should be observed in any use of water spray on an unignited flammable atmosphere.

- "WATER IS CAPABLE, UNDER SOME CIRCUMSTANCES, OF PROMOTING EXPLOSIONS OF HYDROCARBON-AIR MIXTURES RATHER THAN INHIBITING THEM" (Mullins and Penner 1959).
- "WATER SPRAYS MAY INCREASE THE RATE OF FLAME TRAVEL" (Eggleston, Herrera, and Pish 1975).

The practical consequences of these two factors is still in debate. However, Pikaar (1985) cautions:

"WHATEVER THE TRUE CONCLUSION, CAUTION REQUIRES THAT WHERE SUCH MEASURES [WATER SPRAYS] TO PROMOTE FLAMMABLE CLOUD DISPERSION ARE APPLIED, THE SYSTEM SHOULD BE ABLE TO DILUTE THE RELEASE TO BELOW THE LFL [LOWER FLAMMABLE LIMIT]."

Ignition Suppression

Eggleston (Eggleston, Herrera, and Pish 1975) in an investigation of the use of water spray found that ignition of a flammable mixture was possible even when an unusually high water rate of 1.8 gpm/foot² was used. (Design density of sprinkler systems range from less than 0.1 to 0.6 gpm/foot², (Bryan 1976). Those of water spray systems for prevention of flammable gas cloud formation range upwards from 0.6 gpm/foot² (NFPA, 1985). The 1.8 gpm foot² is equivalent of the discharge of a 100 gpm 1½-inch 60° pattern handline about 7½-feet from a fire.)

They concluded, that, "Any ignition source which could exist within a typical [water] spray would also serve to ignite a flammable vapor mixture. The protection afforded by the water spray would serve only to make the existence of an ignition source less probable." (Eggleston, Herrera, and Pish 1975)

Rothchild and Guzdar (1976) studied the use of passive systems for ignition prevention and suppression at cutter heads in mining equipment. They found that water spray systems could reduce the frequency or probability of ignitions through two mechanisms:

- Directly, acting as a coolant
- Indirectly, as an aid to ventilation

Agbede, et al. (1982) were able to effectively control ignitions by applying water sprays to the back side of mining cutters to cool the hot rock pathway. They found that spray orientation, water pressure, flow, and spray nozzle pattern and characteristics were important.

Tests by Watts (1976) using the explosive PETN as a source of ignition of ethylene-air or hydrogen-air mixtures found that the amount of PETN required to detonate these mixtures was increased some 3 or 4 times when water spray was applied. The water spray did not stop a detonation or deflagration after ignition, it only raised the energy required for ignition.

Water spray is able to reduce the probability of ignition of a flammable vapor cloud but seemingly only if it can quickly cool the ignition source. As pointed out by Eggleston, et al. (1975) if the ignition source could survive the water spray then ignition of the vapor cloud was possible.

CAUTION: IF OPEN FLAMING OR SPARKING OF THE IGNITION SOURCE CONTINUES DURING APPLICATION OF WATER SPRAY, IGNITION OF A FLAMMABLE ATMOSPHERE SHOULD BE ANTICIPATED.

Inerting

Water as an inert diluent has been used for many years in steam smothering systems in process plants and aboard ship. (One may remember the attempt at Texas City to smother with steam the ammonium nitrate fire in the ship's hold) (Greiner 1972).

Rothchild and Guzdar (1976) found in the mining study, that, "... some atmospheres, such as methane and air that would otherwise be explosive can be made inert by the addition of water."

Based on theory, 18 percent of water (liquid) by weight is required to inert a methane-air atmosphere. 'Fine fogs with water droplet size around 1 micron [1/25,000 inch] can inert the atmosphere as predicted, but the combination of fine drops and high water content is difficult to achieve in practice,' (Rothchild and Guzdar 1976).

Spray systems may produce an average droplet size of around 100 microns which is far too large. Therefore even at 18 percent concentration, spray systems are completely ineffective at inerting the atmosphere. Hodnett (1981) states that the optimum size of droplets in a spray for fire fighting is in the range of 300 to 1,000 microns. (The NBFU (1955) gives a figure of 350 microns.)

Note that these droplet sizes are 300-350 to 1,000 times the size effective for inerting at the 18 percent concentration. If water vapor is used instead of fine spray, the concentration required jumps to approximately 26 to 27 percent water by weight to inert a methane-air atmosphere. Liquid water is more effective than water vapor as a coolant because of the high latent heat of water (970 BTU/lb.) compared to its specific heat (1 BTU/lb.). Even with fine mists, the total moisture content that can be produced is generally less than 3 percent by weight or only ⅓ that required.

The problem in developing water spray inerting nozzles may be the air entrainment. Rothchild and Guzdar (1976) found that fine sprays tend to educt a large quantity of air "... thus diluting the moisture concentration with air. This dilution effect is particularly severe when large quantities of fine sprays are used to achieve high moisture concentration limiting the maximum concentration achievable to a low value." As we noted previously, fine sprays entrain more air than coarse sprays. Therefore, if inerting spray nozzles are designed

for handline use, they may have to be of a radical design which minimizes air entrainment. Inerting with current handline nozzles is impractical.

Quenching

Quenching, as used in this context, is analogous to the prevention of flame travel or propagation by fine mesh or narrow spaces, the principle behind flame arrestors and electrical equipment for hazardous locations.

In general, water sprays outside the laboratory have not been successful in quenching flame propagation through a flammable vapor cloud. Watts (1975) and Eggleston et al. (1975) have experimented with large scale confined vapor clouds. They both concluded that the water spray curtain would not act as a flame arrestor. In fact, Eggleston et al. (1975) and others have reported that flame propagation as measured by flame speed and luminosity were enhanced by the water spray.

Studies at the U. S. Bureau of Mines by Liebman, et al. (1978) and by Sapko, et al. (1977), and as reported by Stafford (1981) (see also Smith and Van Doorn (1981)) indicate that practical quenching systems for mining equipment seemed feasible but that they required more water than for inerting systems. It should be noted that the volume to be protected by these systems was quite limited, about 0.45m³, and flows of 9 gpm were required with a 56 micron SWM (surface weight mean) droplet. Sapko, et al. (1977) also felt that this water requirement could be reduced if the droplet diameter were also reduced. Water volume requirements were increased if particle size were increased. Raising the droplet to 100 microns (SWM) diameter almost doubled the water requirement. Guban (1979) has calculated that a water spray system to protect an area of some 200 m square would require flows of about 1,125,000 gpm even with very fine droplet size. With the droplet size found useful for fire fighting handlines (350 to 1,000 microns), the water requirements are extremely large.

Therefore, quenching with currently available handline nozzles is not practical even on a very modest scale.

Infrared Radiation Attenuation

Water curtain protection of exposures has been used for many years in an attempt to prevent ignition through radiant heating.

Little research has been conducted on the effectiveness of such systems, but one paper by Heselden and Hinkley (1965) found transmission of radiation from a standard radiant panel ranged from 8 to 95 percent. Factors of importance in their calculations were droplet size,

spray density, and the length of travel through the water spray. Using flows of 3 gal/ft/min they felt that at least a 50 percent attenuation could be achieved at pressures within normal for handlines with nozzles giving coarse droplet size spray comparable to sprinklers. Higher pressures gave finer-sized spray and greater attenuation.

Reischl (1979) conducted experiments using a liquid propane burner and a steel reflector and applied water spray streams from two commercially available 1½-inch nozzles and one booster nozzle. The streams were directed toward the burner/reflector to simulate normal protective shielding by handlines.

Pattern and flow were the major determinants of attenuation. The booster line flowing 25 gpm provided far less protection at any pattern than did the 85-95 gpm 1½-inch lines.

Patterns of 90° were somewhat more protective than those of 60°. Thirty degree patterns from the booster line were about half as effective as the booster line 90° pattern. Reischl calculated that the 90°, 1½-inch pattern could about double the time a fire fighter could safely stay exposed to a 'hot' (radiant) fire.

Direct application of water spray to the exposed surface is more effective in preventing ignition than attempts at shielding the infrared radiation (Hodnett, 1986 (a)). Shielding of nozzlemen seems to be the only practical use of handline infrared attenuation.

Conclusions

In concluding this brief overview of some of the major questions involving use of water spray for control of vapor clouds, we will summarize each of the four areas considered.

• Preventing Vapor Cloud Formation

Work by Greer et al. (1980, 1981 (a) (b)) which was sponsored by the USCG and later the USEPA led to the conclusion that the only feasible control technique for the prevention or control of vapor or cloud formation using water was when it was enhanced by a foam liquid and applied as a foam over the exposed surface. Foam application is well established for flammable liquid control. Special HAZ MAT foams have been investigated and control or reduction of vaporization documented.

• Reducing Vapor Clouds

(Gross and Hiltz (1985)). Covering with a layer of water has been used on a small scale in controlling a carbon disulfide spill and was credited with limiting the extent of a subsequent fire. (MCA) Emulsification has been used with some success but mainly in fixed systems (Hodnett, 1986 (a)).

Again, Greer (1980, 1981 (a) (b)) found that vapor scrubbing or vapor phase reaction were impractical or ineffective as general tools for reduction of vapor clouds.

Anhydrous ammonia sorption by handlines as demonstrated by Greiner (1984) seems to be one exception to Greer's evaluation.

- **Controlling Vapor Clouds**

Several studies have indicated the effectiveness of ventilation or barrier effects (air movement) in controlling vapor clouds. Yet Greer (1980, 1981 (a) (b)) found them to be either impractical or ineffective. Perhaps the question is not *are* they effective but *how* effective and what limits should be placed on the size of cloud you attempt to control. McQuaid and Roberts (1982) indicate that fixed water spray ventilator systems may be effective at material discharge rates of up to 10 kg/s. Watts (1976) found a control limit for ethylene at 600 cfm using a single downward spray entraining about 24,000 cfm. Calculations based on fixed sprays indicate water spray handlines may only be 20 to 25 percent as effective as the spray used by Watts. Beresford (1982) has suggested upward spray chimneys using standard fire department deluge sets or monitors and at flows (1,000 to 3,500 gkp) and pressures compatible with modern fire pumps.

- **Preventing or Controlling Ignition of Vapor Clouds**

Water spray handlines are ineffective in preventing or controlling ignition unless they are capable of extinguishing the ignition source.

Water spray can be effective in reducing radiant heat exposures of fire fighters and thus provide some protection against radiant (flash) burns. Direct application of water spray to the exposed surface is even more effective.

General Rules for Using Water Spray Handlines in Controlling Vapor Clouds

- *Preplan* your response
- *Evacuate* as necessary before cloud arrival
- *Control* all sources of ignition
- *Never enter* a flammable vapor cloud
- *Never enter* a toxic vapor cloud without adequate personal protective equipment
- *Ventilate* as required to render the cloud non-toxic or non-flammable
- *Provide* a dependable backup water supply and reserve lines for rescue.

Can water spray *increase* the hazard of a flammable vapor cloud?

Water Reactions with Enriched Gas or Vapor Mixtures

Billett (in Mullins and Penner, 1959) and others have shown that the presence of water vapor in confined vapor-rich spaces (concentrations about twice stoichiometric) can give rise to very rapid flame travel, with the normally slow moving luminous flame becoming quite rapid and nonluminous denoting more complete combustion. Temperatures are too low to attribute this phenomena to simple chemical dissociation of the water and subsequent hydrogen burning. From the literature it is not clear what effect, if any, could be attributed to the turbulence or increased mixing of the fuel-air mixture caused by the introduction of the water.

Similar effects have also been noted by Eggleston, et al. (1975), and by Watts (1979) in field tests of fixed water spray dispersion systems using nearly stoichiometric mixtures.

Flame speeds of some 130 feet/sec. have been measured with water spray in contrast to an average 30-40 feet/sec. without waterspray. (Pikaar, 1985). Tests indicate that at the lower flame speeds, pressure rise at the edge of vapor clouds is insignificant (Pikaar, 1985).

McQuaid and Roberts (1982) state that computer models indicate flame speeds on the order of 165 feet/s can produce noticeable blast effects. Pikaar (1985) and McQuaid and Roberts

have (1982) calculated that flame speeds from 500 to 1000 feet/s can create devastating pressure waves.

The question is, can water spray accelerate flame speeds into ranges which produce significant pressure effects from deflagration and/or can water spray enhance the transition from deflagration to detonation?

We do not know the answer to this question, but both Gagan (1978) and Pikaar (1985) after extensive review of the literature caution on the use of water spray.

As Pikaar (1985) warns,

"Attention has been drawn to turbulence in all stages of cloud development and combustion. Turbulence promotes dilution in the release and dispersion phases while in the combustion phase it enhances flame speeds. However, comparison of flame speeds in large bag tests with those measured in field trials shows that normal atmospheric turbulence has no great effect on cloud combustion. The situation may be different if special measures are taken to excite turbulence in a cloud with the aim of promoting its dilution, for instance, the installation of water sprays. Previous experiments to answer this question suggest that water sprays created higher flame speeds though opinions as regards the interpretation of results differed. Whatever the true conclusion, caution requires that where such measures to promote flammable cloud dispersion are applied, the system should be able to dilute the release to below the LFL."

APPENDIX II

**Request for Assistance in Preventing
Hazards in the Use of Water Spray (Fog)
Streams to Prevent or Control Ignition of
Flammable Atmospheres**

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

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REQUEST FOR ASSISTANCE IN PREVENTING
HAZARDS IN THE USE OF WATER SPRAY (FOG) STREAMS
TO PREVENT OR CONTROL IGNITION OF FLAMMABLE ATMOSPHERES

WARNING!

FIRE DEPARTMENTS AND TEAMS RESPONDING TO INCIDENTS INVOLVING FLAMMABLE GAS OR VAPOR MIXTURES ARE CAUTIONED THAT THE USE OF WATER SPRAY (FOG) STREAMS TO PREVENT IGNITION OR CONTROL FLAME PROPAGATION MAY BE EXTREMELY DANGEROUS:

- o SIGNIFICANT FIRES OR EXPLOSIONS CAN OCCUR DESPITE THE USE OF WATER SPRAY. UNDER CERTAIN CONDITIONS, THE USE OF WATER SPRAY MAY IN FACT INCREASE THE SEVERITY OF SUCH FIRES AND EXPLOSIONS.
- o IT IS UNLIKELY THAT HANDLINES USING STANDARD FIRE DEPARTMENT WATER SPRAY (FOG) NOZZLES UNDER FIELD CONDITIONS CAN PREVENT IGNITION.
- o IT IS UNLIKELY THAT HANDHELD HOSE STREAMS CAN PRODUCE A WATER SPRAY WITH SUFFICIENTLY SMALL DROPLET SIZE AND UNIFORMLY HIGH WATER CONCENTRATIONS TO RENDER INERT A FLAMMABLE ATMOSPHERE.
- o THE USE OF WATER SPRAY CANNOT BE RELIED UPON TO QUENCH A FIRE IN A FLAMMABLE ATMOSPHERE.

INTRODUCTION

In response to requests for assistance by Federal, state, and local health agencies who have jurisdiction, the National Institute for Occupational Safety and Health (NIOSH) conducts selected investigations of occupational fatalities. Recently NIOSH was called to investigate an incident which occurred as a hazardous materials (HAZMAT) team responded to a "man down" emergency in a storage tank recently emptied of toluene. In the attempt to gain immediate access to the tank to rescue the victim, members of the team began to saw an opening in the side of the tank while blanketing the area being cut with water fog, both inside and outside the tank. An explosion occurred which instantly killed one HAZMAT team member and injured 15 others.

July 1985

BACKGROUND

Water, in the form of "water spray" or "fog patterns," is frequently used by fire departments and other response teams to prevent or control fire when dealing with flammable materials. The use of water sprays in this way derives from several factors:

- o traditional use of water by firefighters to extinguish fires,
- o belief that water sprays may provide critical ventilation,
- o ready availability and relative ease of application of water sprays, and
- o effectiveness of water sprays in controlling some of the hazards of flammable materials.

In investigating the circumstances of the incident summarized above, investigators from NIOSH also reviewed various reported uses of water sprays to control hazardous materials.* This review identified at least 20 different suggested uses of water in the control of hazardous materials. In at least some of the situations described, the use of water fog actually posed a significant additional risk to the safety of firefighters or other personnel. One example is the attempt to prevent, control, or diminish a gas-air or vapor-air explosion using water spray or fog delivered by handlines.

Accordingly, this alert, directed to fire departments and HAZMAT teams specifically, warns that certain uses of water may be hazardous. These dangerous uses of water should be avoided.

REPORTED USES OF WATER SPRAYS

Studies by numerous laboratories have identified four prime mechanisms through which water spray could influence the ignition and propagation of a fire or explosion in a flammable atmosphere. Water spray has been used to:

- o ventilate or otherwise reduce the concentration of the fuel to a level below that which is flammable,
- o raise the required ignition energy beyond that available,
- o render the flammable atmosphere inert, or
- o quench or prevent the propagation of an incipient or developed flame front.

*The National Institute for Occupational Safety and Health (NIOSH) intends to publish a more detailed report on water spray at a later date.

The water spray requirements for each of these control mechanisms differ, as do their methods of application. Experience with use of water sprays for these purposes, including potential hazards, is briefly summarized below.

1. Concentration Reduction

Various techniques involving use of water spray have proven successful in laboratory and field trials and in some actual incidents. For example, air entrained in water spray has been shown to dilute, ventilate, or move flammable vapors or gases. In addition, water droplets in spray may absorb soluble vapors or gases under certain conditions.

However, in some experimental cases the water spray did not reduce the concentration of flammable vapors below the threshold of flammability, and ignition occurred. In those instances, the flame traveled through the water spray resulting in a more severe fire or explosion than would have occurred without the water spray.

2. Raising Required Ignition Energy

The results of several laboratory studies indicate that water sprays directed on "hot spots" caused by frictional cutting can significantly reduce the likelihood of ignition. By using a fine water spray directed on the hot path of a mining bit cutting into rock, researchers have prevented ignition of a flammable methane-air mixture. The water density of the covering spray, the size of droplets, and the work surface being cooled were critical factors in the success of this control measure.

Other studies using an explosive as the source of ignition of flammable ethylene-air or hydrogen-air mixtures showed that the strength of the charge necessary to obtain an explosion was considerably increased with the use of a water spray. In both situations, however, higher levels of ignition energy still caused ignitions, i.e., the water spray was not sufficiently effective to prevent ignition.

3. Rendering a Flammable Atmosphere Inert

Water as steam can render a flammable atmosphere inert. For example, when the concentration of water in the atmosphere was about 26% by volume, a highly flammable methane-air mixture was rendered inert. This concentration of water in the atmosphere is approximately 10 times that which the atmosphere can normally contain at room temperatures. This approach is normally impractical for field use because it requires production of a droplet size 30-100 times finer than that produced by standard fire department water spray (fog) equipment.

4. Quenching Flame Propagation

Quenching, or cooling a flame below the temperature required to propagate it in a flammable atmosphere, can be achieved only if the water droplets can be made small enough so that the distance between them is below a critical dimension. To produce a sufficiently fine mist in a fixed spray system usually requires a pressure in excess of 1,000 psig. Further, some systems even require the use of a high explosive to break up and disperse the water droplets.

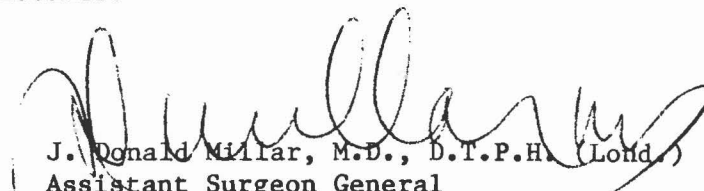
Fire departments and other teams responding to incidents involving flammable gas or vapor mixtures are urged to approach the control of flammable atmospheres with extreme caution. The use of a water spray (fog) does not eliminate the need for other recognized control methods to dilute the flammable atmosphere and to prevent ignition due to sparks, arcs, or open flames.

REQUEST FOR ASSISTANCE

NIOSH requests that the technical information and warning contained in this ALERT be disseminated to personnel of fire departments, HAZMAT teams personnel, fire training academies, and other emergency response organizations.

Should further information be desired, please contact the Division of Safety Research, 944 Chestnut Ridge Road, Morgantown, West Virginia 26505-2888, Telephone (304) 291-4809.

We greatly appreciate your assistance.



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BIBLIOGRAPHY

A.D. Little, Inc. (1974). Evaluation of LNG Vapour Control Methods. Arlington, VA: American Gas Association.

Abdel-Gayed RG, and Bradley D. (1977). Dependence of Turbulent Burning Velocity on Turbulent Reynolds Number and Ratio of Laminar Burning Velocity to RMS Turbulent Velocity. 16th. Symposium on Combustion sponsored by the Combustion Institute.

Abdel-Gayed RG, and Bradley D. (1982). The Influence of Turbulence Upon the Rate of Turbulent Burning. Proceedings of the International Conference on Fuel Air Explosions at McGill University, Montreal: University of Waterloo Press.

Accidental Episode Manual, PB 210 814. Environmental Protection Agency. (January 1972).

Ackerman DM. (1984) The Status of Safety Techniques for Storage, Loading and Unloading of LPG, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Adcock CT, and Weldon JD. (1967) Vapor Release and Explosion. Loss Prevention 1:70-74.

A Guide for Your Protection: Gas, Electricity, Firemanship. Baltimore Gas and Electric Company.

Agbede RO, Whitehead KL, Mundell RL, and Saltsman RD. (1982) Frictional Ignition Suppression by the Use of Cutter-Drum Mounted Sprays, PB 83 191 593. U.S. Department of the Interior, Bureau of Mines.

Akita K. (1973) Some Problems of Flame Spread Along a Liquid Surface. Proceedings of the Fourteenth Symposium on Combustion, Pittsburgh, PA: pp. 1075-1083.

Ale BJM, and Whitehouse JJ. (1984) Computer Based System for Risk Analysis of Process Plants, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Alger RS, Alvares NJ, and Lipska AE. (1971) The Destruction of High-Expansion Fire-Fighting Foam by the Components of Fuel Pyrolysis and Combustion, AD 882 649. White Oak, MD: Naval Ordnance Laboratory. (February 1971).

Alger RS, Alvares NJ, Lipska AE, and Inman LH. (1972) The Destruction of High-Expansion Fire-Fighting Foam by the Components of Fuel Pyrolysis and Combustion - Part II, AD 744 647. White Oak, MD: Naval Ordnance Laboratory.

Allinson JP. (1966) Protecting Liquid Petroleum Gas Vessels from Fire. The Engineer (July 22, 1966): p. 125.

Alvares NJ, and Lipska AE. (1972) The Effect of Smoke on the Production and Stability of High Expansion Foam. Journal of Fire and Flammability 3:88-113. (April 1972).

American Gas Association. (1974). LNG Safety Program - Interim Report on Phase II Work, AGA Project IS-3-1. (July 1, 1974).

American Petroleum Institute. (1985) Evaluation of Fire Fighting Forms as Fire Protection for Alcohol Containing Fuels, API Publication 2300.

American Petroleum Institute. (1980) Guide for Fighting Fires In and Around Petroleum Storage Tanks. (March 1980).

Anderson C, Cowgill G, Townsend W, and Zook J. (1974) The Effect of a Fire Environment on a Railroad Tank Car Filled with LNG, Report No. FRA-OR and D 75-37. Washington, DC: Federal Railroad Administration.

Anhydrous Ammonia. NIOSHTIC 27722.

Andrews WB. (1980) Assessment of the Risk of Transporting Liquid Chlorine by Rail, PNL 3376. Richland: Battelle Pacific Northwest Labs.

Andriev G, Neff DE, and Meroney RN. (1983) Heat Transfer Effects During Cold Dense Gas Dispersion. Gas Research Institute Report 83/0082.

Angelini E. (1985) Water Spray Protection, in Fire Protection Manual for Hydrocarbon Processing Plants. pp. 224-227.

Anthony EJ. (1975) Some Aspects of Unconfined Gas and Vapour Cloud Explosions. Journal of Hazardous Materials 1:289-301.

Attalah S, and Raj PK. (1974) Radiation from LNG Fires, American Gas Association Project IS-3-1 (July 1, 1974)

Auton TR, and Pickles JH. (1978) The Calculation of Blast Waves from the

Explosion of Pancake Shaped Vapour Clouds. Central Electricity Research Laboratories Note No. RD/L/N 210/78.

Babkin VS, and V'Yun AV. (1975) Effect of Water Vapor on the Normal Burning Velocity of a Methane-Air Mixture at High Pressures. Combustion Explosion and Shockwave 11(1):339. (January 1975).

Baker WE, Cox PA, Westine PS, Kulesz JJ, and Strehlow RA. (1983) Explosion Hazards and Evaluation. Amsterdam: Elsevier Press.

Baldock PJ. (1970) Accidental Releases of Ammonia: An Analysis of Reported Incidents. Loss Prevention 13:35-42.

Ball WL. (1970) A Review of Atmospheric Ammonia Research Study. Ammonia Plant Safety 12:1-7.

Becker TP. (1985) Critical Potential of Gas/Air and Gas/Oxygen Mixtures During Deflagration of Large, Free Gas Clouds. German Chemical Engineering 8(5):31. (September 1985).

Bellus F, Vincent R, Cochard H, and Mauger J. Controlling the Hazards from LNG Spills on the Ground LNG Fire-Fighting Methods and their Effects Application to Gas De France Terminals. LNG Conference Volume 5. (Undated).

Bennett GF, Feates FS, and Wilder IRA. (1982) Hazardous Materials Spills Handbook. New York, NY: McGraw-Hill.

Beresford TC. (1982) The Use of Water Spray Monitors and Fan Sprays for Dispersing Gas Leakages. North Western Branch Papers Inst. Chem. Eng.

Berlad AL, and Yang CH. (1960) A Theory of Flame Extinction Limits. Combustion and Flame 4:325-333.

Bernett MK, Halper LW, Jarvis NL, and Thomas TM. (1970) Effect of Adsorbed Monomolecular Films on the Evaporation of Volatile Organic Liquids. Industrial and Engineering Chemistry Fundamentals 9:150.

Billingham J. (1980) Massive Water Shuttle Used in Rail Tank Car Incident. Fire Command (August 1980):11-13.

Birch AD, Brown DR, and Dodson MG. (1980) Ignition Probabilities in Turbulent Mixing Flows, Report No. MRS E 374. Solihull: Midlands Research Station, British Gas.

Blackmore DR, et al. (1982) Dispersion and Combustion Behavior of Gas Clouds Resulting from Large Spillages of LNG Onto the Sea. Transactions of the Institute of Marine Engineers, Volume 94.

Blackmore DR, Eyre JA, and Summers GG. (1983) Large-Scale Study into the Behavior of Gas Clouds. Fire (January 1983):393-396.

Blackmore DR, Herman MN, and Woodward JL. (1982) Heavy Gas Dispersion Models, in Dense Gas Dispersion. Amsterdam: Elsevier Press. pp. 107-128.

Blanken JM. (1980) Behavior of Ammonia in the Event of a Spillage. Ammonia Plant Safety 22:25-34.

Blokker EF. (1984) From Risk Analysis to Decision Analysis, in Heavy Gas and

Risk Assessment, Volume 3. Boston MA: D. Reidel.

Bloom SG. (1980) A Mathematical Model for Reactive, Negatively Bouyant Atmospheric Plumes, in Heavy Gas and Risk Assessment. p. 103.

Bowen JE. (1981) To Aspirate or Not Aspirate AFFF? Tests, Advice Help Answer Question. Fire Engineering (February 1981):38-43.

Bowman BR, Sutton SB, and Comfort WJ. (1979) The Impact of LNG Spills on the Environment: A Comparison of Dispersion Models and Experimental Data. 25th Annual Technical Meeting. Seattle, WA: Institute of Environmental Sciences.

Boyle GJ, and Kneebone A. (1972) Laboratory Investigations into the Characteristics of LNG Spills on Water, Evaporation, Spreading and Vapor Dispersion. Shell Research Report to American Petroleum Institute.

Bradley CI, Carpenter RJ, Waite PJ, Ramsay CG, and English MA. (1982) Recent Development of a Simple Box-Type Model for Dense Vapour Cloud Dispersion, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Braker W, and Mossman AL (1971) Matheson Gas Data Book, 5th. Edition. East Rutherford, NJ: Matheson Gas Products.

Brandeis J, and Ermak DL. (1983) Numerical Simulation of Liquefied Fuel Spills: II - Instantaneous and Continuous LNG Spills on an Unconfined Water Surface. Int. J. Numerical Methods in Fluids 3:347-361.

Bray GA. (1964) Fire Protection of Liquid Petroleum Gas Storage Tanks. The Institution of Gas Engineers. (June 1964).

Bray GA. (1980) Applying Water to LPG Spill Fires. Fire (May 1980):667-668.

Bray KNC, and Moss JB. (1981) Spontaneous Acceleration of Unconfined Flames, in Proceedings of 1st. Specialists Meeting of the Combustion Institute. University of Bordeaux.

Breslin MK, and Royer MD. (1977) Use of Selected Sorbents and an Aqueous Film Forming Foam on Floating Hazardous Materials, PB 82 108 895. Washington, DC: U.S. Environmental Protection Agency.

Briggs AA, and Webb JS. (1986) Testing Concludes Petrol Can Reduce the Effectiveness of Some Foams. Fire (January 1986):45-48.

Briggs AA. (1979) Protection of Large Flammable Storage Tanks During Repair by Means of Nitrogen-Filled High Expansion Foam. Journal of Hazardous Materials 3:17-31.

Briggs AA. (1979) Correlation Between Small and Full Scale Tests in a Series of Fluorochemical Fire Fighting Foam Trials. Fire Technology 15(1):20-24.

Briggs AA. (1986) Issues Raised by Foam Fire Tests. Fire (July 1986):45.

Briggs AA. (1978) Trials of Fluorochemical Agents. Fire (September 1978):166-167.

Briggs GA. (1973) Diffusion Estimation for Small Emissions. NOAA:NTIS.

Briggs T. FRS Investigates Methods of Dealing with Gasohol Fires. Fire (May 1982):679-681.

Brighton PWM, Prince AJ, and Webber DM. (1984) Determination of Cloud Area and Path from Visual and Concentration Records. Proceedings of Symposium on Heavy Gas Dispersion Trials on Thorney Island. Sheffield.

Brighton PWM, Prince AJ, and Webber DM. (1985) Determination of Cloud Area and Path from Visual and Concentration Records. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Brighton PWM. (1985) Area Averaged Concentrations, Height Scales and Mass Balances. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Britter RE, and Griffiths RF. (1982) Dense Gas Dispersion. Amsterdam: Elsevier Press.

Britter RE, and Griffiths RF. (1982) The Role of Dense Gases in the Assessment of Industrial Hazards, in Dense Gas Dispersion. Amsterdam: Elsevier Press. pp. 3-12.

Britter RE. (1980) The Ground Level Extent of a Negatively Bouyant Plume in a Turbulent Boundary Layer. Atmosphere and Environment 14:779.

Brossard J, et al. (1984) Characterization of the Pressure Field Induced by the Explosions in Air of a Hydrocarbon Air Mixture, with Slow Deflagration or Fast Deflagration, in Proceedings of the 9th. International

Symposium on the Prevention of Occupational Accidents and Diseases in the Chemical Industry. Luzerne.

Brown D, Craig R, Edwards M, Henderson N, and Thomas TJ. (1981) Techniques for Handling Landborne Spills of Volatile Hazardous Substances, PB 82 105 230. Municipal Environmental Research Laboratory (September 1981).

Brown DP. (1978) Proposed Volatile Spill Suppression Concepts in Control of Hazardous Material Spills. pp. 303-308.

Brown LE, and Romine LM. (1979) Fighting Liquefied Gas Fires with Foam. Hydrocarbon Processing (September 1979):321-331.

Brown LE, and Romine LM. (1979) Liquefied Gas Fires: Which Foam? Hydrocarbon Processing 58(9):321-332.

Brown LE, Martinsen WE, Muhlenkamp SP, and Puckett GL. (1976) Small Scale Tests on Control Methods for Some Liquefied Natural Gas Hazards, AD A033 522. U.S. Department of Transportation. (May 1976).

Brown LE. (1982) Flammable Liquid Gases, in Hazardous Materials Handbook, pp. 10-65 to 10-80.

Bryan JL. (1976) Automatic Sprinkler and Standpipe Systems. Boston, MA: National Fire Protection Association.

Bryan JL. (1974) Fire Suppression and Detection Systems. Beverly Hills, CA: Glencoe.

Bull DC, Ellsworth JE, and Hooper G. (1978) Initiation of Spherical Detonation in Hydrocarbon/Air Mixtures.

Sixth International Colloquium on Gas Dynamics of Explosions and Reactive Systems. Stockholm. ACTA ASTR. 5:997.

Burgess D, Murphy JN, Zabetakis MG, and Perlee HE. (1974) Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill, in Fifteenth Symposium on Combustion, Pittsburgh, PA: pp. 289-301.

Burgess DS, Biordi J, and Murphy J. (1972) Hazards of Spillage of LNG into Water. USBM Report 4177.

Burgess DS, Murphy JN, and Zabetakis MG. (1970) Hazards of LNG Spillage in Marine Transportation. USBM Report S-4105.

Burgess DS, et al. (1973) Detonation of a Flammable Cloud Following a Propane Pipeline Break. USBM Report RI 7752.

Buschmann CH. (1975) Experiments on the Dispersion of Heavy Gases and Abatement of Chlorine Clouds. Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterways. Jacksonville, FL.

Byggstoyl S, and Saetran LR. (1982) An Integral Model for Gravity Spreading of Heavy Gas Clouds. Atmosphere and Environment 17(9):1615-1620.

Canavan RF. (1980) Gasohol: Gasoline or Alcohol? Fire Technology 16(1):5-11.

Carbon Disulfide (Carbon Bisulfide) Product Safety Information. (1973).

Carn KK, and Chatwin PC (1985) Variability and Heavy Gas Dispersion. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Carne M, et al. (1971) Buxton Bund Fire Tests. British Gas Council, R & D Division.

Carpenter HJ, and Shackleford WL. (1974) Spectroscopic Radiation Measurements on LNG Diffusion Flames, AGA Project IS-3-1. (July 1, 1974).

Case Histories of Accidents in the Chemical Industry. Washington, DC: Manufacturing Chemists Association.

Cashman JR. (1983) Hazardous Materials Emergencies - Response and Control. Lancaster: Techomic.

Cato GA, and Dobbs WF. (1971) An Ammonia Tank Car Emergency. Ammonia Plant Safety and Related Facilities, pp. 1-4.

Cayuga County (New York) Emergency Management Office. Handling Agricultural Ammonia Emergencies.

Cederwall RT. (1981) Description and Analysis of Burro Series 40 M³ LNG Spill Experiments, Report UCRL 86704. Livermore, CA: Lawrence Livermore National Laboratories. (October 1981).

Challot H. (1966) The Cooling of Liquid and Liquefied Hydrocarbon Storage Tanks. Fire International (April 1966):22-34.

Chan ST, et al. (1981) Simulation of Three-Dimensional, Time Dependent, Incompressible Flows by a Finite Element Method. Proceedings of AIAA 5th. Computational Fluid Dynamics Conference, Palo Alto, CA: June 1981.

Chan ST, Gresho PM, and Ermak DL. (1981) A Three-Dimensional Conservation Equation Model for Simulating LNG Vapor Dispersion in the Atmosphere, Report UCID-19210. Livermore, CA: Lawrence Livermore National Laboratories.

Chan ST, Rodean HC, and Ermak DL. (1982) Numerical Simulations of Atmospheric Releases of Heavy Gases over Variable Terrain, Report UCRL-87256. Livermore, CA: Lawrence Livermore National Laboratories.

Chan ST, and Ermak DL. (1983) Recent Progress in Modeling the Atmospheric Dispersion of Heavy Gases over Variable Terrain Using the Three Dimensional Conservation Equation, Report UCRL-88495. Livermore, CA: Lawrence Livermore National Laboratories.

Chan ST. FEM3 - A Finite Element Model for the Simulation of Heavy Gas Dispersion and Incompressible Flow: User's Manual, Report UCRL-53397. Livermore, CA: Lawrence Livermore National Laboratories.

Chang HR, and Reid RC. (1982) Spreading Boiling Model for Instantaneous Spills of LNG on Water. Journal of Hazardous Materials 7:19-35.

Chatwin PC. (1981) The Influence of Basic Physical Processes on the Statistical Properties of Dispersing Heavy Gas Clouds, in Proceedings of the 7th. Biennial Symposium on Turbulence, Rolla, Missouri.

Chatwin PC. (1982) The Use of Statistics in Describing and Predicting the Effects of Dispersing Gas Clouds, in Dense Gas Dispersion. Amsterdam: Elsevier, pp. 213-230.

Chiesa PJ, and Alger RS. (1980) Severe Laboratory Fire Test for Fire Fighting Foams. *Fire Technology* 16(1):12-21.

Clark WD. (1975) Use of Fire Fighting Foam on Ammonia Spills. AICHE 80th. National Meeting, Boston, Massachussettes, September 1975.

Clark WD. (1975) Using Fire Foam on Ammonia Spills. *Safety in Ammonia Plants* 18:40-41.

Clough TC. (1973) Research on Friction Reducing Agents. *Fire Technology* 9(1):32-45.

Cocks AT, and McElroy WJ. (1983) The Absorption of Hydrogen Chloride by Aqueous Aerosols. *Atmosphere and Environment* 18(7):1471-1483.

Coevert K, Grooyhuizen TH, Pasman HJ, and Trense RW. (1974) Explosions of Unconfined Vapour Clouds. *Loss Prevention and Safety Promotion in the Process Industries: The Hague*: 145-157.

Coleman JC. (1986) Test Methods V. Practical Experience. *Fire* (April 1986):42-43.

Colenbrander GW, and Puttock JS. (1983) Dense Gas Dispersion Behavior: Experimental Observations and Model Developments. 4th. International Symposium on Loss Prevention and Safety Promotion in the Process Industries. Harrogate.

Colenbrander GW. (1980) A Mathematical Model for the Transient Behavior of Dense Vapour Clouds. *Proceedings of the 3rd. International Symposium on Loss Prevention and Safety Promotion in the Process Industries*. Basle.

Compressed Gas Association. Handling Acetylene Cylinders in Fire Situations, SB-4. New York, NY: Compressed Gas Association.

Control and Extinguishment of LPG Fires, DOE/EV/06020-T3. U.S. Department of Energy (August 1980).

Control of Hazardous Material Spills, PB 228 736. U.S. Environmental Protection Agency (1974).

Cousin C, and Briggs AA. (1986) Tests Show Unfoamed Agents Capable of Increasing Fire Potential in Fuels. *Fire* 78(970):20-21. (April 1986).

Coward HF, and Gleadall JJ. (1930) Extinction of Methane Flames by Water Vapor. *J. Chem. Soc.* (1930):243.

Coward HF, and Jones GW. (1952) Limits of Flammability of Gases and Vapors, Bulletin 503. Washington, DC: U.S. Bureau of Mines.

Cox RA, Pyman MA, Sheppard PA, and Cooper JPS. (1980) Models for Evaluating the Probabilities and Consequences of Possible Outcomes Following Releases of Toxic or Flammable Gases, in *Heavy Gas and Risk Assessment*. Dordrecht: D. Reidel. p. 185.

Cox RA, and Carpenter RJ. (1980) Further Development of a Dense Vapour Cloud Dispersion Model for Hazard Analysis, in *Heavy Gas and Risk Assessment*. Dordrecht: D. Reidel. p. 55.

Cox RA, and Roe DR. (1977) A Model of the Dispersion of Dense Vapour Clouds. 2nd. International Symposium on Loss Prevention and Safety Promotion in the Process Industries. Heidelberg.

Cybulski W. (1975) Coal Dust Explosions and their Suppression. Washington, DC: U.S.Bureau of Mines.

Damon GH, Mason CM, Hanna NE, and Forshey DR. (1977) Safety Recommendations for Ammonium Nitrate-Based Blasting Agents, PB 271 906. Washington, DC: U.S. Bureau of Mines.

Davenport JA. (1977) A Survey of Vapor Cloud Incidents. Loss Prevention 11:39-49.

Davenport J. (1983) A Study of Vapor Cloud Incidents - An Update. 4th. International Symposium on Loss Prevention and Safety Promotion in the Process Industries. Harrogate.

Davenport JA. (1977) Prevent Vapor Cloud Explosions. Hydrocarbon Processing (March 1977):205-214.

Davies ME, and Singh S. (1985) The Phase II Trials: A Data Set on the Effect of Obstructions. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Davies ME, and Singh S. (1985) Thorney Island: Its Geography and Meteorology. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Deaves DM. (1985) Three Dimensional Model Predictions for the Upwind Building Trial of Thorney Island, Phase II. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

DeFaveri DM, Pastorino R, Fumarola F, and Ferraiolo G. (1984) Mixing of Gas Clouds by Water Barriers. Journal of

DeNevers N. (1983) Spread and Down-Slope of Negatively Bouyant Clouds. Atmosphere and Environment 18(10):2023-2027.

DeSteele JG, and Rhoads RE. (1982) Research and Development Needs and Opportunities in LGF Safety and Environmental Control, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Deaves DM. (1982) Application of a Turbulence Flow Model to Heavy Gas Dispersion in Complex Situations, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Department of Employment. (1975) The Flixborough Disaster-Report of the Court of Inquiry. London: Her Majesty's Stationery Office (HMSO).

DiMaio LR, Chiesa PJ, and Ott MS. (1975) Advances in Protection of Polar-Type Flammable Liquid Hazards. Fire Technology 11(3):164-174.

DiMaio LR, Lange RF, and Cone FJ. (1984) Aspirating vs. Nonaspirating Nozzles for Making Fire Fighting Foams - Evaluation of a Nonaspirating Nozzle. Fire Technology 20(1):5-10.

DiMaio LR. (1980) Extinguishing Gasohol Fires. Fire Journal (March 1980):60-63.

DiMaio LR. (1980) Gasohol - A New Fire Challenge. Fire (April 1980):604-611.

Dickinson C, et al. (1977) Experiment with Active Field Measures to Reduce Potential Damage in Chlorine Accidents, Report A 40018-H2. Sundbyberg: Swedish Defence Research Establishment.

- Directorate-General of Labour. (1979) Methods for the Calculation of the Physical Effects of the Escape of Dangerous Material. Voorburg, the Netherlands.
- Dirkmaat JJ. (1981) Experimental Studies on the Dispersion of Heavy Gases in the Vicinity of Structures and Buildings. Proceedings of Symposium on Designing with the Wind, Nantes, June 15-19, 1981. pp. III 3-1 to III 3-13.
- Dow Chemical Company. (1981) Dow's Fire and Explosion Index Hazard Classification Guide (5th.) New York, NY: American Institute of Chemical Engineers.
- Downing AG. (1964) Frictional Sparking of Cast Magnesium, Aluminum, and Zinc. Boston, MA: National Fire Protection Association.
- Doyle WH. (1965) Protection in Depth for Increased Chemical Hazards. Fire Journal (September 1965):5-7.
- Drake EM, Harris SH, and Reid RC. Analysis of Vapour Dispersion Experiments. American Gas Association Project IS-3-1: LNG Safety Program.
- Drysdale D. (1985) An Introduction to Fire Dynamics. New York, NY: John Wiley and Sons.
- Duffy AR, Gideon DN, and Putnam AA. (1974) Background. AGA Project IS-3-1 (July 1, 1974).
- Duffy AR, Gideon DN, and Putnam AA. (1974) Dispersion and Radiation Experiments, in LNG Safety Programs, Interim Report on Phase II Work, American Gas Association Project IS-3-1. (July 1974).
- Dyson WL, and Hermann ER. (1971) Reduction of Atmospheric Toluene Diisocyanate by Water Vapor. Am. Ind. Hyg. Assoc. J. 32:741-744 (November 1971).
- Echols WT. (1976) Estimating the Hazardous Radius of Exposure from Accidental Releases of Hydrogen Sulfide Gas, in Control of Hazardous Materials Spills: Information Transfer. Rockville, MD: pp. 201-207.
- Eggleston LA, Herrera WR, and Pish MD. (1976) Water Spray to Reduce Vapor Cloud Spray. Loss Prevention 10:31.
- Eggleston LA, Herrera WR, and Pish MD. (1975) The Use of Finely Divided Water to Reduce the Hazard Potential of Vapor Clouds. Southwest Research Institute (March 1975).
- Eggleston LA, and Pish MD. (1973) Requirements for Explosion-Proof Electrical Equipment in Air Force Hangers, AD 767 600. San Antonio, TX: Southwest Research Institute.
- Eggleston LA. (1967) Evaluation of Fire Extinguishing Systems for Use in Oxygen Rich Atmospheres, AD 714 703. San Antonio, TX: Southwest Research Institute.
- Eidsvik KJ. (1980) A Model for Heavy Gas Dispersion in the Atmosphere. Atmosphere and Environment 14:769-777.
- Eidsvik KJ. (1978) Dispersion of Heavy Gas Clouds in the Atmosphere, Report No. 32/78. Lillestrom: Norwegian Institute for Air Research.

Eidsvik KJ. (1981) Heavy Gas Dispersion Model with Liquefied Release. Atmosphere and Environment 15:1163.

Elkhart Brass. Sheet-Nozzle Flow Data from Untitled Catalog. Elkhart, Indiana.

Elliot DE, Chiesa PJ. A New Foam Rheometer for Studying Fire Fighting Foams. Fire Technology 12(1):66-69.

Elliott DE, and Chiesa PJ. (1973) Automated Surface and Interfacial Measurements of AFFF's. Fire Technology 9(4):275-284.

Elsworth JE, and Eyre JA. (1984) Indirect Initiation of Spherical Detonation in Fuel/Air Mixtures by a Transition Process, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Emblem K, Krogstad PA, and Fannelop TK. (1984) Experimental and Theoretical Studies in Heavy Gas Dispersion, Part I - Experiments, in Atmospheric Dispersion of Heavy Gases and Small Particles. Springer.

Emblem K, and Fannelop TK. (1982) Entrainment Mechanisms of Air in Heavy Gas Clouds, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Enger T, and Hartman DE. (1972) LNG Spillage on Water: II Final Report on Rapid Phase Transformations, Technical Progress Report No. 1-72. Houston, TX: Shell Pipeline Corp.

Erk SD, and Kaczmarek LW. (1970) A System for Dilution of Rocket Oxidizers. Aerospace Medical Research

Laboratory (September 1970): pp. 127-133.

Ermak DL, et al. (1978) A Three-Dimensional Atmospheric Transport Model to Treat Multiple Area Sources, UCRL-52603. Livermore, CA: Lawrence Livermore National Laboratories.

Ermak DL, Chan ST, Morgan DL, and Morris LK. (1982) A Comparison of Dense Gas Dispersion Model Simulations with Burro Series LNG Spill Test Results, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 129-160.

Ermak DL, Goldwire HC, Hogan WJ, Koopman RP, and McRae TG. (1982) Results of 40 M3 LNG Spills Onto Water, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

ESSO/API. (1972) Spills of LNG on Water-Vaporization and Downwind Drift of Combustible Mixtures, ESSO Research and Engineering Report EE 61 E-72.

Evans DB, and O'Neill JG. (1983) Feasibility Study of Extinguishing Gas Well Blowout Fires with Water Sprays. Washington, DC: National Bureau of Standards.

Evans DB, and McCaffrey BJ. Control of Blowout Fires with Water Sprays. Washington, DC: National Bureau of Standards, Center for Fire Research.

Evans D, and Pfenning D. (1985) Water Sprays Suppress Gas-Well Blowout Fires. Oil and Gas J. (April 29, 1985):80-86.

Factory Mutual System. (1967) Handbook of Industrial Loss Prevention, 2nd. Edition. New York, NY: McGraw-Hill.

Fannelop TK, Krogstad PA, and Jacobsen O. (1980) The Dynamics of Heavy Gas Clouds, IFAG B-214. Norwegian Institute of Technology, Division of Aero and Gas Dynamics.

Fannelop TK, and Jacobsen O. (1984) Gravitational Spreading of Heavy Gas Clouds Instantaneously Released. J. of Appl. Math. and Physics 35 (July 1984):559-584.

Fannelop TK, and Zumsteg F. (1984) Special Problems in Heavy Gas Dispersion, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Fay JA, and Lewis DH. (1975) The Inflammability and Dispersion of LNG Vapour Clouds. Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterways. Jacksonville, FL.

Fay JA. (1978) A Preliminary Analysis of the Effect of Spill Size on the Level of Hazard from LNG Spills on Land and Water, in An Approach to Liquefied Natural Gas (LNG) Safety and Environmental Control Research, DOE/EV-0002.

Fay JA. (1980) Gravitational Spread and Dilution of Heavy Vapor Clouds. Proceedings 2nd. International Symposium on Stratified Flows. Tapir, Trondheim 1. pp. 471-494.

Fay JA, and Ranck DA. (1982) Comparison of Experiments on Dense Cloud Dispersion. Atmosphere and Environment 17(2):239-248.

Fay JA, and Ranck DA. (1977) Scale Effects in Liquefied Fuel Vapor Dispersion - Final Report, U.S. Department of Energy Contract DE-AC02-77 EV 04204.

Fay JA. (1975) Unusual Fire Hazard of LNG Tanker Spills. Combustion Science and Technology 7:47-49.

Feldbauer GF, Heigel JJ, McQueen W, Whipp RH, and May WG. (1972) Spills of LNG Onto Water: Vaporisation and Downwind Drift of Combustible Mixture. ESSO Research and Engineering Co. Report EE61E-72.

Ferroni G, Antincendi S, and Lev Y. (1983) Tests Into Compatibility of Fluoroprotein Foams with Alcohol/Petrol Blends. Fire Prevention 159 (May 1983):21-26.

Fiedler F, and Tangermann-Dlugi G. (1980) Turbulent Dispersion of Heavy Gases in the Atmospheric Boundary Layer After Ground Level Release, in Heavy Gas and Risk Assessment. p. 157.

Fire FL. (1986) The Common Sense Approach to Hazardous Materials. Fire Engineering.

Fire Technology Abstracts. (1980) Mine Fire and Smoke, Prevention and Safety, PB 81 850 414. Citations from the Fire Technology Abstracts Data Base (September 1980).

Fishburn B, Slagg N, and Lu P. (1981) Blast Effect from a Pancake Shaped Fuel Drop - Air Cloud Detonation (Theory and Experiment). J. Hazardous Materials 5:65-75.

Fittes DW, and Richardson DD. (1963) The Influence of Alcohol Concentration on the Effectiveness of Protein Forms in Extinguishing Fires in Gasoline-Alcohol Mixtures. Journal of the Institute of Petroleum 49:150.

- Fitzgerald RJ. (1958) Mechanical Ventilation and Fog Nozzles. W.N.Y.F. (January 1958):8-15.
- Fleischer MT. (1980) Mitigation of Chemical Spills: An Evaporation/Air Dispersion Model for Chemical Spills on Land. Shell Development Co., Westhollow Research Center. (December 1980).
- Fletcher B. (1982) Sudden Discharge of a Superheated Fluid to Atmosphere. Proceedings of Symposium on the Assessment of Major Hazards. Manchester, April 14-16, 1982. Institute of Chemical Engineers, Symposium Series 71.
- Flothmann D, and Mjaavatten A. (1984) Qualitative Methods of Hazard Identification, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.
- Flothmann D, and Nikodem HJ. (1980) A Heavy-Gas Dispersion Model with Continuous Transition from Gravity Spreading to Tracer Diffusion, in Heavy Gas and Risk Assessment, p. 89.
- Focus on Hazardous Materials - Chlorine (CLX) Industrial Fire World (May/June 1986):29-30.
- Forster H, Kramer H, and Schon G. (1980) Dispersion of Gasoline in Road Tunnels After Release of Major Quantities, in Heavy Gas and Risk Assessment, p. 141.
- French RJ, and Hinkley PL. (1954) Resistance of Fire Fighting Foams to Destruction by Petrol. Journal of Applied Chemistry 4:513.
- Friel JV, Hiltz RH, and Marshall MD. (1973) Control of Hazardous Chemical Spills by Physical Barriers, PB 221 493. Washington, DC: U.S. Environmental Protection Agency.
- Friel JV, Hays HE, and Hiltz RH. (1973) The Development of High Expansion Foam Systems for the Suppression of Respirable Coal Dust. U.S. Department of Health, Education and Welfare Contract HSM 099-71-14.
- Fritz RH, and Jack GG. (1983) Water in Loss Prevention: Where Do We Go From Here? Hydrocarbon Processing (August 1983):77-90.
- Fry JF, and French RJ. (1951) A Laboratory Method of Comparing the Efficiencies of Fire-Fighting Air-Foams. Journal of Applied Chemistry (October 1951):429-433.
- Fry JF, and French RJ. (1951) A Mechanical Foam-Generator for Use in Laboratories. Journal of Applied Chemistry (October 1951):425-429.
- Fuchs P. (1984) On the Extinguishing Effect of Various Extinguishing Agents and Extinguishing Methods with Different Fuels. Fire Safety Journal 7:165-175.
- Furno A. (1978) Mine Face Ignition Quenching, IC 8768. Washington, DC: U.S. Bureau of Mines.
- Garrett AJ, and Murphy CE. A Puff-Plume Atmospheric Desposition Model for Use at SRP in Emergency Response Situations, DP-1595. U.S. Department of Energy. (Undated).
- Gas Research Institute. (1981) 1982-1986 Five-Year Research and Development Plan. Chicago, IL: Gas Research Institute.

Geiger W, and Synofzik R. (1980) A Simple Model for the Explosion of Pancake Shaped Vapour Clouds. 3rd. International Symposium on Loss Prevention and Safety Promotion in the Process Industry. Basle.

Geiger W, and Synofzik R. (1980) Influence of Dispersion Behavior of Dense Explosive Gases on the Possible Strength of Explosion, in Heavy Gas and Risk Assessment, p. 245.

Geiger W. (1982) Present Understanding of the Explosion Properties of Flat Vapor Clouds, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Geiger W. (1984) Pressure-Enhancing Mechanisms in Unconfined Vapour Cloud Explosions, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Georgakis C, Congalidis J, and Williams GC. (1979) Model for Non-Instantaneous LNG and Gasoline Spills. Fuel 58:113-120.

Germeles AE, and Drake EM. (1975) Gravity Spreading and Atmospheric Dispersion of LNG Vapor Clouds. Proceedings of 4th. International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterway. Jacksonville, FL: pp. 519-539.

Geyer GB. (1969) Extinguishing Agents for Hydrocarbon Fuel Fires. Fire Technology 5(2):151-159.

Gideon DN, Putnam AA, and Duffy AR. (1974) Comparison of Dispersion from LNG Spills Over Land and Water. Final Report on AGA Project IS-3-1.

Giesbrecht H, Hess K, Leuckel W, Maurer B, and Stoeckel A. (1980) Analysis of the Potential Explosion Effects of Flammable Gases During Short Time Release into the Atmosphere, in Heavy Gas and Risk Assessment. p. 207.

Giesbrecht H, Hess K, Leuckel W, and Maurer B. (1981) Analysis of Explosion Hazards on Spontaneous Release of Inflammable Gases into the Atmosphere. German Chemical Engineering 4:304-314.

Giesbrecht H, Seifert H, and Leuckel W. (1982) Dispersion of Vertical Free Jets, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Goldwire HC, et al. (1983) Coyote Series Data Reports, LLNL/NWC 1981 Spill Tests, UCID-19953. Livermore, CA: Lawrence Livermore National Laboratories.

Gotaas Y. (1985) Heavy Gas Dispersion and Environmental Conditions as Revealed by the Thorney Island Experiments. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Gowar RG. (1978) Developments in Fire Protection of Offshore Platforms - 1. Applied Science. London.

Greenwood DV. (1981) The Containment and Dispersion of Gases by Water Sprays. I. Chem. E. Symp. Proceedings. Manchester.

Greer JS, and Gross SS. (1980) The Practicality of Controlling Vapor Release from Spills of Volatile Chemicals Through Cooling, in Control of Hazardous Material Spills. pp. 130-133.

Greer JS, Gross SS, Hiltz RH, and McGoff MJ. (1981) An Evaluation of Cooling as a Vapor Mitigation Procedure for Spilled Volatile Chemicals. Municipal Environmental Research Laboratory (September 1981).

Greer JS, Gross SS, Hiltz RH, and McGoff MJ. (1981) Modification of Spill Factors Affecting Air Pollution. Volume II - The Control of the Vapor Hazard from Spills of Liquid Rocket Fuels, PB 82 208 390. Municipal Environmental Research Laboratory (September 1981).

Greiner ML. (1983) Ammonium Nitrate Hazards and Handling. Fertilizer Progress (January/February 1983).

Greiner ML. (1972) Ammonium Nitrate Safety. Chicago, IL: National Safety Council.

Greiner ML. (1984) Emergency Response Procedures for Anhydrous Ammonia Vapor Release. Ammonia Plant Safety (and Related Facilities) 24:109-114.

Griffiths RF, and Kaiser GD. (1982) Production of Dense Gas Mixtures from Ammonia Releases - A Review, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 197-212.

Griffiths RF, and Kaiser GD. (1979) The Accidental Release of Anhydrous Ammonia to the Atmosphere - A Systematic Study of Factors in Influencing Cloud Density and Dispersion, UKAEA Report SRD R 154.

Griffiths RF, and Megson LC. (1983) The Effect of Uncertainties in Human Toxic Response on Hazard Range Estimation for Ammonia and Chlorine. Atmosphere and Environment 18(6):1195-1206.

Griffiths RF. (1978) Observations of

Non-Bouyant Behavior of Ammonia Following Accidental Discharges to the Atmosphere, in Canvey: An Investigation of Potential Hazards from Operations in the Canvey/Thurrock Area. London: Her Majesty's Stationery Office.

Griffiths RF, and Harper AS. (1985) A Speculation on the Importance of Concentration Fluctuations in the Estimation of Toxic Response to Irritant Gases. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Gross SS, and Hiltz RH. (1982) Evaluation of Foams for Mitigating Air Pollution from Hazardous Spills, PB 82 227 117. Washington, DC: U.S. Environmental Protection Agency.

Gross SS. (1980) Application of Foams to Hazardous Chemical Spills, in Control of Hazardous Material Spills. pp. 88-91.

Gross SS. (1978) Evaluation of Foams for Mitigating Air Pollution from Hazardous Materials Spills, in Control of Hazardous Material Spills. pp. 394-398.

Gudiksen P, et al. (1986) Emergency Response Planning for Potential Accidental Liquid Chlorine Releases, UCRL 53685. Livermore, CA: Lawrence Livermore National Laboratories. (May 1986).

Gugan K. (1979) Unconfined Vapor Cloud Explosions. Houston, TX: Gulf.

Guise AB, and Zeratsky ED. Fire Extinguishing Agents and Their Application, in Safety and Accident Prevention in Chemical Operations, 2nd. Edition. New York, NY: Wiley. pp. 357-398.

Hastrup P. (1984) Indoor Fatal Effects of Outdoor Toxic Gas Clouds. *Journal of Occupational Accidents* 5:279-290.

Haddock SR, and Williams RJ. (1979) The Density of an Ammonia Cloud in the Early Stages of Atmospheric Dispersion, UKAEA Report SRD R 103. *J. Chem. Tech. Biotechnol.* 29:655-672.

Haessler WM. (1974) *The Extinguishment of Fire* (Revised Edition). Boston, MA: National Fire Protection Association.

Haessler WM. (1986) *Theory of Fire and Explosion Control*, in *Fire Protection Handbook*, 16th. Edition. Boston, MA: National Fire Protection Association.

Hall DJ, Barrett CF, and Ralph MO. (1974) Experiments on a Model of an Escape of Heavy Gas, Warren Springs Laboratory Report LR 217 (AP) Department of Trade and Industry.

Hall DJ, Hollis EJ, and Ishaq H. A Wind Tunnel Model of the Portion Dense Gas Spill Field Trials. Warren Springs Laboratory Report LR 394 (AP).

Hall DJ. (1979) Further Experiments on a Model of an Escape of Heavy Gas, Warren Springs Laboratory Report LR 312 (AP). Department of Trade and Industry. p. 47.

Hall DJ. Further Experiments on the Model of an Escape of Heavy Gases. Warren Springs Laboratory Report LR 382 (AP).

Hall DJ, and Waters RA. (1985) Wind Tunnel Model Comparisons with the Thorney Island Dense Gas Release Field Trials. in *Heavy Gas Dispersion Trials at Thorney Island*. Elsevier.

Hall SF, Martin D, and MacKenzie J. Gas Cloud Explosions and their Effect on Nuclear Power Plant. Phase I: Basic Development of Explosion Codes. Luxembourg: European Communities Commission. EUR 8955.

Hampson TR. (1976) Chemical Leak at a Bulk Terminals Tank Farm, in *Control of Hazardous Material Spills*. pp. 214-218.

Hand TD, Ford AW, Malone PG, Thompson DW, and Mercer RB. (1978) A Feasibility Study of Response Techniques for Discharges of Hazardous Chemicals that Sink, AD AO 60 792. Department of Transportation.

Hanna S, and Munger B. (1983) A Survey of Emergency Models and Applications. Part I: Models Developed for Hazardous Spills Applications. Air Pollution Control Association 76th. Annual Meeting Atlanta, June 19-24, 1983.

Hanna SR, Briggs GA, and Hosker RP. (1982) *Handbook on Atmospheric Diffusion*, DOE/TIC 11223. Washington, DC: U.S. Department of Energy.

Hanson D. (1986) First Tests Completed at New Chemical Spill Test Site. *C & EN* (September 1, 1986):20-21.

Hardy HL, and Purnell CJ. (1978) Use of Foam for the Emergency Suppression of Vapour Emissions from Organic Isocyanate Liquid Surfaces. *Annals of Occupational Hygiene* 21:95-98.

Harris NC. (1982) Some Problems in Risk Assessment Involving Gas Dispersion, in *Heavy Gas and Risk Assessment*, Volume 2. Boston, MA: D. Reidel.

Harris NC. (1984) The Application of Heavy Gas Dispersion in a Risk Assessment Model, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Harris NC. (1985) A User's View on the Data Obtained and Those Which May Still be Required. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Hartwig S, and Flothmann D. (1980) Open and Controversial Problems in the Development of Models for the Dispersion of Heavy Gas, in Heavy Gas and Risk Assessment. p. 1.

Hartwig S. (1980) Heavy Gas and Risk Assessment, in Proceedings of Symposium on Heavy Gas, Frankfurt, September 3-4, 1979. Holland: D. Reidel.

Hartwig S. (1983) Heavy Gas and Risk Assessment, Volume 2. Dordrecht: D. Reidel.

Hartwig S. (1985) Heavy Gas and Risk Assessment, Volume 3. Dordrecht: D. Reidel.

Hartwig S. (1984) Heavy Gases in our Industrial and Technical Society and our Needs for Further Research, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Hartwig S. (1982) Identification of Problem Areas Related to the Dispersion of Heavy Gases, Von Karman Institute Lecture Series 1982-3. Brussels.

Hartwig S. (1982) Open and Controversial Topics in Heavy Gas Dispersion and Related Risk Assessment Problems, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Hartwig S. (1980) Resume - What is Still To Do and Where are We on Safe Ground? in Heavy Gas and Risk Assessment. p. 287.

Hartwig S. (1985) Improved Understanding of Heavy Gas Dispersion Due to the Analysis of the Thorney Island Trials Data. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Haselman LC. Effect of Humidity on the Energy Budget of a Liquefied Natural Gas, EV 0085. Washington, DC: U.S. Department of Energy.

Hatton AP, and Osborne MJ. (1979) The Trajectories of Large Fire Fighting Jets. Int. J. Heat and Fluid Flow 1(1):37-41.

Havens JA, and Spicer TO. (1985) Development of An Atmospheric Dispersion Model for Heavier than Air Gas Mixtures, DTCG-23-80-C-20029. United States Coast Guard.

Havens JA, and Spicer TO. (1982) Further Analysis of Catastrophic LNG Vapor Dispersion, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Havens JA. A Description and Assessment of the Sigmet LNG Vapor Dispersion Model, CT-M-3-79. United States Coast Guard.

Havens JA. (1982) A Description and Computational Assessment of the Sigmet LNG Vapor Dispersion Model, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 181-196.

- Havens JA. (1982) A Review of Mathematical Models for Prediction of Heavy Gas Atmospheric Dispersion. I. Chem. E. Symp. The Assessment of Major Hazards.
- Havens JA. (1978) An Assessment of the Predictability of LNG Vapor Dispersion from Catastrophic Spills Onto Water. Proceedings of the 5th. International Symposium on the Transport of Dangerous Goods by Sea and Inland Waterways. Hamburg.
- Havens JA, and Spicer TO. (1984) Gravity Spreading and Air Entrainment by Heavy Gases Instantaneously Released in a Calm Atmosphere, in Atmospheric Dispersion of Heavy Gases and Small Particles. Springer. pp. 177-188.
- Havens JA. (1977) Predictability of LNG Vapor Dispersion from Catastrophic Spills Onto Water, An Assessment, Report CG-M-09-77. p. 211.
- Havens JA. (1981) Development of Vapor Dispersion Models for Non-Neutrally Bouyant Gas Mixtures, DTCG 23-80-C-20029. U.S. Coast Guard.
- Health and Safety Commission. (1982) Flammability (Evolution of Highly Flammable Gases in Contact with Damp Air or Water) [Test 13], in Methods for the Determination of Physico-Chemical Properties - Notification of New Substances Regulations.
- Heffington WM, and Gaines WR. (1981) Flammability Calculations for Gas Mixtures. Oil and Gas Journal (November 16, 1981):87-90.
- Henry MF. (1984) Flammable and Combustible Liquids Code Handbook, (Second Edition). Boston, MA: National Fire Protection Association.
- Hertzber GM, Litton CD, Donaldson WF, and Burgess D. (1974) The Infrared Radiance and the Optical Detection of Fires and Explosions, in Fifteenth Symposium on Combustion, Pittsburgh, pp. 137-144.
- Heselden AJM, and Hinkley PL. (1965) Measurements of the Transmission of Radiation Through Water Sprays. Fire Technology 1(2):130-137. (May 1985).
- Heskestad G. Meroney RN, Kothari KM, and Neff DE.(1983) Effectiveness of Water Spray Curtains in Dispersing LNG Vapor Clouds. Proceedings of AGA Transmission Conference, Seattle. Paper 83-T-69. pp. T-169 to T-183.
- Heskestad G, et al. (1976) Air Entrainment Into Water Sprays and Spray Curtains, Technical Report FMRC Serial No. 22533. Norwood: Factory Mutual Research Corp.
- Heskestad G, Kung HC, and Todtenkopf NF. (1976) Air Entrainment Into Water Sprays and Spray Curtains. The American Society of Mechanical Engineers. pp. 1-12.
- Hess K, Hoffman W, and Stoeckel A. (1974) Propagation Processes After the Bursting of Tanks Filled with Liquid Propane - Experiments and Analytical Model, in Loss Prevention and Safety Promotion in the Process Industries. Elsevier.
- Heudorfer W, and Hartwig S. (1982) A Comparison of Consequences of Different Types of UF6 Accidents, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Heudorfer W. (1984) Heavy Gas Cloud and Turbulence, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Hickey HE (1980) Hydraulics for Fire Protection. Boston, MA: National Fire Protection Association.

Hiltz RH, and Friel JV. (1976) Application of Foams to the Control of Hazardous Chemical Spills, in Control of Hazardous Material Spills. pp. 293-302.

Hiltz RH, and Gross SS. (1980) The Use of Foams to Control the Vapor Hazard from Liquefied Gas Spills, in Control of Hazardous Material Spills. pp. 119-122.

Hiltz RH. (1982) Mitigation of the Vapor Hazard from Silicon Tetrachloride Using Water-Based Foams. Journal of Hazardous Materials 5(3):169-176. (February 1982).

Hiltz RH. (1982) Vapor Hazard Control, in Hazardous Materials Spills Handbook. pp. 10-21 to 10-33.

Hird D. (1960) Extinguishing Room Fires with High and Low Pressure Water Sprays. V.F.D.B. Zeit 9:58-61. (Special Issue).

Hirst WJS, and Eyre JA. (1982) Maplin Sands Experiments 1980: Combustion of Large LNG and Refrigerated Liquid Propane Spills on the Sea, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Hirst WJS. (1982) Combustion Experiments with Large LNG and Propane Spills on Sea. Second Symposium on Heavy Gases and Risk Assessment. Frankfurt.

Hirst WJS. (1984) Combustion of Large-Scale Releases of Pressurized Liquid Propane, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Hixson RS (1980) Vapor Phase Detonations in Light Hydrocarbons. PhD Thesis, Washington State University. Pullman.

Hjertager G. (1983) Influence of Turbulence on Gas Explosions. Proceedings of International Symposium on the Control and Prevention of Gas Explosions. London.

HMCRI. (1976) Control of Hazardous Material Spills. Silver Spring.

HMCRI (1978) 1978 Conference on Control of Hazardous Material Spills. Silver Spring.

HNCRI (1980) 1980 Conference on Control of Hazardous Material Spills. Silver Spring.

HMCRI. (1982) 1982 Hazardous Material Spills Conference. Silver Spring.

HMCRI. (1984) 1984 Hazardous Material Spills Conference. Silver Spring.

HMCRI. (1974) Control of Hazardous Material Spills. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills.

HMCRI. (1979) Oil and Hazardous Material Spills. Silver Spring: Hazardous Materials Control Research Institute.

Hodnett RM, editor. (1985) Automatic Sprinkler Systems Handbook, Second Edition. Boston, MA: National Fire Protection Association.

Hodnett RM. (1981) Water and Water Additives for Fire Fighting, in Fire Protection Handbook, 15th. Edition. Boston, MA: National Fire Protection Association.

Hodnett RM. (1986) Water and Water Additives for Fire Fighting, in Fire Protection Handbook, 16th. Edition. Boston, MA: National Fire Protection Association.

Hodnett RM. (1986) Water Spray Protection, in Fire Protection Handbook, 16th. Edition. Boston, MA: National Fire Protection Association.

Hoehne VO, Luce RG, and Miga LW. (1970) The Effect of Velocity, Temperature, and Gas Molecular Weight on Flammability Limits in Wind-Blown Jets of Hydrocarbon Gases, Report to the API. Battelle Memorial Institute.

Hofmann J. (1982) Modelling of Fire for Risk Assessment in Petrochemical Industries, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Hogan WJ, Ermak DL, and Koopman RP. (1982) Predicting the Hazards from Large Spills of Liquefied Gaseous Fuels, in 1982 Hazardous Material Spills Conference, pp. 391-398.

How Boots and Coots Put Out Oil Fires - Don't Trust Lab Tests Says Texas Expert. Fire 79(972):35. (June 1986).

How to Handle LP-Gas Emergencies, in LPG Fire Control. Scony: Mobil Oil Co.,

Inc.

Howerton AE. (1975) Estimating Area Affected by a Chlorine Release. New York, NY: The Chlorine Institute.

Hughes JR. (1978) Storage and Handling of Petroleum Liquids. London: Charles Griffen.

Huibregtse KR, Scholz RC, Wullschleger RE, Moser JH, Bollinger ER, and Hansen CA. (1977) Manual for the Control of Hazardous Material Spills, Volume 1: Spill Assessment and Water Treatment Techniques, PB 276 734. Industrial Environmental Research Laboratory. (November 1977).

Hull R. (1981) Potential LPG Dangers Indicate Need for Stronger Controls. Fire (December 1981):375-377.

Hunger MM. (1968) Effectiveness of High Expansion Foam Generated from Air Contaminated with Combustion Products, Progress Report No. 2. Project 930-30. Naval Applied Science Laboratory. (August 6, 1968).

International Study Group on Risk Analysis. (1985) Risk Analysis in the Process Industries. Institution of Chemical Engineers.

Isman WE, and Carlson GP. (1980) Hazardous Materials. Encino: Glencoe.

Isman WE. (1982) Fire Department Fined for Flushing Fuel. The International Fire Chief (February 1982):17-19.

Isman WE. (1983) Training Personnel to Handle a Hazardous Materials Incident. Fire Engineering (February 1983):42-46.

Ivanov EN. (1966) Calculation of the Necessary Rate of Spraying. Fire Prevention and Fire Fighting Symposium, Fire Research Station, Boreham Wood, Herts.

Jackson RB. (1970) Oxygen Difluoride Handling Manual. National Aeronautics and Space Administration. (December 1970).

Jacobsen O. (1984) Modelling of Heavy Gas Dispersion. Norwegian Institute of Technology.

Jacobsen KH. The Hazardous Nature of Some Liquid Propellants. NIOSHTIC 5319.

Jagger SF, and Kaiser SD. (1981) The Accidental Release of Dense Flammable and Toxic Gases from Pressurized Containment - Transition from Pressure Driven to Gravity Driven. 11th. NATO/CCMS ITM on Air Pollution Modeling and its Applications, Amsterdam. (November 1981).

Jagger SF. (1983) Development of Crunch: A Dispersion Model for Continuous Releases of a Denser than Air Vapour into the Atmosphere. UKAEA: SRD Report R 229.

Jagger SF. (1982) Formulations of the Dense Gas Dispersion Problem, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Jamison WB, and Hadi H. (1975) Ignition Suppression for Continuous Miners. First Symposium on Underground Mining, Louisville. (October 1975).

Jamison WB, and Hadi H. (1976) Ignition Suppression Device, PB 261 292. U.S. Bureau of Mines. (August 1976).

Jayaraman NI, Kissell FN, Cross W, Janosik J, and Odoski J. (1981) High-Pressure Shrouded Water Sprays for Dust Control, PB 81 231 458. U.S. Bureau of Mines. (June 1981).

Jazayeri B. (1975) Impact Cryogenic Vapor Explosions, MS Thesis. Cambridge, MA: Massachusetts Institute of Technology.

Jeacocke GJ. (1980) Transporting LPG: The Safety Arguments. Fire (May 1980):668-669.

Johnson DR. (1985) Thorney Island Trials: Systems Development and Operational Procedures. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Johnson OW. (1961) Water on Oil Fires. NFPA Quarterly (October 1961):141-146.

Jones CD. (1979) On the Structure of Instantaneous Plumes in the Atmosphere. Journal of Hazardous Materials 7:87-112.

Kaiser GD, and Walker BC. (1978) Releases of Anhydrous Ammonia from Pressurized Containers - The Importance of Denser-Than-Air Mixtures. Atmosphere and Environment 12:2289.

Kaiser GD. (1979) Examples of the Successful Application of a Simple Model for the Atmospheric Dispersion of Dense Cold Vapours to the Accidental Release of Anhydrous Ammonia from Pressurized Containers. UKAEA Report SRD R 150.

Kaiser GD. (1981) The Accidental Release of Anhydrous Ammonia to the Atmosphere - Evidence for the Occurrence of Denser-Than-Air Mixtures. Loss Prevention Bulletin 38:1-22.

Kalelkar AS, and Cece J. (1974) Hazards of Liquid Ammonia Spills. Ammonia Plant Safety 16:56-58.

Kansa EJ, Ermak DL, Chan ST, and Rodean HC. (1983) Atmospheric Dispersion of Ammonia: An Ammonia Fog Model, UCRL - 88649. Livermore, CA: Lawrence Livermore National Laboratory.

Katz DL, and Sliepcevich CM. (1971) LNG/Water Explosions: Cause and Effect. Hydrocarbon Processing (November 1971):240-244.

Kaufmann S. (1976) Decision Making and Flammable Spill Handling, in Control of Hazardous Material Spills, pp. 320-322.

Kawenski EM, Nagy J, and Conn JW. (1969) Further Developments of an Ignition Quenching Device. International Conference of Safety in Mine Research, Tokyo.

Kawenski EM, Price GC, and Stephan CR. (1979) Frictional Ignition of Methane by Continuous-Mining Machines in Underground Coal Mines, DE 83 902 805. Mine Safety and Health Administration.

Keller VW, Anderson BJ, Burns RA, Lala GG, Meyer MB, and Beard KV. (1986) Development Testing of Large Volume Water Sprays for Warm Fog Dispersal, Technical Paper 2607. Washington, DC: National Aeronautics and Space Administration. (June 1986).

Kelly C. (1977) Dealing with Chlorine

Emergencies. Firehouse (December 1977):12-13.

Kent JH, and Williams FA. (1974) Extinction of Laminar Diffusion Flames for Liquid Fuels, in Fifteenth Symposium on Combustion, Pittsburgh. pp. 315-325.

Kilmartin J. (1984) Major Disaster Averted in Massive Escape of Vinyl Chloride. Fire Journal (January 1984):62-69.

Kinnebrock W. (1980) Notes on Experiments About the Behavior of Liquid Gases During Release, in Heavy Gas and Risk Assessment. p. 173.

Kirby DC, and Deroo JL. (1984) Water Spray Protection for a Chemical Processing Unit: One Company's View. Plant/Operations Progress 3:254-257. (October 1984).

Klauser W. (1980) CO₂ in the Atmosphere - Its Risk and Behavior During Release From the Point of View of Industry, in Heavy Gas and Risk Assessment. p. 255.

Klem TJ. (1985) Explosion in Cold Storage Kills Fire Fighter. Fire Journal (March 1985):43-80.

Klem TJ. Explosion in Cold Storage Kills Firefighter. Plant/Operations Progress 5(1):27-30.

Kletz TA. (1977) Unconfined Vapor Cloud Explosions. Loss Prevention 11:50-58.

Kneebone A, and Prew LR. (1974) Shipboard Jettison Tests of LNG Onto the Sea. Proceedings 4th. International Conference on LNG. Algiers.

Kocherga NG. (1971) Prevention of Methane Ignitions by Use of Water Spraying During Operation of the Cutting Tools on Mining Machines. Safety Extraction with Electromechanical Equipment. pp. 3-9.

Koopman RP, Cederwall RT, Ermak DL, Goldwire HC, Hogan WJ, McClure JW, McRae TG, et al. (1982) Analysis of Burro Series 40 M3 LNG Spill Experiments, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 43-84.

Koopman RP, Kamppinen LM, Hogan WJ, and Lind CD. (1981) Burro Series Data Report: LLNL/NWC 1980 Spill Tests, UCID 19075. Livermore CA: Lawrence Livermore National Laboratory.

Koopman RP, McRae TG, Goldwire HC, Ermak DL, and Kansa EJ. (1984) Results of Recent Large-Scale NH_3 and N_2O_4 Dispersion Experiments, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Koopman RP, and Thompson D. (1984) Description of a Test Site for Large-Scale Heavy Gas Dispersion and Combustion Experiments, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Koopman RP, et al. Description and Analysis of Burro Series 40 M³ LNG Spill Experiments, UCRL 53186. Livermore, CA: Lawrence Livermore National Laboratory.

Koopman RP. (1979) Data and Calculations of Dispersion on 5 M3 LNG Spill Tests, UCRL - 52876. Livermore, CA: Lawrence Livermore National Laboratory.

Kroop RK, and Martin JE. (1974) Treatability of Aqueous Film-Forming Foams used for Fire Fighting. Report No. AFWL-TR-73-279.

Kuhl AL, Kamel MM, and Oppenheim AK. (1973) Pressure Waves Generated by Steady Flames, in Fourteenth Symposium on Combustion, Pittsburgh. pp. 1201-1215.

Kung HC, You HZ, and Han Z. (1984) Effects of Water Discharge Rate and Drop Size on Spray Cooling in Room Fires, in Chemical and Physical Processes in Combustion. Pittsburgh, PA: Combustion Institute. pp. 30-1 to 30-4.

Labes WG. (1976) Evaluation of Fire Protection Spray Devices: The State-of-the-Art, PB 256 190. Fire Protection and Safety Engineering Department (June 1976).

Lagadec P. (1982) Major Technological Risk - an Assessment of Industrial Disasters. New York, NY: Pergamon.

Lambert AE. (1953) Quart. Instn. Fire Engineers Edinb. 13:28.

Lapin A., and Foster RH. (1967) Oxygen Diffusion in the Atmosphere from Liquid Oxygen Pools. Adv. Cryo. Eng. 13:555.

Lark JJ, Pizatella TJ, Bochnak PM, and Jensen RC. (1982) Selected Ignited Leaks During LPG Transfer Operations. Professional Safety (June 1982).

Layman L. (1955) Attacking and Extinguishing Interior Fires. Boston, MA: National Fire Protection Association.

Layman L. (1953) Fire Fighting Tactics. Boston, MA: National Fire Protection Association.

Layman L. Water - The Universal Extinguishing Agent. Elkhart: Elkhart Brass (Undated).

Lease W. (1975) Development and Testing Services of a Fire Protection System for Coal Augers, PB 249 865. U.S. Bureau of Mines (October 1975).

Leck MJ, and Lowe DJ. (1985) Development and Performance of the Gas Sensor System. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Ledbetter JO. (1978) Exclusion Area for Safety from High-Pressure Sour Gas Leaks. Am. Ind. Hyg. Assoc. J. 39(7):586-592. (July 1978).

Lederwall RT, et al. Burro Series 40 M3 LNG Spill Experiments, UCRL-86704. Livermore, CA: Lawrence Livermore National Laboratory.

Lee JH, Guirao CM, Chiu KW, and Back GG. (1977) Blast Effects from Vapor Cloud Explosions. Loss Prevention 11:59-70.

Lee JH, Knystautas R, and Guirao CM. (1974) Critical Power Density for Direct Initiation of Unconfined Gaseous Detonations, in Fifteenth Symposium on Combustion, Pittsburgh. pp. 53-67.

Lees FP. (1980) Loss Prevention in the Process Industries, 2 Volumes. London: Butterworths.

Lev Y. (1981) A Novel Method for Controlling LNG Pool Fires. Fire Technology 17(4):275-284.

Lev Y. (1981) The Use of Foam for LNG Fire Fighting. Fire Technology 17(1):17-24.

Lewis DJ. (1980) Unconfined Vapour Cloud Explosions, Historical Perspective and Predictive Method Based on Incident Records. Progress in Energy and Combustion Science 6.

Leyer JC, Guerraud C, and Manson N. (1974) Flame Propagation in Small Spheres of Unconfined and Slightly Confined Flammable Mixtures, in Fifteenth Symposium on Combustion, Pittsburgh. pp. 645-653.

Leyer JC. (1981) An Experimental Study of Pressure Field by Exploding Cylindrical Clouds. Euromech Colloquium 139 on Uncontrolled Blasts and Explosions in Industry. Aberystwyth (UK).

Liebman I, and Richmond JK. (1974) Suppression of Coal-Dust Explosions by Passive Water Barriers in a Single-Entry Mine, PB 231 102. U.S. Bureau of Mines.

Liebman I, and Richmond JK. (1981) Suppression of Coal Dust Explosion by Water Barrier in a Conveyor Belt Entry, PB 81 233 306. U.S. Bureau of Mines.

Liebman I, Corry J, Pro R, and Richmond JK. (1978) Extinguishing Agents for Mine Face Gas Explosions, PB 283 878. U.S. Bureau of Mines.

Liebman I, Corry J, and Richmond JK. (1976) Water Barriers for Suppressing Coal Dust Explosions, PB 258 110. US. Bureau of Mines.

Lind CD, and Whitson JC. (1974)
Explosion Hazards Associated with Spills
of Large Quantities of Hazardous
Materials - Phase I, USCG Report
CG-D-30-75, AD A 001 242.

Lind CD, and Whitson JC. (1977)
Explosion Hazards Associated with Spills
of Large Quantities of Hazardous
Materials - Phase II. USCG Report
CG-D-85-77, AD A 047 585.

Lind CD. (1980) Vapor Cloud Explosion
Study. 6th. International Conference on
Liquefied Gas, Kyoto.

Lind CD. (1975) What Causes Unconfined
Vapor Cloud Explosions? Loss Prevention
9:101-105.

Lindeken CL, Gaskill JR, and Taylor RD.
Effect of Smoke on the Formation and
Stability of High Expansion Foam.

Linville JL (editor) (1984) Industrial
Fire Hazards Handbook (Second Edition).
Boston, MA: National Fire Protection
Association.

Lohmeyer A, Meroney RN, and Plate EJ.
(1980) Model Investigations on the
Spreading of Heavy Gases Released from
an Instantaneous Volume Source at the
Ground. Proceedings of the 11th.
NATO/CCMS International Technical
Meeting on Air Pollution Modeling and
its Applications. Amsterdam, November
25-28, 1980. p. 1.

Lunn GA. (1984) The Maximum
Experimental Safe Gap: The Effects of
Oxygen Enrichment and the Influence of
Reaction Kinetics. Journal of Hazardous
Materials 8:261-270.

Lyons VJ, and Margle JM. (1986)

Velocity Profiles in Laminar Diffusion
Flames, NASA Technical Paper 2596. (May
1986).

Magee RS, and Reitz RD. (1974)
Extinguishment of Radiation Augmented
Plastic Fires by Water Sprays, in
Fifteenth Symposium on Combustion,
Pittsburgh. pp. 337-347.

Makay D, and Matsugu RS. (1973)
Evaporation Rates of Liquid Hydrocarbon
Spills on Land and Water. Can. J. Chem.
Eng. 51:434-439.

Marshall VC. (1981) Letter to the
Editor. Journal of Hazardous Materials
4:299-300.

Marshall VC. (1977) How Lethal are
Explosions and Toxic Escapes? Chemical
Engineer (August 1977):573-577.

Martinsen WE, and Cavin WD. (1981) LPG
Land Transportation and Storage Safety,
DOE/EV/06020-T5. U.S. Department of
Energy.

Martinsen WE, Muhlenkamp SP, and Olson
LJ. (1977) Disperse LNG Vapors with
Water. Hydrocarbon Processing (July
1977):261-266.

Masters RW. (1986) Using Water
Effectively at the Hydrocarbon Pressure
Fire. American Fire Journal (December
1986):22-35.

Maurer B, Hess K, Giesbrecht H, and
Leuckel W. (1977) Modeling of Vapour
Cloud Dispersion and Deflagration after
Bursting of Tanks Filled with Liquefied
Gas. 2nd. International Symposium on
Loss Prevention and Safety Promotion in
the Process Industries. Frankfurt.

Mausteller JW. (1979) Vapor Mitigation for Spilled Volatile Chemicals by Film and Foam Covers, in Oil and Hazardous Material Spills. pp. 109-114.

May WG, McQueen W, and Whipp RH. (1973) Dispersion of LNG Spills. Hydrocarbon Processing (May 1973):105-109.

McCaffrey BJ. (1985) Radiation Measurements of Large CH₄ Jet Diffusion Flames and the Effect of Water Sprays, in Chemical and Physical Processes in Combustion. Pittsburgh, PA: Combustion Institute. pp. 71-1 to 71-4.

McCaffrey BJ. (1985) Jet Diffusion Flame Suppression Using Water Sprays - Final Report. Combustion Science and Technology 40(3):107-136.

McCaffrey BJ. (1984) Jet Diffusion Flame Suppression Using Water Sprays - An Interim Report. National Bureau of Standards. (January 1984).

McCaffrey BJ. (1984) Jet Diffusion Flame Suppression Using Water Sprays: An Interim Report, PB 84 159 052. U.S. Department of the Interior. (January 1984).

McCoy JF, Schroeder WE, Rajan SR, Ruggieri SK, and Kissel FN. (1985) New Laboratory Measurement Method for Water Spray Dust Control Effectiveness. Am. Ind. Hyg. Assoc. J. 46(12):735-740.

McCoy JF, Melcher J, Valentine J, Monaghan D, Muldoon T, and Kelly J. (1983) Evaluation of Charged Water Sprays for Dust Control, PB 83 210 476. U.S. Bureau of Mines (January 1983).

McDaniel DE. (1974) Fire Extinguishing Effectiveness of a Synthetic Surfactant Foam, USCG AD 786 631.

McKiernan JV, and McDowell C. (1986) Handling Hazardous Materials Transportation Emergencies, in Fire Protection Handbook, 16th. Edition. Boston, MA: National Fire Protection Association.

McNaughton DJ, and Berkowitz CM. Overview of U.S. Research Activities in the Dispersion of Dense Gases, in Heavy Gas and Risk Assessment. p. 15.

McQuaid J, and Fitzpatrick RD. (1983) Air Entrainment by Water Sprays: Strategies for Application to the Dispersion of Gas Plumes. Journal of Occupational Accidents 5:121-133.

McQuaid J, and Fitzpatrick RD. (1981) The Uses and Limitations of Water-Spray Barriers. Symposium on the Containment and Dispersion of Gases by Water Sprays sponsored by the Institute of Chemical Engineers, Manchester, November 11, 1981.

McQuaid J, and Moodie K. (1983) The Scope for Reduction of the Hazard of Flammable or Toxic Gas Plumes. Journal of Occupational Accidents 5:135-141.

McQuaid J, and Roberts AF. (1982) Loss of Containment - Its Effects and Control. I. Chem. E. Jubilee Symposium. pp. B19 to B35.

McQuaid J. (1975) Air Entrainment into Bounded Axisymmetric Sprays. Proc. Inst. Mech. Eng. 189:197-202.

- McQuaid J. (1979) Dispersion of Heavier-Than-Air Gases in the Atmosphere. Health and Safety Executive Paper 8. Sheffield: HSE.
- McQuaid J. (1980) Dispersion of Heavier-than-Air Gases in the Atmosphere: Review of Research and Progress Report on HSE Activities. HSL Technical Paper No. 8. Sheffield: HSE.
- McQuaid J. (1980) Dispersion of Heavy Gases by the Wind and by Steam or Water Spray Barriers. Process Safety Lecture Teeside Polytechnic. (July 9, 1980).
- McQuaid J. (1978) Examination of Entrained Air-Flow Rate Data for Large-Scale Water Spray Installations. Health and Safety Laboratories.
- McQuaid J. (1977) Examination of Entrained Air-Flow Rate Data for Large Scale Water Spray Installations. Health and Safety Laboratories Technical Paper No. 1.
- McQuaid J. (1982) Future Directions of Dense-Gas Dispersion Research, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 231-247.
- McQuaid J. (1983) Large Scale Experiments on the Dispersion of Heavy Gas Clouds. I.U.T.A.M. Symposium on Atmospheric Dispersion of Heavy Gases and Small Particles. Delft.
- McQuaid J. (1984) The Box Model of Heavy Gas Dispersion: A Useful and Practical Tool. Journal of Occupational Accidents 6:253-261.
- McQuaid J. The Design of Water-Spray Barriers for Chemical Plants. 2nd. International Symposium on Loss Prevention and Safety Promotion in the Process Industries, Volume 2. Heidelberg: p. 511.
- McQuaid J. (1976) The Design of Water Spray Ventilators. Journal of Occupational Accidents 1:9-19.
- McQuaid J. (1982) The HSE Large Scale Experiments. Von Karman Institute Lecture Series 1982-3. Brussels.
- McQuaid J. (1985) Objectives and Design of the Phase I Heavy Gas Dispersion Trials. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.
- McRae MH. (1984) Ammonia Explosion Destroys Ice Cream Plant. Fire Command (April 1984):36-37.
- McRae TG, et al. (1984) Eagle Series Data Report, UCID-20063. Livermore, CA: Lawrence Livermore National Laboratory.
- McRae TG. (1982) Preliminary Analysis of RPT Explosions in the LLNL/NWC LNG Spill Tests, UCRL-87564. Livermore, CA: Lawrence Livermore National Laboratory.
- Mecca JE, and Ludwick JD. (1970) The Development of a Long Lived High Explosion Foam for Entrapping Air Bearing Noble Gas. Douglas United Nuclear Report No. DUN-SA-41. (August 1970).
- Meldrum DN. (1972) Aqueous Film-Forming Foams: Facts and Fallacies. Fire Journal 66(1):57.

Meldrum DN. (1982) Fighting Chemical Fires with Foam, in Safety and Accident Prevention in Chemical Operations, 2nd. Edition. New York, NY: Wiley. pp. 399-420.

Meldrum DN. (1977) Fighting Fire with Foam: Basics of Effective Systems. Society of Fire Protection Engineers, Technology Report 79-2. (May 1977).

Melvold RW, Byroade JD, and McCarthy LT. (1984) Emergency Response Procedures for Control of Hazardous Substance Releases, in 1984 Hazardous Material Spills Conference. pp. 141-150.

Merony RN, Lohmeyer A, and Plate EJ. (1981) Model Investigations of the Spreading of Heavy Gases Released from an Instantaneous Source at the Ground, in Air Pollution Modeling and its Application. Plenum. pp. 433-448.

Meroney RN, Neff DE, and Cermak JE. (1978) Wind Tunnel Modeling of LNG Spills. Proceedings AGA Transmission Conference, Montreal, May 8 - 10, 1978. pp. T 217 to T 223.

Meroney RN, Neff DE, and Heskestad G. (1984) Wind Tunnel Simulation of U.K. Health and Safety Executive Water Spray Curtain Dense Gas Dispersion Test. J. of Boundary Layer Meteorology 28:107-119.

Meroney RN, Neff DE, and Kothari KM. (1980) Behavior of LNG Vapor Clouds: Tests to Define the Size, Shape, and Structure of LNG Vapor Clouds: Annual Report for 1979-1980. Gas Research Institute Report GRI 79/0073. Chicago.

Meroney RN, and Lohmeyer A. (1982)

Gravity Spreading and Dispersion of Dense Gas Clouds Released Suddenly into a Turbulent Boundary Layer. Gas Research Institute Report 81/0025.

Meroney RN, and Lohmeyer A. (1984) Prediction of Propane Cloud Dispersion by a Wind Tunnel Calibrated Box Model. Journal of Hazardous Materials 8:205-221.

Meroney RN, and Lohmeyer A. (1984) Statistical Characteristics of Instantaneous Dense Gas Clouds Released in an Atmospheric Boundary Layer Wind Tunnel. Journal of Boundary Layer Meteorology 28:1-22.

Meroney RN, and Neff DE. (1980) Dispersion of Vapor from LNG Spills - Simulation in a Meteorological Wind Tunnel: Six Cubic Meter China Lake Spill Series. Proceedings of 4th. Colloquium on Industrial Aerodynamics, Aachen, FRG, June 18-20, 1980. pp. 303-320.

Meroney RN, and Neff DE. (1982) Dispersion of Vapor from LNG Spills - Simulation in a Meteorological Wind Tunnel: Six Cubic Meter China Lake Spill Series. Journal of Wind Engineering and Industrial Aerodynamics 10:1-19.

Meroney RN, and Neff DE. (1984) Heat Transfer and Humidity Effects During Cold Dense Gas Dispersion, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Meroney RN, and Neff DE. (1984) Heat Transfer Effects During Cold Dense Gas Dispersion: Wind Tunnel Simulation of Cold Gas Spills. American Society of Mechanical Engineers Winter Meeting. December 1984.

Meroney RN, and Neff DE. (1980) Laboratory Simulation of Liquid Natural Gas Vapor Dispersion Over Land or Water. Wind Engineering, Volume 2. New York, NY: Pergamon. pp. 1139-1150.

Meroney RN, and Neff DE. (1981) Physical Modeling of Forty Cubic Meter LNG Spills at China Lake, California, in Air Pollution Modeling and Its Application. Plenum.

Meroney RN. (1979) Lift-Off of Bouyant Gas Initially on the Ground. Journal of Industrial Aerodynamics 5:1-11.

Meroney RN. (1982) Wind-Tunnel Experiments on Dense Gas Dispersion, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 85-106.

Mertens W, and Cook D. (1986) Using the Right Foam is Critical to Achieving Target Response Time. Fire (March 1986):33-34.

Meyer E. (1977) Chemistry of Hazardous Materials. New York, NY: Prentice-Hall.

Milke JA. Literature Survey for Work Related to the Suppression of Blowout Fires and Extinction of Gaseous Diffusion Flames with Water. Letter Report to the Minerals Management Service.

Miller CF, Leone FA, and Bryan W. (1985) Liquefied Gaseous Fuels Spill Test Facility: Site Evaluation Study. Livermore, CA: Lawrence Livermore National Laboratory. (February 1985).

Miller J, and Paddock J. (1984) Acetic Anhydride Spill at Thorp, Wisconsin, in

1984 Hazardous Material Spills Conference. pp. 45-49.

Mine Safety and Health. (1981) Coal Mine Ignitions of Methane by Friction Show Five-Year Rise. U.S. Department of Labor/MSHA. (May/June 1981).

Ministry of International Trade and Industry (Japan) (1974) A Report on the Experimental Results of Explosions and Fires of Liquid Ethylene Facilities. Translated for Insurance Technical Bureau. London.

Mitchell DW, and Nagy J. Water as an Inert for Neutralizing the Coal Dust Explosion Hazard. U.S. Bureau of Mines.

Mitchell RL. (1982) Chlorine, in Hazardous Materials Spills Handbook. pp. 10-52 to 10-64.

Moen IO, Donato M, Knystantzas R, and Lee JH. (1980) Flame Acceleration Due to Turbulence Produced by Obstacles. Combustion and Flame 39:21.

Montague TJ, and MacNeil AR. (1980) Mass Ammonia Inhalation. Chest 77:496-498. (April 1980).

Moodie K. (1981) Experimental Assessment of Full-Scale Water Spray Barriers for Dispersing Dense Gases. North Western Branch Papers, Institution of Chemical Engineers.

Moodie K. (1985) The Use of Water Spray Barriers to Disperse Spills of Heavy Gases. Plant/Operations Progress 4:234-241. (October 1985).

Moran HE, Burnett JC, and Leonard JT. (1971) Suppression of Fuel Evaporation by Aqueous Film of Fluorocarbon Surfactant Solutions, NRL Report No. 7247. AD 723 189.

Morgan DL, Morris LK, and Ermak DL. (1983) Slab: A Time Dependent Computer Model for the Dispersion of Heavy Gases Released in the Atmosphere, UCRL-53383. Livermore, CA: Lawrence Livermore National Laboratory.

Morgan DL, Chan ST, Morris LK. (1984) Phenomenology and Modeling of Heavy Gas Dispersion, in 1984 Hazardous Material Spills Conference. pp. 302-310.

Morgan DL. (1983) Simulations and Parameter Studies of Heavy Gas Dispersion Using the Slab Model, UCRL-88516. Livermore, CA: Lawrence Livermore National Laboratory.

Morgan HP, and Bullen ML. (1976) A Method of Extracting Smoke from Buildings Using a Water-Air Jet Pump. Fire Technology 12(4):311-319.

Mudan KS. (1984) Blast Waves in Partially Confined Spaces - A Numerical Simulations Model, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Mudan KS. (1984) Hydrocarbon Pool and Vapor Fire Data Analysis. U.S. Department of Energy. (October 1984).

Mullins BP, and Penner SS. (1959) Explosions, Detonations, Flammability and Ignition. New York, NY: Pergamon Press.

Mullins BP. (1955) Spontaneous Ignition of Liquid Fuels. London: Butterworths.

Nagy J, and Verakis HC. (1983) Development and Control of Dust Explosions. New York, NY: Dekker.

Nagy J, Kawenski EM, and Barrett EA. (1970) Control of the Dust Explosion Hazard on Coal Mine Shuttle Car Runways. U.S. Bureau of Mines.

Nakakuki A, and Takahashi M. (1971) Extinction of Liquid Fuel Fires with Water Sprays. Bulletin of the Fire Prevention Society (Japan) 20(2):83-99.

Nakakuki A. (1972) Water Spray Properties and Extinction with Single Spray Nozzles. Fire Technology 8(1):(February 1972).

Napier DH, and Roopchand DR. (1986) An Approach to Hazard Analysis of LNG Spills. Journal of Occupational Accidents 7:251-272.

NAS. (1973) Evaluation of the Hazard of Bulk Water Transportation of Industrial Chemicals (A Tentative Guide), CG-D-63-74, AD 775 756. U.S. Coast Guard.

NAS. (1974) System for Evaluation of the Hazards of Bulk Water Transportation of Individual Chemicals, CG-D-113-74, AD 782 476. U.S. Coast Guard.

Nash P. (1975) The Essentials of Sprinkler and Other Water Spray Fire Protection Systems. Fire Prevention (108):15-26.

National Board of Fire Underwriters. Characteristics of Water Spray Nozzles, Including Those Designed as Fog Nozzles, for Fire Fighting Use. New York, NY: NBFU.

National Board of Fire Underwriters.
(1955) The Mechanism of Extinguishment
of Fire by Finely Divided Water.

National Fire Protection Association.
(1952) Studies of Fire Department "Fog"
or Water Spray Nozzles. Boston, MA:
National Fire Protection Association.

National Fire Protection Association.
(1985) Fire Fighter Dies in Ammonia
Explosion. Fire Command (February
1985):43-44.

National Fire Protection Association.
(1975) Manual on Aircraft Rescue and
Fire Fighting Techniques for Fire
Departments Using Structural Fire
Apparatus and Equipment (NFPA
406M-1975). Boston, MA: National Fire
Protection Association.

National Fire Protection Association.
(1985) Standard for the Installation of
Sprinkler Systems (NFPA 13-1985).
Boston, MA: NFPA.

National Fire Protection Association.
(1978) Standard for Water Spray Fixed
Systems for Fire Protection. (NFPA
15-1985). Boston, MA: NFPA.

National Fire Protection Association.
(1978) Standard on Explosion Prevention
Systems (NFPA 69-1978). Boston, MA:
NFPA.

National Fire Protection Association.
(1984) The National Electrical Code
(NFPA 70-1984). Boston, MA: NFPA.

National Foam. National Foam
Engineering Manual. Lionville.

Neary RM. (1960) Handling Cryogenic

Fluids. Boston, MA: National Fire
Protection Association.

Nedved M. (1980) Explosions -
Prevention and Control. Occupational
Health 32:358-362. (July 1980).

Neff DE, and Meroney RF. (1981) The
Behavior of LNG Vapor Clouds. Colorado
State University for Gas Research
Institute.

Neff DE, and Meroney RN. (1979)
Dispersion of Vapor from LNG Spills -
Simulation in a Meteorological Wind
Tunnel of Spills at China Lake Naval
Weapons Center. Fluid Mechanics and
Wind Engineering, Report CER 78-79
DEN-RNM 41: Colorado State University.
p. 77.

Neff DE, and Meroney RN. (1982) The
Behavior of LNG Vapor Clouds: Wind
Tunnel Tests on the Modeling of Heavy
Plume Dispersion. Gas Research
Institute Report 80/0145.

Nettleton MA. Detonation and
Flammability Limits of Gases in Confined
and Unconfined Situations. Fire
Prevention Science and Technology
(23):29-30.

Nettleton MA. (1976) Alleviation of
Blast Waves from Large Vapour Clouds.
Journal of Occupational Accidents 1:3-8.

Nettleton MA. (1976) Some Aspects of
Vapour Cloud Explosions. Journal of
Occupational Accidents 1:149-158.

Nicolson PC, and Artman DD. (1977) A
Technique for the Evaluation of AFFF
Sealing Characteristics. Fire
Technology 13(1):13-20.

Nikodem HJ. (1982) Examples of Analyses of Gas Cloud Explosion Hazards, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

Nikodem HJ. (1980) Risk Analysis for Storage and Transport of LNG, in Heavy Gas and Risk Assessment. p. 177.

NIOSH. (1978) A Guide for Developing a Training Program for Anhydrous Ammonia Workers, DHHS (NIOSH) Publication No. 79-119. Cincinnati, OH.

NIOSH. (1986) NIOSH Alert: Request for Assistance in Preventing Fatalities Due to Fires and Explosions in Oxygen-Limiting Silos, DHHS (NIOSH) Publication No. 86-118.

Noll G. (1986) Evaluating the Use of Firefighting Foams. Fire Engineering (February 1986):44-49.

Noll G. (1986) Personal Communication (Document Review) Washington, DC: American Petroleum Institute (August 18, 1986).

Norman EC, and Dowell HA. (1980) Using Aqueous Foams to Lessen Vaporization from Hazardous Chemical Spills. Loss Prevention 13:27-33. (AIChE).

Norman EC, and Dowell HA. (1978) The Use of Foams to Control Vapor Emissions from Hazardous Material Spills, in Control of Hazardous Material Spills. pp. 399-405.

Norman EC. (1982) Vapor Mitigation by the Use of Foam: Case History and Large-Scale Outdoor Tests, in 1982 Hazardous Material Spills Conference. pp. 363-365.

Nuclear Weapons Firefighting Procedures. Department of the Army Technical bulletin. (February 1976).

Nusbaum MS. (1975) Molten Aluminum - Water Explosion Initiation Mechanism Study. Chicago, IL: ITT Research Institute.

Nussey C, Mercer A, and Fitzpatrick RD. (1984) The Effect of Uncertainty in Chlorine Toxicity Data on Risk Estimation, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Nussey C, Davies JKW, and Mercer A. (1985) The Effect of Averaging Time on the Statistical Properties of Sensor Records. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Office of Technology Assessment. (1986) Transportation of Hazardous Materials, OTA-SET-304. Washington, DC: U.S. Congress Office of Technology Assessment.

Office of Technology Assessment. (1986) Transportation of Hazardous Materials: State and Local Activities, OTA-SET-305. Washington, DC: U.S. Congress.

Office of Technology Assessment. (1986) Transportation of Hazardous Materials: State and Local Activities, OTA-SET-301, Washington, DC: U.S. Congress Office of Technology Assessment.

Opschoor G. (1980) The Spreading and Evaporation of LNG - and Burning LNG - Spills on Water. Journal of Hazardous Materials 3:249-266.

Pacific Northwest Laboratory. (1981) Assessment of Research and Development (R&D) Needs in Ammonia Safety and Environmental Control, PNL - 4006. U.S. Department of Energy.

Pacific Northwest Laboratory. (1979) Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: A Status Report, DOE/EV - 0036. U.S. Department of Energy.

Pacific Northwest Laboratory. (1982) Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: Third Status Report, PNL - 4172. U.S. Department of Energy.

Page SJ. (1982) An Evaluation of Three Wet Dust Control Techniques for Face Drills, PB 82 177 320. U.S. Bureau of Mines. (January 1982).

Palazzi E, Fumorola G, De Faveri DM, and Gerraiolo G. (1984) Flammability Limits with Short Duration Gas Releases. Plant/Operations Progress 3:159-163. (July 1984).

Parker RO, and Spata JK. (1968) Downwind Travel of Vapors From Large Pools of Cryogenic Liquids. First International Conference on Liquefied Natural Gas, Chicago, IL, (April 7-12, 1968).

Parker RO (1970) A Study of Downwind Vapor Travel from LNG Spills. AGA Distribution Conference, Seattle, WA, (May 25-28, 1970).

Parker RO. (1974) A Vapor Dispersion Data Correlation Compared to a Vapor Dispersion Model, AGA Project IS-3-1 (July 1, 1974).

Pelto PJ, Baker EG, and Hall RJ. (1979)

Assessment of LNG Release Prevention and Control, DOE/EV-0046. U.S. Department of Energy.

Perry RH, Green DW, and Maloney JO. (1984) Perry's Chemical Engineers' Handbook. New York, NY: McGraw-Hill. p. 3-73.

Peterson P. (1986) Special Systems for Explosion Damage Control, in Fire Protection Handbook, 16th. Edition. Boston, MA: National Fire Protection Association.

Pfenning DB, and Cornwell JB. (1985) Computerized Processing of Thorney Island Trial Data for Comparison with Model Predictions. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Picknett RG. (1981) Dispersion of Dense Gas Puffs Released in the Atmosphere at Ground Level. Atmosphere and Environment 15:509.

Picknett RG. (1978) Field Experiments on the Behaviour of Dense Gas Clouds - Parts 1-3, Porton Report PTN/IL 1154/78/1 to 3.

Pietersen CM. (1984) Calculation of Intoxification Effects in a Risk Analysis Associated with Toxic Gases, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Pignato JA, Huber JC, Hottinger JJ, and Sierakowski MJ. (1982) Foam Agent to Mitigate the Vapors from Hazardous Material Spills, in 1982 Hazardous Material Spills Conference, pp. 366-372.

Pignato JA. (1984) Evaluation Test for Foam Agent Effectiveness. Fire Engineering (July 1984):45-48.

- Pignato JA. (1983) Enhancement of Fire Protection with Directional Cooling Spray Nozzles by Use of AFFF. *Fire Technology* 19(1):5-13.
- Pikaar MJ. (1985) Unconfined Vapour Cloud Dispersion and Combustion - An Overview of Theory and Experiments. *Chemical Engineering Research Design* 63(March 1985):75-81.
- Porteous WM. (1975) Super Heating and Cryogenic Vapor Explosions. Cambridge, MA: Massachussettes Institute of Technology (Ph.D. Thesis).
- Powell F, and Billinge K. (1975) Ignition of Firedamp by Friction During Rock Cutting. *The Mining Engineer* (May 1975):419-426.
- Powell F, and Billinge K. (1981) The Use of Water in the Prevention of Ignitions Caused by Machine Picks. *The Mining Engineer* (August 1981):81-85.
- Properties and Essential Information for Safe Handling and Use of Anhydrous Ammonia. Manufacturing Chemists Association, Inc. (1952).
- Puttock JS, et al. (1982) Maplin Sands Experiments 1980: Dispersion Results from Continuous Releases of Refrigerated Liquid Propane and LNG. NATO/CCMS 13th. International Technical Meeting on Air Pollution Modeling, Cannes.
- Puttock JS, Blackmore DR, and Colenbrander GW. (1982) Field Experiments on Dense Gas Dispersion, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 13-42.
- Puttock JS, Colenbrander GW, and Blackmore DR. (1982) Maplin Sands Experiments 1980: Dispersion Results from Continuous Releases of Refrigerated Liquid Propane, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.
- Puttock JS, and Colenbrander GW. (1985) Thorney Island Data and Dispersion Modelling. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.
- R & D Associates and Colorado State University. (1978) Liquefied Natural Gas Wind-Tunnel Simulation and Instrumentation Assessments. U.S. Department of Energy Report SAN/W 1364-01. p. 390.
- Rabie RL, Fowles GR, and Fickett W. (1979) The Polymorphic Detonation. *Phys. Fluids* 22:422.
- Radusch R. Observations on the Most Favorable Size Drops for Extinguishing Fires with Atomized Water and on the Range of a Stream of Water Spray. V.F.D.B. Zeilschrift Forschung and Techvik Im Brandschnitz Z.
- Raj PK, Hagopian J, and Kalelkar AS. (1974) Prediction of Hazards of Spills of Anhydrous Ammonia Onto Water, NTIS AD 779 400.
- Raj PK, Hagopian JH, Kalelkar AS, and Cece J. (1975) Predicting Hazards from Ammonia Spills. *Ammonia Plant Safety* 17:102-108.
- Raj PK. (1981) Models for Cryogenic Liquid Spill Behavior on Land and Water. *Journal of Hazardous Materials*. Amsterdam: 5:111-130.

Puttock JS, Colenbrander GW, and

- Raj PK, and Kalelkar AS. (1974) Assessment Models in Support of the Hazard Assessment Handbook, CG 446 3 AD 776 617. U.S. Coast Guard. (January 1974).
- Raj PK. (1979) A Criterion for Classifying Accidental Liquid Spills into Instantaneous and Continuous Types. *Combustion Science and Technology* 19:251.
- Raj PK, and Hagopian JH. (1974) Hazards Presented by the Release of Anhydrous Ammonia on Water, Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. pp. 179-187.
- Raj PK, and Reid RC. Fate of Liquid Ammonia Spilled Onto Water. *Environmental Science and Technology* 12(13):1422-1425.
- Raj PK. (1982) Ammonia, in Hazardous Material Spills Handbook. pp. 10-34 to 10-51.
- Raj PK, et al. (1979) Experiments Involving Pool and Vapour Fires from Spills of LNG on Water, Report No. 82404. Arthur D. Little.
- Ramsdell JV, and Hinds WT. (1971) Concentration Fluctuations and Peak-to-Mean Concentration Ratios in Plumes from a Ground Level Continuous Point Source. *Atmosphere and Environment* 5:483-495.
- Ramsey CG, Sylvester-Evans R, and English MA. (1982) Siting and Layout of Major Hazardous Installations. I. Chem. E. Symp. Series No. 71.
- Rasbash DJ, Rogowski ZW, and Stark GWV. (1960) Mechanism of Extinction of Liquid Fire with Water Spray. *Combustion and Flame* 4(3):223-234.
- Rasbash DJ, and Rogowski ZW. (1954) The Extinction of Liquid Fires with Water Sprays. *Chemistry and Industry* (London):693-695.
- Rasbash DJ. (1980) An Examination of Fire Hazards Arising from the Transport of Liquid Fuels. *Fire* (February 1980):479-481.
- Raybutt P. (1982) Procedures for the Use of Risk Analysis in Decision Making, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.
- Reed JD. (1974) Containment of Leaks from Vessels Containing Liquefied Gases with Particular Reference to Ammonia. Loss Prevention Symposium, The Netherlands. (May 1974).
- Rees D. (1981) Forced Dispersion of Gases by Water and Steam. BP Research Centre Report No. 20-913.
- Reid JD. Dispersion of Denser-than-Air Gases, Report AQRB-80-005-L. Atmospheric Environment Service (Canada).
- Reid RC. (1980) Boiling of LNG on Typical Dyke Floor Materials, GRI 79/0026. LNG Research Center, Massachusetts Institute of Technology, for Gas Research Institute.
- Reid RC, and Smith KA. (1978) Behavior of LPG on Water. *Hydrocarbon Processing* (April 1978):117-121.
- Reid RC. (1980) Some Theories on Boiling Liquid Expanding Vapour Explosions. *Fire* (March 1980): 525-526.

- Reijnhart R, Piepers J, and Toneman LH. (1980) Vapour Cloud Dispersion and the Evaporation of Volatile Liquids in Atmospheric Wind Fields - I. Theoretical Model. *Atmosphere and Environment* 14:751-757.
- Reijnhart R, and Rose R. (1980) Vapour Cloud Dispersion and the Evaporation of Volatile Liquids in Atmospheric Wind Fields - II. Wind Tunnel Experiments. *Atmosphere and Environment* 14:759-762.
- Reischl U. (1979) Water Fog Stream Radiation Attenuation. *Fire Technology* 15(4):262-270.
- Report of the 10th. International Symposium on the Prevention of Occupational Accidents and Diseases in the Chemical Industry, CIS 85-2037.
- Riethmuller ML. (1985) Computer Processing of Visual Records from the Thorney Island Large Scale Gas Trials. in *Heavy Gas Dispersion Trials at Thorney Island*. Elsevier.
- Rijnmond Public Authority. (1982) Risk Analysis of Six Potentially Hazardous Industrial Objects in the Rijnmond Area. D.Reidel.
- Ripley DJ. (1986) Personal Communication (Document Review). Marinette, WI: Ansul Fire Protection, International Department, Wormald U.S., Inc. (July 24, 1986).
- Roberts AF, and Pritchard DK. (1982) Blast Effect from Unconfined Vapour Cloud Explosions. *Journal of Occupational Accidents* 3:231-247.
- Roberts AF. (1974) Extinction Phenomena in Liquids, in *Fifteenth Symposium on Combustion*, Pittsburgh, pp. 305-313.
- Rodean HC, et al. (1984) Vapor Burn Analysis for the Coyote Series LNG Spill Experiments, UCRL - 53530. Livermore, CA: Lawrence Livermore National Laboratory.
- Rodean HC, and Cedarwall RT. (1982) Analysis of Turbulent Wind-Velocity and Gas-Concentration Fluctuations During the Burro Series 40-M3 LNG Spill Experiments, . Livermore, CA: Lawrence Livermore National Laboratory.
- Roebuck B, and Rooker K. (1982) An Automatic Suppression System for Coal Dust Explosions. Health and Safety Executive, Research Paper 14.
- Roebuck B. (1985) The Presentation and Availability of the Data and Plans for Future Analysis. in *Heavy Gas Dispersion Trials at Thorney Island*. Elsevier.
- Ronk R, White MK, and Linn H. (1984) Personal Protective Equipment for Hazardous Materials Incidents: A Selection Guide, DHHS (NIOSH) 84-114. PB 85 222 230.
- Ronk R. (1985) Request for Assistance in Preventing Hazards in the Use of Water Spray (Fog) Streams to Prevent or Control Ignition of Flammable Atmospheres. Morgantown, WV: National Institute for Occupational Safety and Health, Division of Safety Research. (See Appendix 2).
- Rosenhan AK. (1986) Fire Department Apparatus, Equipment, and Facilities, in *Fire Protection Handbook*, 16th. Edition. Boston, MA: National Fire Protection Association.

Rosenzweig JJ. (1980) A Theoretical Model for the Dispersion of Negatively Bouyant Vapor Clouds. Cambridge, MA: Massachussettes Institute of Technology (Ph.D. Dissertation)

Ross JA. (1981) The National Electrical Code Handbook (Second Edition). Boston, MA: National Fire Protection Association.

Rosser WA, Inami SH, and Wise H. (1961) Study of the Mechanisms of Fire Extinguishment of Propellants, ASD Technical Report 61-143. Dayton, OH: Wright-Patterson AFB, Aeronautical Systems Division.

Rothchild RD, and Guzdar AR. (1976) Longwall Ignition Suppression, PB 270 696. U.S. Department of Commerce. (September 1976).

Rottman JW, Hunt JCR, and Mercer A. (1985) The Initial and Gravity Spreading Phases of Heavy Gas Dispersion: Comparison of Models with Phase I Data. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Rottman JW, Simpson JE, Hunt JCR, and Britter RE. (1985) Unsteady Gravity Current Flows Over Obstacles: Some Observations and Analysis Related to the Phase II Trials. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Ryckman MD, Rains BA, and Miller RL. (1980) Flammable Liquid Spills - Response and Control. Control of Hazardous Materials Spills. HMCRI.

Ryderman A. (1982) Testing of Foam as a Fire Extinguishing Medium for Polar Solvent and Petroleum Fires.

FOU-Brand. pp. 12-16.

Sadee C, Samuels DE, and O'Brien TP. (1976) The Characteristics of the Explosion of Cyclohexane at the Nypro (UK) Flixborough Plant on 1st. June 1974. Journal of Occupational Accidents 1:203-235.

Sakagami J, and Kato M. Diffusion and Vapour Rise of Methane Vapour from a Real Source in Air Stream. Natural Science Report of Ochanomizu University 19(2):59-66.

Salzer IO, Sun SM, Schwendeman JL, and Wurstner AL. (1970) Foam Suppression of Respirable Coal Dust. Dayton, OH: Monsanto.

Sapko MJ, et al. (1977) Quenching Methane-Air Ignitions with Water Sprays, PB 266 727. U.S. Bureau of Mines.

Sapko MJ, Furno AL, and Kuchta JM. (1977) Quenching Methane-Air Ignitions with Water Sprays. U.S. Dept. of Commerce, Pittsburgh Mining and Safety Research Center.

Sass HM. (1984) Technical and Cultural Aspects of Risk Perception, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Schmit KM, Lee TE, Mitchen KM, and Spiteri EE. (1978) How to Cope with Aluminum Alkyls. Hydrocarbon Processing (November 1978):341-353.

Schnatz G, Kirsch L, and Heudorfer W. (1982) Investigation of Energy Fluxes in Heavy Gas Dispersion, in Heavy Gas and Risk Assessment, Volume 2. Boston, MA: D. Reidel.

- Schnatz G, and Flothman D. (1980) The 'K' Model and its Modification for the Dispersion of Heavy Gases, in Heavy Gas and Risk Assessment. p. 125.
- Schnatz G. (1984) Major Results of the BMFT-HSE Heavy Gas Project, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.
- Schuler G. (1961) Experimental and Theoretical Investigations of Water Curtains. V.F.D.B Zeitschrift 10(2):65-68. (May 1961).
- Schulze RH. (1982) Atmospheric Dispersion, in Hazardous Materials Spills Handbook. pp. 10-13 to 10-20.
- Seekamp H. (1960) Investigations on the Effectiveness of Water Curtains. V.F.D.B. Zeitschrift 9(1):34-38. (February 1960).
- Seery DJ, and Palmer HB. (1960) The Influence of Secondary Atmospheric Moisture Upon Carbon Monoxide Flames. Combustion and Flame 4:289-292.
- Sergeant RJ, and Robinett FE. (1968) An Experimental Investigation of the Atmospheric Diffusion and Ignition of Boil-Off Vapors Associated with a Spillage of Liquefied Natural Gas. TRW Systems, Inc. Report No. 08072-7. American Gas Association.
- Shaver DK, and Berkowitz RL. (1983) Guidelines Manual: Post Accident Procedures for Chemicals and Propellants, AD A126 636. U.S. Department of Transportation.
- Shaw P, and Briscoe F. (1978) Evaporation from Spills of Hazardous Liquids on Water. Proceedings of 5th. International Symposium on the Transport of Dangerous Goods by Sea and Inland Waterways. Hamburg.
- Shimy AA. (1970) Calculating Flammability Characteristics of Hydrocarbons and Alcohols. Fire Technology 6(2):135-139.
- Simmons JA, Erdman RC, and Naft BN. (1974) Risk Assessment of Large Spills of Toxic Materials. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. pp. 166-175.
- Slater DH. (1978) Vapour Clouds. Chemistry and Industry (May 6, 1978):295-302.
- Smart PMT. (1951) The Use of Water Sprays as Protection Against Radiant Heat, F.P.E. Note No. 66/1951. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization.
- Smith AJ. (1981) Managing Hazardous Substances Accidents. New York, NY: McGraw-Hill.
- Smith JM, and Van Doorn M. (1981) Water Sprays in Confined Applications: Mixing and Release from Enclosed Spaces. North Western Branch Papers Institution of Chemical Engineers.
- Smith M. (editor) (1968) Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. New York, NY: American Society of Mechanical Engineers.

Spicer TO, and Havens JA. (1984) Development of a Heavier-than-Air Dispersion Model for the U.S. Coast Guard Hazardous Assessment Computer System, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Spicer TO, and Havens JA. (1984) Modeling the Phase I Thorney Island Experiments. Symposium on the Thorney Island Heavy Gas Trials. HSE.

Spicer TO. (1985) Development of an Experimental and Mathematical Model for Heavier-than-Air Gas Dispersion in the Atmosphere. University of Arkansas (Ph.D. Dissertation).

Spicer TO, and Havens JA. (1985) Modeling the Phase I Thorney Island Experiments. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Stafford S. (1981) Devices to Quench Methane Flames Work in Lab, But Not Yet in Practice. Mine Safety and Health (July-August 1981):8-13.

Stecher GE. (1953) Fire Prevention and Protection Fundamentals. Philadelphia, PA: The Spectator.

Stock M, and Geiger W. (1984) Assessment of Vapour Cloud Explosion Hazards Based on Recent Research Results. Proceedings of 9th. International Symposium on the Prevention of Occupational Accidents and Diseases in the Chemical Industry. Luzern.

Strazisar AJ, Stein RI, and Tomb TF. (1972) Use of Steam to Control Respirable Coal Dust at the Point of Generation, PB 209 576. U.S. Bureau of Mines.

Strehlow FA. (1973) Unconfined Vapor

Cloud Explosions - an Overview. 14th. Symposium on Combustion. Pittsburgh, PA. pp. 1189-1200.

Stull DR. (1977) Fundamentals of Fire and Explosion. New York, NY: American Institute of Chemical Engineers.

Sumner CA, and Pfann JR. (1976) Sulfer Trioxide Spill Control, in Control of Hazardous Material Spills. HMCRI. pp. 192-196.

Super Vacuum Manufacturing Company. (1972) Super Vac Drill Manual and Operating Instructions for Smoke Ejectors. Loveland: Super Vacuum Manufacturing Co., Inc.

Sykes WG, Johnson RH, and Hainer RM. (1963) Ammonium Nitrate Explosion Hazards. Chemical Engineering Progress 59(1):66-71.

Takimoto HH, Lewis S, and Hiltz R. (1984) Vapor Suppressant Foam Systems for Propellant Spills, in 1984 Hazardous Material Spills Conference. pp. 125-128.

Tamas J. (1986) Determining Physical Properties for Multicomponent Hydrocarbon Mixtures. Chemical Engineering (September 29, 1986):103-108.

Taylor MW, Lind CD, and Cece JM. (1978) Vapor Cloud Explosion Study, in Control of Hazardous Material Spills. pp. 406-410.

Te Riele PHM. (1977) Atmospheric Dispersion of Heavy Gases Emitted at or Near Ground Level. 2nd. International Symposium on Loss Prevention and Safety Promotion in the Process Industries. Heidelberg.

Teele BW. (1981) Fire Department Facilities, Apparatus, and Equipment, in Fire Protection Handbook, 15th. Edition. Boston, MA: National Fire Protection Association.

The Assessment of Major Hazards. I. Chem. E. Symp. Manchester. (1982).

The Chlorine Institute. (1981) Calculating the Area Affected by Chlorine Releases. New York, NY: The Chlorine Institute.

Thomas PH. (1952) Absorption and Scattering of Radiation by Water Sprays of Large Drops. British Journal of Applied Physics 3(12):385-393.

Thompson NJ. (1964) Fire Behavior and Sprinklers. Boston, MA: National Fire Protection Association.

Thorne PF. (1978) The Dilution of Flammable Polar Solvents by Water for Safe Disposal. Journal of Hazardous Materials 2:321-332.

Tomb TF, Emmerling JE, and Kellner RH. (1972) Collection of Airborne Coal Dust by Water Spray in a Horizontal Duct. Am. Ind. Hyg. Assoc. J. 33:715-721. (November 1972).

Turner DB. (1970) Workbook of Atmospheric Dispersion Estimates. U.S. Department of Health, Education, and Welfare. NTIS PB 191 482.

Tuve RL, and Peterson HB. (1950) Naval Research Lab: Report 3725. (August 1950).

Tuve RL, et al. (1964) A New

Vapor-Securing Agent for Flammable-Liquid Fire Extinguishment. NRL Report 6057.

Tuve RL. (1976) Principles of Fire Protection Chemistry. Boston, MA: National Fire Protection Association.

Underwriters Laboratories. Proposed Second Edition of the Standard for Portable Spray Hose Nozzles for Fire Protection. 401 Draft.

Underwriters Laboratories. Standard for Portable Spray Hose Nozzles for Fire Protection Service, UL 401-86.

University Engineers. (1971) LNG Vapor Dispersion and Fire Tests. Norman. (December 1971).

University Engineers. (1974) An Experimental Study on the Mitigation of Flammable Vapor Dispersion and Fire Hazards Immediately Following LNG Spills on Land. American Gas Association Project IS-100-1. (February 1974).

University Engineers. (1972) LNG Fire Control, Fire Extinguishment, and Vapor Dispersion Tests - Final Report. Norman. (July 1972).

Unterberg W, Melvold RW, Flaherty LM, McCarthy LT. (1984) Procedures for Selection of Countermeasures for Hazardous Substance Releases, in 1984 Hazardous Material Spills Conference. pp. 151-161.

U.S. Bureau of Mines (1978) Coal Mine Fire and Explosion Prevention. Proceedings of Bureau of Mines Technology Transfer Seminars, PB 278 499.

U.S. Public Health Service. Workbook of Atmospheric Dispersion Estimates. NTIS PB 191 482.

Valencia-Chavez JA, and Reid RC. (1979) The Effect of Composition on the Boiling Rates of Liquefied Natural Gas for Confined Spills on Water. *Int. J. Heat Mass Transfer* 22:831-838.

Van Buijtenen CJP [also Van Buytenen] (1980) Calculation of the Amount of Gas in the Explosive Region of a Vapour Cloud Released in the Atmosphere. *Journal of Hazardous Materials* 3:201.

Van Den Berg AC. (1985) The Multi-Energy Method: A Framework for Vapour Cloud Explosion Blast Prediction. *Journal of Hazardous Materials* 12:1-10.

Van Dolah RW, Zabetakis MF, Burgess DS, and Scott GS. Flame Propagation, Extinguishment and Environmental Effects on Combustion. *Fire Technology*.

Van Dolah RW, Zabetakis MF, Burgess DS, and Scott GS. (1962) Review of Fire and Explosion Hazards of Flight Vehicle Combustibles, IC 8137. U.S. Bureau of Mines.

Van Doorn M, and Smith JM. (1980) Gas Cloud Containment with Water Sprays. 3rd. International Symposium on Loss Prevention and Safety Promotion in the Process Industries. pp. 15-1068 to 15-1077.

Van Doorn M. (1981) The Control and Dispersion of Hazardous Gas Clouds with Water Sprays. Delft: Delft University Press.

Van Eijndhoven PP, Niewenhuizen JK, and Wally R. (1974) The Cooling of LPG Storage Tanks in Case of Fire. Loss Prevention and Safety Promotion in the Process Industries. The Hague. pp. 405-424.

Van Heugten WHH, and Duijm NJ. (1985) Some Findings Based on Wind Tunnel Simulation and Model Calculations of Thorney Island Trial No. 008. in Heavy Gas Dispersion Trials at Thorney Island. Elsevier.

Van Ulden AP. (1984) A New Bulk Model for Dense Gas Dispersion: Two-Dimensional Spread in Still Air, in Atmospheric Dispersion of Heavy Gases and Small Particles. Springer. pp. 419-440.

Van Ulden AP. (1974) On the Spreading of a Heavy Gas Released Near the Ground. Loss Prevention and Safety Prevention Seminar. Delft.

Van Ulden AP. (1974) On the Spreading of a Heavy Gas Released Near the Ground. Proceedings of International Loss Prevention Symposium. The Hague.

Van Ulden AP. (1979) The Unsteady Gravity Spread of a Dense Cloud in a Calm Environment. NATO/CCMS Conference. (November 1979).

Verhagen TLA, and Van Butyenen CJP. (1984) Validation of the TNO Heavy Gas Dispersion Model, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Vervalin CH. (1985) Fire Protection Manual for Hydrocarbon Processing Plants, Volume 3. Houston, TX: Gulf.

Vervalin CH. (1981) Fire Protection Manual for Hydrocarbon Processing Plants, Volume 2. Houston, TX: Gulf.

Vincent GC, and Howard WB. (1976) Part I: Hydrocarbon Mist Explosions - Prevention by Explosion Suppression. Loss Prevention 10:43.

Vincent GC, Nelson RC, Howard WB, and Russel WW. (1976) Part II: Hydrocarbon Mist Explosions - Prevention by Water Fog. Loss Prevention 10:55.

Volkwein JC, Vinson RP, and Thimons ED. (1982) Effectiveness of Three Water Spray Methods Used to Control Dust During Bagging. U.S. Bureau of Mines Report of Investigations.

Walls WL. (1971) Fire Protection for LNG Plants. Hydrocarbon Processing (September 1971):205-208.

Walls WL. (editor) (1986) Liquefied Petroleum Gases Handbook. Boston, MA: National Fire Protection Association.

Walls WL. (1985) Cope with LNG Plant Fires, in Fire Protection Manual for Hydrocarbon Processing Plants. pp 454-458.

Walton WH, and Woolcock A. (1960) The Suppression of Airborne Dust by Water Spray. Proceedings of Conference on Aerodynamics. Leatherhead, Surrey. (B.C.U.R.A.). pp. 129-153.

Warden J. (1983) Breakthrough Claimed for Foam Solutions. Fire (September 1983):156.

Watts JW. (1976) Effects of Water Spray

on Unconfined Flammable Gas. Loss Prevention 10:48.

Webber DM, and Brighton PWM. (1984) A Mathematical Model of a Spreading, Vaporized Liquid Pool, in Heavy Gas and Risk Assessment, Volume 3. Boston, MA: D. Reidel.

Webber DM. (1983) The Physics of Heavy Gas Cloud Dispersal, SRD R-243. Culcheth:UKAEA.

Welker JR, Wesson HR, and Brown LE. (1974) Use Foam to Disperse LNG Vapors? Hydrocarbon Processing (February 1974):119-120.

Welker JR, Wesson HR, and Sliepcevich CM. (1969) LNG Spills - To Burn or Not to Burn. Distribution Conference - American Gas Association. Philadelphia. (May 12-15, 1969).

Welker JR, et al. Effectiveness of Fire Control Agents on Chemical Fires. USCG Contract DOT CG 42 355 A.

Welker JR, et al. Liquefied Gas Fires: Which Foam. USCG Contract DOT CG 42 355A.

Welker JR. (1982) Vaporization, Dispersion and Radiant Fluxes from LPG Spills, DOE/EV/07020-1. U.S. Department of Energy.

Welker JR. (1974) Vapor Dispersions from LNG Spills. AGA Project IS-3-1. (July 1, 1974).

Wells GL. (1980) Safety in Process Plant Design. London: George Godwin.

Wesson HR, et al. (1974) Vapor Depression, Fire Control and Fire Extinguishment of High Evaporation Rate LNG Spills. AGA Operating Section Proceedings D-1974.

Wesson HR, Welker JR, Brown LE, and Sliepcevich CM. (1973) Fight LNG Fires with Foam? Hydrocarbon Processing (October 1973):165-171.

Wesson HR, Welker JR, and Brown LE. (1972) Control LNG-Spill Fires. Hydrocarbon Processing (December 1972):61-64.

Wesson HR. (1974) Fire Control and Vapor Suppression. AGA Project IS-3-1. (July 1, 1974).

West NH, Brown LE, and Wilker JR. (1974) Vapor Dispersion, Fire Control, and Fire Extinguishment for LNG Spills. AGA Project IS-100-1. (February 1974).

Westbrook CK, and Haselman LC. (1980) Chemical Kinetics in LNG Detonations. Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: Second Status Report. USDOE/EV 0085 Report F.

Whiting LD, Shaffer RE, and Frickel RH. Feasibility Study of Response Techniques for Discharge of Hazardous Chemicals that Vaporize. Chemical Systems Lab. Aberdeen Proving Ground.

Whiting LD, and Shaffer RE. (1978) Feasibility Study of Hazardous Vapor Amelioration Techniques, in Control of Hazardous Material Spills. pp. 384-393.

Wiekema BJ. (1982) An Analysis of Vapour Cloud Explosions Based on Accidents, in Heavy Gas and Risk

Assessment, Volume 2. Boston, MA: D. Reidel.

Wiekema BJ. (1980) Vapour Cloud Explosion Model. Journal of Hazardous Materials 3:221-232.

Wilcox DC. (1971) An Empirical Vapor Dispersion Law for a LNG Spill. TRW Systems Report on AGA Project IS-33-4.

Williams JR. (1970) Polar Solutions and Fire-Fighting Foam. Loss Prevention 4:53-57.

Williams JR. (1964) NFPA Quarterly: Q58-2. (July 1964).

Williams JR. (1968) Effects of Combustion Products on High-Expansion Foam. Fire Journal (November 1968):32-36.

Windebank CS. (1980) PUVCE and BLEVE - Two Words that could Spell Disaster. Fire (April 1980):617-618.

Wood JD. (1974) Contingency Plans for the Disposal of Chlorine from the Ohio River Barge Incident, March 1972. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. pp. 176-178.

Woodward JL, Havens JA, McBride WC, and Taft JR. (1982) A Comparison with Experimental Data of Several Models for Dispersion of Heavy Vapor Clouds, in Dense Gas Dispersion. Amsterdam: Elsevier. pp. 161-180.

Woodworth M. (1958) Oil Froth Fire at Signal Hill Refinery. NFPA Quarterly 52(2):85-98.

Yao C. and Kalelkar AS. (1970) Effect of Drop Size on Sprinkler Performance. Fire Technology 6(4):254-268.

Zabetakis MG. (1965) Flammability Characteristics of Combustible Gases and Vapors, AD 701 576. U.S. Bureau of

Mines.

Zeman O. (1980) The Dynamics and Modeling of Heavier-than-Air, Cold Gas Releases, UCRL 15224. Livermore, CA: Lawrence Livermore National Laboratory.

