# Hazardous Materials Response Technology Assessment

United States Fire Administration
Federal Emergency Management Agency

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## *INTRODUCTION*

Hazardous materials incidents are uncontrolled releases, illegal releases or threatened releases of hazardous substances or the hazardous by-products of substances. Preparing for these incidents is a basic requirement for all fire and rescue departments. The presence of hazardous materials or toxic chemicals at an incident location or other emergency situation adds a new dimension of risk to those responding to an incident especially if there are casualties. The fundamental difference between a hazardous materials incident and other emergencies is the potential for acute risk from contamination to both patient and responder. These incidents can create a toxic risk to civilians and emergency responders, and even a long term or delayed toxic risk when the environment is affected by hazardous materials. In some cases, traditional practices must be altered to avoid compounding a critical situation.

Since the late 1960s there has been much discussion about the effects suffered when chemicals are released or spilled into the environment or when one is exposed to many of the chemicals used in industry. With this newfound knowledge, government action soon followed. Throughout this manual there are references to the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA). Although OSHA was established in 1974, it was not until 1986 that both of these organizations received their power through a legislative action. The Superfund Amendments and Reauthorization Act (SARA) was passed mandating regulation in the storage, transportation, use, and disposal of chemicals into the environment. Within this document, several provisions were established of which Title I and Title III are the most important to emergency responders.

Title I mandates that OSHA and EPA establish regulations on training, emergency response, safety, and associated hazardous materials activities. Within this title, OSHA 29 CFR (Code of Federal Regulations) 1910.120 and EPA 40 CFR 311 were established. These federal regulations outlined training standards and mandated written standard operating procedures (SOPs) for hazardous materials incidents.

Title III sets requirements that industry report the chemicals used or stored in the workplace. Tier 2 reports are required by this title. These reports supply emergency responders with an inventory of what chemicals may be found in an industrial setting. Part of the reporting requirements require businesses to supply a material safety data sheet (MSDS) for each chemical that meets the reporting requirements. The MSDS supplies the responder with valuable data about a particular chemical. Title III further requires planning for hazardous materials emergencies on the state and local level.

Hazardous materials pose many problems. One of the obvious problems is determining what constitutes a hazardous materials incident. Many agencies are involved with the handling, use, and the problems associated with hazardous materials. Each of these agencies has identified hazardous materials as it relates to their realm of service. Several examples of these identifiers are listed below:

- The EPA defines a hazardous material as a substance that may be potentially harmful to the public's health or welfare if it is discharged into the environment.

- The Department of Transportation (DOT) defines a hazardous material as any substance or material in any form or quantity that poses an unreasonable risk to safety and health and to property when transported in commerce.

- The American Conference of Governmental Industrial Hygienists (ACGIH) does not define hazardous materials but has established levels of chemical substances that a person can be exposed to without sustaining permanent injury. These values guide industry in setting exposure limits on particular chemicals commonly found in their environment.

- OSHA and the National Institute for Occupational Safety and Health Administration (NIOSH) view a hazardous material from the standpoint of potential hazard. They rate conditions that may cause injury or death as they are found in the working environment, whether they are obvious or not.

Recent years have seen the passage of laws regulating the storage, transportation, and use of hazardous materials. These laws have also addressed planning for the incident, training standards, and skill competencies. OSHA identifies several levels of competency in the CFR 1910.120 document. Among these levels are Awareness, Operations, Technician, Specialist, and Incident Commander.

Responders have been taught that the primary objective is to save life and property, which many times requires immediate action. Responders may not be able to act immediately at a hazardous materials incident. A risk versus benefit analysis must be done in order to manage the scene appropriately. As difficult as it may be, no offensive action may be the most appropriate action to take. The more typical approach to this type of situation may be an indirect one. Evacuation of surrounding areas or other defensive measures may be the appropriate life-saving technique.

The problems encountered at a hazardous materials incident are many. The primary threats involve injury to the emergency worker and harm to the community. Without emergency personnel, the situation cannot be handled in a safe or timely manner. When dealing with this type of incident, personal safety should always be the primary concern.

This manual is designed to familiarize readers with various technologies that are available (and in development) that a fire and/or rescue department could use to control and mitigate a hazardous materials incident. In addition, this manual provides concepts, terminology, and key considerations that may help in the management of incidents of hazardous material contamination. The manual is intended to illustrate the characteristics of hazardous materials technologies and is not intended as a definitive guide on establishing a hazardous materials program in a department

Not all of the technologies described herein have been developed specifically for use by fire and emergency response departments. Some of the technologies described in this manual are being used in other fields, such as private industry or the military, and other technologies are still in the research and development stages. Nonetheless, discussion of these transferable and pending technologies here may provide departments with ideas about how to improve an existing technology or develop a new one.

# CHAPTER I – REVIEW OF PERSONAL PROTECTIVE CLOTHING LEVELS

## Overview

The purpose of personal protective clothing and equipment (PPE) is to shield or isolate responders from the chemical, physical, radiological, and biological hazards that may be encountered at a hazardous materials incident. No single combination of PPE is capable of protecting against all hazards. For any given situation, PPE should be selected to provide an adequate level of protection. Over-protection as well as under-protection can be hazardous and should be avoided. It is important that only response personnel who have completed the required training and familiarization with various models of PPE be allowed to use PPE. The improper use of PPE, especially during a hazardous materials incident, can be life threatening

It must be remembered that the use of PPE can itself create significant hazards, such as heat stress, physical and psychological stress, impaired vision, reduced mobility, and distorted communication. In general, the higher the level of PPE protection, the greater are the risks associated with its use.

The selection of PPE, based on the requirements of 29 CFR 1910 is key to protecting the safety and health of response personnel. This should be done by qualified and knowledgeable professionals to ensure that selected PPE protects responders from incident specific hazards posed by their task and work zone. Selection of the most combinations of respiratory protection and protective clothing will depend on:

*Photo courtesy of Drager*

- Level of knowledge of chemical, biological or radiological hazards;
- Properties such as toxicity, radioactivity, route of exposure, and matrix of the contaminants known or suspected of being present;
- Concentrations of the contaminants that are known or suspected of being present;
- Potential for exposure to contaminants in air, liquids, soils, or by direct contact with hazardous materials;
- Physical hazards; and
- Climatic conditions.

Structural firefighting ensembles are designed to protect against temperatures associated with structural fires and toxic products of combustion. This includes several components, each meeting NFPA standards: helmet, positive-pressure SCBA, PASS device, coat, pants, gloves, boots, and a hood made of fire-resistant material. Structural firefighting clothing alone does not provide adequate protection against many common hazardous materials. Therefore, it is to be used on incidents where contact with splashes of hazardous materials and/or hazardous atmospheres are unlikely.

The EPA classifies four levels of chemical protection: level A through level D. The specific levels of PPE and necessary components for each level have been divided into four categories according to the degree of protection afforded.

### *Level A PPE*

Level A PPE is worn when the highest level of respiratory, skin, and eye protection is needed. Level A respiratory protection is positive pressure, full face-piece self-contained breathing apparatus (SCBA) or positive pressure supplied air respirator (with escape bottle for immediately dangerous to life or health (IDLH) or potential IDLH atmosphere). Protective clothing provides maximum skin protection. It is used when the potential exists for splash or immersion by chemicals and/or radiologically contaminated liquids, or for exposure to vapors, fumes, gases, or particulates that are harmful to skin or capable of being absorbed through the skin. This class of protection is acceptable for radiological work activities categorized as “High” involving pressurized, large volume liquids, or closed system breach. Level A protective clothing includes:

- Totally encapsulating, non-permeable, chemical-resistant suit;
- Coveralls inner suit;
- Modest clothing under coveralls (e.g., shorts and T-shirt/long underwear);
- Disposable gloves and boot covers (worn over fully encapsulating suit);
- Boots, chemical-resistant, steel toe and shank (depending on suit construction, worn over or under suit boot);
- Hard hat (under suit); and
- Hearing protection (as needed).

Other protective apparatus which may be used includes:

- Cooling unit/system,
- 2-way radio communications, and
- Cold weather gear/clothing.

Hazardous materials technicians use chemical and vapor protection (level A) suits most often. These suits are made of non-absorbing materials specifically designed for protection where chemical splash or vapors are likely. Personnel selected to wear and operate in a hazardous material incidents with these suits should be trained and certified as hazardous materials technicians.

### *Level B PPE*

Level B PPE is worn when the highest level of respiratory protection is needed, but a lesser level of skin protection is needed. Level B respiratory protection is positive pressure, full face-piece self-contained breathing apparatus (SCBA) or a positive pressure supplied air respirator (with escape bottle for immediately dangerous to life or health (IDLH) or potential IDLH atmosphere). Level B protective clothing provides a high level of skin protection. It is
used when the potential exists for contact with chemicals and/or radiologically contaminated liquids that could saturate/penetrate cloth coveralls (e.g., immersion or inundation of contaminants). Also, potential vapors, fumes, gases, or dusts containing levels of chemicals harmful to skin or capable of being absorbed through the skin are not anticipated. This class of protection is acceptable for radiological work activities categorized as "High" involving pressurized or large volume liquids, or closed system breach . Level B protective clothing includes:

- Hooded one-piece non-permeable, chemical resistant outer suit;
- Coveralls inner suit(s);
- Modest clothing under coveralls (e.g., shorts and T-shirt/long underwear);
- Outer chemical resistant work gloves (rated for contaminants) taped to outer suit;
- Inner gloves of light weight PVC or latex rubber taped to inner suit (cotton liners optional);
- Chemical resistant steel-toe boots taped to inner suit;
- Disposable outer boot covers (booties) taped to outer suit;
- Hard hat (as needed); and
- Hearing protection (as needed).

Other protective apparatus which may be used includes:

- Cooling unit/system, and
- Cold weather gear/clothing.

### *Level C PPE*

Level C PPE is worn when the criteria for using air-purifying respirators are met, and a lesser level of skin protection is needed. Level C respiratory protection includes an air-purifying respirator, full-face or half-mask, cartridge- or canister-equipped. Level C protective clothing provides a moderate level of skin protection. It is used when the potential exists for contact with chemicals and/or radiologically contaminated materials, but when protection from liquids (chemical and/or radioactive) is not required. It is used when potential vapors, fumes, gases, or dusts are not suspected of containing levels of chemicals harmful to skin or capable of being absorbed through the skin. This class of protective clothing is appropriate for most routine radiological work activities. Level C protective clothing includes:

- Coveralls;
- Modest clothing under coveralls (e.g., shorts and T-shirt/long underwear);
- Rubber/chemical resistant outer gloves rated for contaminant;
- Inner gloves of light weight PVC or latex rubber;
- Safety glasses or safety goggles (not required with full face respirator);
- Face-shield if splash hazard exists (not required with full face respirator);
- Steel-toe rubber boots;
- Outer disposable booties;
- Hood may be required for radiological work;
- Hard hat (as needed); and
- Hearing protection (as needed).

Other Level C protective apparatus which may be used includes:

- Cooling unit/system; and
- Cold weather gear/clothing.

### *Level D PPE*

Level D PPE refers to work conducted without respiratory protection. This level should be used only when the atmosphere contains no known or suspected airborne chemical or radiological contaminants and oxygen concentrations are between 19.5% and 23%. There is no respiratory protection requirement for Level D due to the nature. Level D protective clothing provides a low level of skin protection. It is used when there is no potential for contact with hazardous levels of chemicals or radiological contamination. Level D protective clothing includes:

- Coveralls;
- Modest clothing under coveralls;
- Work gloves where appropriate;
- PVC or latex rubber surgical/light weight gloves when sampling or handling any potentially contaminated surface or item;
- Safety glasses or safety goggles;
- Steel-toe rubber boots where wet decontamination methods are required or steel-toe leather boots and outer boot covers; and
- Hard hat.

Other Level D protective apparatus which may be used include:

- Cold weather gear/clothing,
- Protection from biological-hazards/pests, and
- Hearing protection.

Structural firefighting turnout gear is Level D PPE. Turnout gear is highly permeable and can easily absorb and withhold hazardous materials. The vapor barrier found in turnout gear can also trap hazardous materials inside the protective envelope, exposing the firefighter to these substances. Accordingly, turnout gear should not be considered hazardous material protective clothing.

## *CHAPTER II – BREATHING APPARATUS*

### *Self-Contained Breathing Apparatus*

Self-contained breathing apparatus (SCBA) is the most widely used respiratory protection for fire service responders today. Rescue teams that are adjuncts to fire departments have access to SCBA because it is used for firefighting. SCBA protects the rescuer from breathing toxins in the environment by supplying air on demand from an air cylinder carried by the rescuer on his/her back. Positive-pressure air prevents contaminants from leaking into a rescuer's mask should a leak in the mask seal occur. Different capacity cylinders are rated for 30-, 45-, or 60-minute supplies of air; however, the actual times decrease with the increased breathing rates associated with physical exertion. (The above ratings are nominal times, based on assumed respiration and air-consumption rates.) SCBA units weight 25 to 35 pounds, depending on the model and cylinder capacity. Newer models of SCBA meet rigorous fire-resistance and safety standards.

*Photo courtesy of Indian Springs*

Some manufacturers provide breathing apparatus with convertible features, such as adjustable harnesses, which allow either 30- or 60-minute air supply. Another manufacturer provides a harness that holds two 60-minute cylinders, thereby doubling the time duration.

Hazardous materials incidents usually are protracted because it is necessary to take precautions to ensure the personal protective levels are adequate. Many hazardous materials can be absorbed through the skin, and SCBA alone is not enough protection. Therefore, SCBA is usually used in conjunction with the whole-body protection provided by encapsulated suits. This has ramifications for the "work-effort duration" of a SCBA.

This increased protection requires longer duration SCBA air supplies. The wearer of the SCBA uses air while putting on the encapsulated suit over the SCBA. The wearer must travel from a safe area, "the warm zone," often considerable distances to the "hot zone," perform work, and return to the warm zone for decontamination. The breathing air must last until the decontamination is complete, the encapsulated suit is removed, and


*Photo courtesy of MSA*

the breathing apparatus is removed. It can be life threatening to run out of air before the decontamination is complete because of the time involved with accessing and leaving the decontamination area. SCBA generally is limited to about 15 to 30 minutes per 4500 pounds per square inch (psi) air supply.

### *Manifold Supplied-Air Breathing Apparatus*

Manifold supplied-air breathing apparatus are SCBAs that use multiple air cylinder units with refill ports on the SCBA manifold so the unit can be filled while in use without removal of the harness or any components. With these units, the manifold is part of the harness. The drawback of this system is that the refill capability cannot be used if the wearer is in an encapsulated suit which encloses the SCBA unit.

**Training –** Rescuers using SCBAs should attend a course that provides instruction in the principles of operation, techniques for donning and doffing, maintenance and inspection requirements, and hands-on experience in recharging SCBAs. Any course that addresses the contents of NFPA 1001 is acceptable.

**Costs –** SCBAs vary in cost depending on the size of the cylinder and the harness. Most SCBAs range between $1,000 and $2,000. SCBAs with manifolds will generally cost more than standard SCBAs.

**Future Trends –** There is a trend to make SCBA more comfortable and easier to use. Future SCBAs will be smaller, lighter and have an increased air capacity.

## ***Supplied-Air Breathing Apparatus and Breathing Air Cylinders on Carts***

Supplied-air breathing apparatus (SABA) are breathing systems that use an air cylinder on the rescuer's back and a mask that is equipped with a long high-pressure hose, (called an "umbilical line"). This umbilical line is connected to a cart (also called a "caddy") that carries two or more cylinders that provide air to the rescuer. These systems are referred to as "deep well masks" because they are used in confined space rescue.

*Photo courtesy of Drager*

Although the SABA concept is not new, refinements have improved the capabilities of such units greatly. For example, air supply manifolds allow a monitor to switch the air supply over to a full cylinder without breathing interruption. The empty cylinder can be replaced with a full cylinder for extended duration incidents.

This resupply system can provide an unlimited and uninterrupted supply of air to hazardous materials personnel, assuring that full cylinders are available, or that empty cylinders can be refilled. This is a very compact system that can be wheeled into the hot zone. The SABA is designed for longer duration use than SCBA and often is easier and safer to use, because the air can be resupplied outside of an encapsulated suit. This system effectively eliminates the risk of air depletion associated with the use of SCBA, further ensuring complete and thorough decontamination of personnel. This increases the work-effort duration of the hazardous materials responder.

SABA eliminates the weight and bulk of an SCBA air cylinder. Some models have emergency escape air cylinders mounted to the harness to be used in conjunction with the remote air supply systems. The escape cylinder permits the wearer to disconnect the umbilical line for quick evacuation of the hot zone.

Still other manufacturers provide dual-purpose ports for attaching SABA airlines while the SCBA cylinder is carried on the back to serve as a backup air supply. This feature also allows the option to detach from the umbilical line, use the SCBA for a period of time, and then reattach the air supply hose.

There are some limitations to the SABA systems, most notably that the maximum travel distance is limited to 300 feet, which is the maximum length of high-pressure air supply hose. Most hot zones will be greater than 300 feet, so, SABA air-supply carts must be wheeled in along with resupply air. In the hot zone, the system must be monitored to ensure that air cylinders are changed when necessary; this limits other responsibilities that the air monitor might assume.

Additionally, the umbilical lines can get in the way and become a trip hazard, particularly while working in encapsulated suits with limited vision. When using the buddy system in the hot zone, it is important to watch each other’s hoselines to ensure they do not become entangled.

**Training –** Rescuers using SABAs should attend a course that provides instruction in the principles of operation, techniques for donning and doffing, maintenance and inspection requirements, and hands-on experience in recharging SABAs.

**Costs –** SABAs vary in cost depending on the size of the cylinder and the harness. Most SABAs cost between $500 and $1,000.

**Future Trends –** There is a trend to make SABA more comfortable and easier to use. Future SABAs will be smaller, lighter and have an increased air capacity.

### *Closed-Circuit Rebreathing Systems*

Closed-circuit rebreathing systems recirculate exhaled air, filter out excess carbon dioxide, and replenish the oxygen content within a closed system. This recycling process gives rebreathers the ability to supply from one to four hours of protection. Rebreathers are classified as SCBAs because the filtering


*Photo courtesy of Drager*

process occurs within a closed system (i.e., they are self-contained). Closed system rebreathers rated at 60 minutes actually can last longer than this even under physical duress, whereas standard fire service SCBA rated at 60 minutes usually last only 30 to 40 minutes. Rebreather units offer an extended (but not unlimited) air supply without having to use an umbilical cord. Some of the rebreather models meet heat and fire resistance standards, while some are designed for underwater use. They also deliver a positive-pressure air supply to the mask.

One of the problems of rebreathers is the heat generated within the units. Some require a cooling pack to be inserted into the unit before use. The cooling pack, which is stored in a freezer, cools the exhaled air. Sixty-minute rebreathers typically use a special salt as a cooling mechanism to remove heat from the exhaled air.

The most technically advanced self-contained breathing system is the super-critical cooled cryogenic air system. This is a self-contained cylinder mask adopted from NASA's space shuttle mission technology. Using cryogenics the air is stored at -320° Fahrenheit at 720 psi. A one-hour air supply can be stored in a cylinder the size of a 30-minute supply.

This system uses heat from the body to warm the cooled air for breathing through a body heat exchanger system in the backpack. The exchange of air through the body enables this air unit to cool the body in an encapsulated suit and maintain body temperature within 4° Fahrenheit of normal up to four hours at rest. This cooling effect helps to control the problem of heat stress in encapsulated suits and has the advantage of a small, lightweight air pack. This system requires a special compressed-air-and-liquid-nitrogen device which cools compressed air to -320° Fahrenheit to fill the SCBA devices. A two-hour unit is in development.

**Training –** Rescuers using closed-circuit rebreathing systems should attend a course that provides specialized instruction in the principles of operation, techniques for donning and doffing, maintenance and inspection requirements, and hands-on experience in recharging.

**Costs –** Closed-circuit rebreathing systems usually range in price from $1,500 to $4,500.

**Future Trends –** Future closed-circuit rebreathing systems are projected to have the capacity to be worn for longer durations. The price of these devices also is expected to decrease.

### *Powered-Air Purifying Respirator*

The fire and rescue service long ago abandoned the filter-style mask for compressed air supply; however, the threat of chemical warfare agents used by terrorists has caused response teams to rely again on this type of protection. A chemical or biological incident may last as long as 12 hours, creating a protection requirement that exceeds the practicability of compressed breathing air protection.

Powered-air purifying respirators (PAPRs) have been used primarily by the military, but they will become more prevalent for chemical-biological/hazardous materials and medical teams. The PAPR is a filter-type mask equipped with a battery-powered fan to ensure positive pressure on the face. This type of mask will protect against certain types of chemical and biological agents. However, a PAPR cannot be used in oxygen-deficient atmospheres (i.e., those which have an oxygen concentration lower than 16.5 percent).

A precaution of the PAPR system, as with other hazardous-material PPE is the potential for heat stress as a result of extended-duration duty.

**Training –** Rescuers using PAPRs should attend a course that provides instruction in the principles of operation, techniques for donning and doffing, maintenance and inspection requirements, and hands-on experience in recharging PAPRs.

**Costs –** PAPRs generally range in price from $500 and $1,000.

**Future Trends –** In the coming years, emergency response personnel may expect to use PAPRs more frequently given the increased threat posed by the use of biological and chemical agents in acts of terrorism.

## CHAPTER III – BASIC TOOLS

Much of the work done in the hot zone by rescue personnel requires mitigation of leaking hazardous materials. Often this is accomplished by constructing temporary beams and dikes to contain hazardous material runoff, or by closing and plugging breached containers. These tasks often require basic handtools like shovels, wrenches, and screwdrivers. Ordinary hand tools are usually made of steel, which can cause sparks if struck, scraped, or dropped, which can be disastrous in an explosive atmosphere.

### Nonsparking Tools

Tools used in a hazardous materials incident must be constructed of nonsparking, nonferrous, non-magnetic, corrosion-resistant metals such as bronze, aluminum, or other alloys. These specialized handtools should be organized in a specially designed kit and inventoried routinely.

Nonsparking safety tools, such as pliers, punches, scrapers, screwdrivers, shears, shovels, wedges, wrenches (adjustable, pipe, hex, double end, lug, etc.), hex keys, and socket sets are commercially available as kits, or they can be purchased individually. A standardized marking system, such as color-coding tools for unit identification, should be expanded to include nonsparking tools. Specific color identification for these safety tools will help ensure that they are not substituted for a tool made of a material that could cause a spark. Checking tools with a magnet is a way to ensure that sparking tools do not end up being used at a hazardous materials incident.

**Training –** Responders should attend a course that provides basic tool awareness and addresses the appropriate use of tools during hazardous materials incidents and decontamination procedures after the incident.

**Costs –** Nonsparking tools range in price from $31 to $400, depending on the type of tool. A prepacked tool kit usually will cost from $800 to $1,000.

**Future Trends –** With the development of new and stronger alloys, it is expected that the tools will last longer and their price will decrease. There is also a trend to sell these tools in pre-fabricated kits. This may be a more affordable alternative for some departments to obtain a limited number of the basic tools required, but may not provide all of the tools necessary to mitigate a hazardous materials incident.

### Drum-Handling Tool

A drum-handling tool is a simple-to-use, one-person tool which allows easy handling of drums in order to overpack them with larger drums. The tool is slipped over the top of the drum so that the upper lip of the drum is caught by the holder on the tool. The lower section of the tool rests on the side of the drum for added support. The drum-handling tool allows the full drum to be lifted quickly to an upright position by one person if the drum is found lying on its side.

In order to overpack drums, the tool allows one person to tip the drum on its side, using something as a fulcrum to lever the bottom of the drum off the ground. While the drum is held in this position, it is easy for a second responder to slip the overpack drum in position over the lower section of the leaking drum. The person using the drum-handling tool then can easily slip the smaller drum into the overpack and stand both of them upright in one motion.

**Training –** Rescuers should attend a course that provides basic tool awareness and addresses the appropriate use of tools during hazardous materials incidents and decontamination procedures after the incident.

**Costs –** This technology ranges in price from $50 to $400, depending on type, size, and whether the tool is nonsparking.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Pipe-Sealing Clamps*

Pipe-sealing clamps are easy-to-use, positive-locking pliers which effectively seal most cracked or broken pipes. They are available in standard iron pipe sizes, as well as standard copper pipe, from ½ inch to three inches in diameter. Pipe-sealing clamps can be used to seal leaking pipes in circumstances which include everything from the simple domestic water leak flooding a cellar to a hazardous material pipe leak that requires full exposure suits. They were originally designed and built by an experienced rescue/haz mat firefighter in New York City. Pipe-sealing clamps are fast-acting and simple tools for leaking pipes that can be used while operating within the suit at hazardous material operations.

**Training –** Rescuers should attend a course that provides basic tool awareness and addresses the appropriate use of tools during hazardous materials incidents and decontamination procedures after the incident.

**Costs –** Pipe-sealing clamps usually range in price from $20 to $100 depending on type, size, and whether they are nonsparking.

**Future Trends –** There do not appear to be any future trends for this technology.

### *Salvage Tools*

A great deal of property damage can be avoided if wet debris and excess water are removed from the floors after hazardous materials operations have been completed. Water on the floor is a particular problem in residential buildings of frame construction. If the water and wet debris are allowed to remain on the floor in these buildings, the wooden floors themselves will be damaged. Over time, the water will drain through the floor and into the ceilings and rooms below, eventually winding up in the cellar or basement. As the water works its way down, it will ruin the furnishings in areas below.

Once the water is into the ceilings and walls, it can travel to remote locations. This condition can necessitate shutting down the electrical service for the entire building instead of in a more confined area if the water is removed. A complete electrical shutdown can cause loss of the heating system, which, in cold climates, can force the relocation of the occupants and the eventual freezing of water lines, causing additional damage to the building.

Some very simple and inexpensive tools can be used to lessen water damage after completing hazardous materials operations. Salvage covers (discussed below) can be used to cover the areas below to protect them. A great deal of water can be removed before it drains through the common wood floors. “Squeegees” can be used to keep the water confined to a small area within the building, or to push water outdoors to the exterior of the house. Water from the upper floor can be removed to the exterior by pushing the water down the stairs and out the doors using squeegees and brooms. A very simple water diversion channel can be made by piling the wet debris to form a series of levies and dikes so that squeegees can be used to push the water through the channel and out of the building. The debris that was used to form the channel is removed after as much water as possible has been removed from the building.

Large volumes of water are used frequently in hazardous materials incidents. Most of this water will fall to the ground and drain away from the site of the incident. This “hazardous material runoff” may, in some cases, present a serious risk to the environment. Therefore, every attempt to contain hazardous material runoff should be made.

***Note***: All items (including clothing, equipment, liquids) used in the decontamination procedure that cannot be completely decontaminated should be considered hazardous. Clothing and equipment should be collected, treated, stored, and disposed of based on the type and level of contamination according to applicable federal, state and local regulations. Drainage and/or collection systems for contaminated liquids should be established and approved containers should be used. Wash water should be collected for proper disposal. Procedures to contain contaminated water or decontamination fluids (i.e., collection of contaminated runoff, containment of overspray) should be developed and included as part of the decontamination plan. Waste minimization should be a consideration, secondary only to rescuer safety and health protection requirements.

**Training –** Rescuers should attend a course that provides basic tool awareness and addresses the appropriate use of tools during hazardous materials incidents and decontamination procedures after the incident.

**Costs –** Salvage tools range in price from $5 to $400, depending on the type of tool and whether the tool is nonsparking.

**Future Trends –** There is a trend to sell these tools in pre-fabricated kits. This may be a more affordable way to obtain a limited number of basic tools but may not provide all the tools necessary to mitigate a hazardous materials incident.

### *Salvage Covers*

Salvage covers can be used to protect furnishings both in and below the hazardous materials area. In many commercial buildings, spreading salvage covers over the undamaged stock can prevent damage to the stock. In frame structures, spreading salvage covers below the affected area can protect the furnishings from damage caused by water draining through the ceilings. They can be used to cover the floors and stairs that are to be used to channel water from the building. They can be used around ceiling electrical fixtures, which usually collect and drop a great deal of water out of the ceilings below the affected area. Salvage covers can be nailed to the ceilings around the leaking area and formed into a through to carry the water to a sink, a bathtub, or out a window. Material of salvage covers must be compatible with the products present, and should be disposed of or cleaned if exposed to products.

**Training –** Rescuers should attend a course that provides basic tool awareness and addresses the appropriate use of tools during hazardous materials incidents and decontamination procedures after the incident.

**Costs –** Salvage covers can range in price from $10 to $100, depending on the material and size of the cover.

**Future Trends –** There is a trend to sell these covers in prefabricated kits with varying sizes of covers. This may be more affordable for obtaining a limited number of covers, but may not provide all the covers necessary to mitigate a hazardous materials incident.

*Photo courtesy of Indian Springs*

### *Gas Cylinder Repair Kits*

Gas cylinder repair kits have the necessary devices and tools required for temporary repair and containment of gas leaks. Kits include items needed to control different gas containers, including chlorine, sulfur dioxide, anhydrous ammonium, and anhydrous hydrogen fluoride. It is important to realize that a chlorine gas kit may not have the appropriate equipment to contain an anhydrous hydrogen fluoride leak, and therefore should not be used. Three basic kit designs (for each gas) may be used, depending on the size and type of the gas container, (e.g., cargo tanks, tank cars, and cylinders) and whether the repair is to a valve or a sidewall.

**Training –** Users of gas cylinder repair kits must be trained to the Technician level even though these kits are relatively easy to use. Users should practice with cylinder repair kits while wearing Level A PPE because of its ability to hamper manual dexterity. A basic understanding of container design and use of the devices and tools is required. Most companies include training videos or classes with the purchase of their product.

**Costs –** These kits usually range in price from $1,500 to $3,500, depending on the desired kit

**Future Trends –** Based on present gas container design, there does not appear to be a likelihood for further development of this technology; however, kits for other gases may be developed, depending on need.

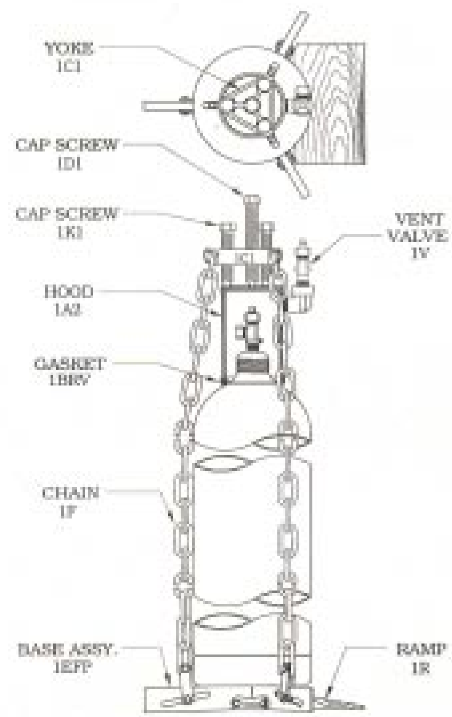



*Photo courtesy of Indian Springs*

### *Vacuums*

Industrial vacuums are now available for use on hazardous materials incidents. Many of these vacuums can be used for locations where flammable gases, vapors, or finely pulverized dusts are present. They also can be used for the recovery of fuel, oil, and solvents. Most industrial vacuums are portable and available in electric and air-operated versions, and in sizes ranging from five to 55 gallons. These vacuums can be set up in minutes anywhere and can control dust, debris, and toxic substances; most vacuums are designed for both wet and dry recovery. These vacuums should be certified for use in hazardous environments before use.

Necessary attachments for hazardous materials operations include needle and chisel scalars. These are pneumatically driven attachments that can remove fixed depths of materials, dependent on the needle set in use (2 mm, 3 mm, or 4 mm). They operate in a reciprocating manner, chipping the surface. Shrouding collects the dust. Copper beryllium chisels and needles are available for scaling steel surfaces where the presence of combustibles may cause a sparking hazard. These devices cause little to no airborne contamination, and they are capable of decontaminating hard-to-reach areas. According to NIOSH, respiratory protection should be used with exposure to any detectable concentration of beryllium (such as filings or dust from tool use).

These attachments are made of a toxic substance that can be harmful, depending on the amount and duration of exposure. The primary organ that beryllium affects is the lung. Short-term human and animal exposure to high levels of soluble beryllium compounds can lead to the development of inflammation or reddening and swelling of the lungs, a condition known as Acute Beryllium Disease (similar to pneumonia). Onset usually occurs one to two weeks after exposure. Removal of exposure results in a reversal of symptoms. Long-term exposure to beryllium or beryllium oxide has been reported to cause Chronic Beryllium Disease, characterized by shortness of breath, scarring of the lungs, and berylliosis (noncancerous growths in the lungs of humans).

**Training –** Rescuers should attend a course that provides basic tool awareness and addresses the appropriate use of tools during hazardous materials incidents and decontamination procedures after the incident.

**Costs –** This technology ranges in price from $8,000 to $15,000.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

## CHAPTER IV – IDENTIFICATION AND DETECTION TECHNOLOGY

The potential for hazardous materials incidents exists almost everywhere. An unknown substance has the potential to be hazardous and must be treated as such until it is identified. While occurring infrequently, hazardous materials incidents offer a threat to the civilian population and the emergency personnel directed to assist them.

An initial objective of hazardous materials personnel is to identify the product. Every effort should be made to prevent exposure to chemicals during this process. Identifying a hazardous material and obtaining information on its physical characteristics and toxicity are vital steps in the effective management of the hazardous materials incident. Since each compound has its own unique set of physical and toxicological properties, early and accurate identification of the hazardous materials involved in the incident allows rescue personnel to initiate appropriate scene management steps.

### 1996 North American Emergency Response Guidebook

The 1996 *North American Emergency Response Guidebook* (NAERG 96) was developed jointly by Transport Canada, the U. S. Department of Transportation, and the Secretariat of Communications and Transportation of Mexico. It is intended for use by firefighters, EMS personnel, law enforcement officers, and other emergency service personnel who may be the first to arrive at the scene of a transportation incident involving hazardous materials. The NAERG 96 is a guide to help responders identify hazardous materials and the associated risks quickly to protect themselves and the public during the initial response phase (i.e., the first hour or so of the incident). It is recommended that all emergency apparatus carry a copy of the NAERG 96.

Copies of the NAERG 96 are available free of charge to emergency responders through distribution centers. In the United States, to obtain information about ordering the guidebook, call the Hazardous Materials Information Exchange (HMIX) at 1-800-752-6367, or 1-800-367-9592 in Illinois. Information and an on-line version of the NAERG 96 are available on the Internet at http://hazmat.dot.gov/gydebook.htm.

### USFA Hazardous Materials Guide for First Responders

This publication is the result of extensive study of available hazardous materials response resources for first responders undertaken by the United States Fire Administration as a part of the Firefighters' Safety Study Act of 1990 (P.L. 101-446.) The study concluded that, while several excellent and technically accurate resources are available, none are directed to the specific needs of the first responder trained at the Awareness or Operational levels; the training levels of most first responders.

The book provides important information for the initial response to both transportation and fixed facility incidents. It was designed to present the first responder with a maximum amount of useful key information in a limited amount of space. As with any reference, it cannot include all information that might be useful or discuss all situations that might occur; nor can it replace the training and experience of individual responders.

It is assumed that those using the book will have had some training in hazardous materials response. Because most first responders are trained at the Awareness or Operations level, this book is directed at appropriate responses for these levels of training.

This publication is available at no cost through the United States Fire Administration by contacting the publications department at (301) 447-1660 or through the Internet at www.usfa.fema.gov.

### *Hazardous Materials Testing Kits*

Many manufacturers are developing kits designed for onsite identification or categorization of virtually any spilled or abandoned material. Generally, kits are prepacked in easy-to-carry, impact-resistant cases that can be stowed easily in an emergency response vehicle for instant accessibility. These kits contain reagents, glassware, and all other materials needed to perform chemical identification and categorization field tests. Costly delays, evacuations, and public relations problems caused by the need to send unidentified materials for lab analysis can be eliminated.

The system is based on a series of simple field tests arranged in an easily followed flowchart format. Most single-component "unknowns" can be identified positively in three to nine steps, or approximately 10 minutes. Even in cases where the identity of the material cannot be identified, these systems usually can identify the functional (or chemical) group of the material. This may give emergency responders sufficient information to take initial interim action until positive identification can be made. The shelf life of reagents in these kits is usually one year or longer.

*Photo courtesy of Haztech*

**Training** – Personnel contacting hazardous materials for the purposes of product identification must be trained to the Technician Level, per National Fire Protection Association Standard 472, *Standard for Professional Competence of Responders to Hazardous Materials Incidents.* With a minimum of training, hazardous materials personnel can obtain instant field identification of an unknown material. To make maximum use of these kits requires more extensive training (including refresher courses); these courses are from one to two weeks in length. Knowledge of chemistry is helpful, but is not required. Most training courses will satisfy the 29 CFR 1910.120 requirement for emergency response training for hazardous materials technicians. They also will meet the requirements specified in National Fire Protection Association Standard 472, *Standard for*

*Professional Competence of Responders to Hazardous Materials Incidents*. There usually is some cost involved with training. Some companies may include the cost of training in the overall cost of the product.

**Costs –** These products are generally priced around $2,500. There will be additional costs, including replacement of reagents and materials. As mentioned earlier, there also may be some training costs associated with this technology.

**Future Trends –** In the future, this technology will become a valuable tool for fire departments to identify hazardous materials. This is even more likely to be the case if the cost of the test kits comes down.

### *Atmospheric Monitors*

*Photo courtesy of Aim Safety*

Rescue operations in dangerous atmospheres require in-depth training so that rescuers know what the potential risks are and how to properly measure, treat, and control hazards. Responders can measure and monitor atmospheric hazards using monitoring equipment designed for that purpose. Confined spaces can present a variety of atmospheric hazards such as lethal concentrations of toxic gases, concentrations of combustible gases in the explosive range, and deficiencies of oxygen. All three of these situations demand not only the use of SCBA, but also the use of atmospheric monitoring to determine when changes to the atmosphere become dangerous.

Atmospheric monitoring involves the use of electronic instruments to measure concentrations of gases. Different types of monitoring instruments are available and are specific for certain gases. Some atmospheric devices measure for only one specific gas while others are capable of measuring multiple gases simultaneously. Responders must use the appropriate instruments for monitoring the atmospheric hazard in question. This means that emergency personnel must have some idea of the gases which they will be monitoring. Moreover, responders must be capable of properly deploying the instruments and interpreting their readings.

Three types of atmospheric hazards typically can be measured. These include:

- ***Oxygen –*** Atmospheres can be either oxygen-deficient or oxygen-enriched. OSHA has established a hazardous materials incident minimum requirement of 19.5 percent and a maximum acceptable level of 23.5 percent for oxygen concentrations. The normal amount of oxygen in the air is 20.8 percent by volume. Concentrations outside of this range can present either an explosion/flammability hazard or an asphyxiation hazard.

- ***Combustibles*** – According to OSHA Standard 1910.106, any level of combustibles above 10 percent of the lower explosive limit (LEL) is hazardous.[1] Examples of combustible gases include liquefied propane gas (LPG), compressed natural gas (CNG), liquefied natural gas (LNG). Ten percent of the LEL has been established as the minimum safe concentration. Combustible gas meters, which are a type of atmospheric monitor, measure a percentage of the LEL in the atmosphere, and not a total percentage by volume of the atmosphere. Combustible gas meters are calibrated to specific gases. Combustible gas meters are not intended to be used in oxygen-deficient spaces because the sensors require oxygen in order to function. Another limitation is that they cannot measure the presence of combustible airborne mists or sprays.

- ***Toxic gases*** **–** Determining the concentration of toxic gases presents the most difficult atmospheric testing concern for rescue personnel. One reason for the difficulty is the variety of toxic gases that might be present. Additionally, toxic gas monitors must measure very small concentrations that may be difficult to sense, but which could be fatal if inhaled.

*Photo courtesy of Aim Safety*

Most of the instruments used today for testing oxygen, combustible gases, and toxic gases have electrochemical sensors which react to the gas that is being measured. The reaction causes a change in the electrical resistance of the sensor. The instruments read this and convert it to a reading of the gas level which is expressed as a percent by volume of the atmosphere (oxygen), a percentage of the LEL (combustible gases), or parts per million (toxic gases).

In addition to sensors that measure only one gas, sensors that measure several gases simultaneously also are available. Hazardous materials rescue teams should determine what types of atmospheric hazards exist in their response area, and what hazards they are most likely to face or need to monitor before they purchase a sensor. For example, working within sewers presents the potential for several toxic gases, including hydrogen sulfide and carbon monoxide. Hazardous materials incidents around chemicals at an industrial facility also can involve exposure to multiple hazards. For these situations, more comprehensive, multiple gas sensors should be purchased. If the only concern is an oxygen-deficient environment, a less expensive, oxygen-only sensing unit can be purchased.

Multiple gas sensors today commonly measure as many as four hazards, including oxygen deficiencies, combustible gases, and specific toxins (usually carbon monoxide, hydrogen sulfide, sulfur dioxide, nitrogen dioxide, and/or chlorine). There are thousands of possible toxins that rescue personnel can encounter during a hazardous materials incident, it would be virtually impossible for any department to have the capability to monitor all of the toxic atmospheres within their response area. Frequently, departments make arrangements to secure technical assistance in monitoring toxic atmospheres from a local chemical company.

Some of the monitors provide readings immediately after being exposed to the atmosphere while others incorporate a pump (hand-aspirated or battery-operated) which draws the atmosphere over sensors. Most of the instruments also provide an option for using an extension tube for pumping from a remote atmosphere. Hazardous materials personnel should note that manually activated pump units do not continuously monitor the environment.

It is important to note that atmospheres should not be considered safe based solely on a negative meter reading alone. Unmeasured hazards (toxins at structure fires, transportation accidents) and equipment malfunction should always be considered prior to the removal of PPE and respiratory protection.

Hazardous materials responders also should remember that atmospheric sensors must be calibrated and tested regularly. An inaccurate instrument endangers the lives of rescuers. Many instruments now have some sort of self-test capability to assure proper functioning. Earphones, low-battery alarms, audible/visible alarms, contaminated-environment, and sensor deterioration indicators also are available. Newer units, the size of a portable radio, can log what is sensed during is sensed during a rescue.

**Training –** Training in accordance with NFPA 472 should be provided to personnel who are expected to operate atmospheric monitors. Most manufacturers provide classroom or videotape instruction after the purchase of their product.

**Costs –** Gas-sensing monitors range in price from $1,000 to $6,000, depending on the number of gases it detects and the desired accessories.

**Future Trends –** This technology will continue to become smaller, while the number of gases that can be detected by an individual monitor will continue to increase. In addition, the price of these monitors also should decrease in the future.

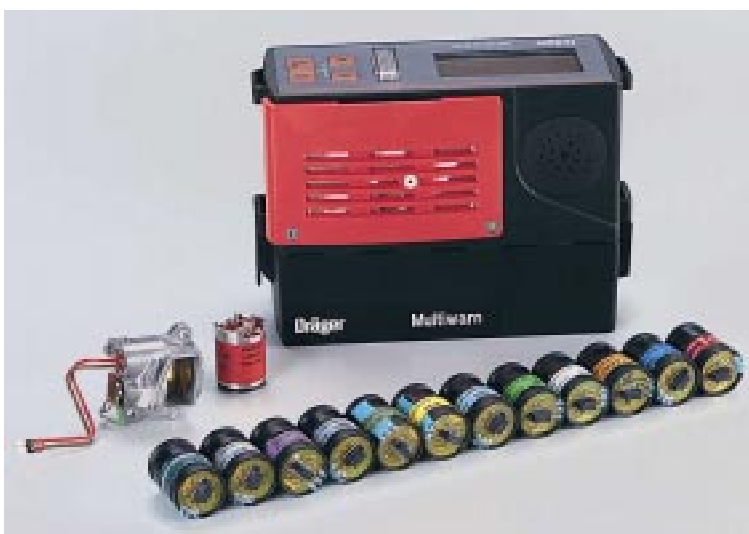



*Photo courtesy of Drager*

### Carbon Monoxide Detectors

The recent publicity focusing on carbon monoxide poisoning has led to the rise of home carbon monoxide detectors. Many of these detectors use sensors with a chemical similar to human hemoglobin. When levels rise to a potentially toxic level, the sensor trips, activating the internal audible alarm. Activations of such home detectors have led to a rise in fire department responses to CO emergencies. Most fire departments today equip their apparatus with CO monitors for such responses. CO monitors for fire departments come in a wide variety of shapes and sizes and offer many features. While some larger monitors offer additional monitoring techniques, other models are as small as cellular phones and can be clipped to a first aid jump-kit or other convenient spot. Most of the models available to fire departments today are hand-held and offer continuous atmospheric sampling, fast, accurate and digital readings. Some even come with breath analysis features allowing emergency personnel to test victims for CO poisoning.

### Portable Analyzers and Mobile Lab Equipment

For many situations requiring ambient air monitoring, no instrument is suitable for rapid deployment to quantify the levels of hazardous or toxic air contaminants present. This is the reason that emergency response air monitoring is very difficult. Portable analyzers (for use in the field) are much more rugged and easier to use than equipment designed for laboratory analyses. Identification of air contaminants using these technologies may be obtained as early as a couple of hours after sampling.

Gas chromatograph/mass spectrometers (GC/MS) can be used to analyze liquids, solids, air, or gas chemical samples at hazardous materials incident scenes. GC/MS instruments are used to separate mixtures of compounds. Samples are injected into the end of a column through which hydrogen gas is flowing continuously. The heat from the hydrogen gas vaporizes the sample and the sample particles separate from one another. The various chemical samples then travel through the mass spectrometer for analysis. The chemical is then bombarded by an electron beam, which causes the molecules to break apart into fragment ions. A full analysis can take from as little as 2 to 45 minutes or as long as 24 to 48 hours to obtain reliable and accurate data in the parts-per-billion range (PPB). Many portable analyzers are affected by atmospheric conditions and interference, and therefore have varying accuracy. Some of these techniques include the use of detector tubes, multiple gas analyzers, organic vapor analyzers (OVA), photoionization detectors (PID), gas chromatography (GC), and mass spectrometry (MS). “Tedlar bags” or “Summa canisters” (made of a material that is inert to a wide range of chemicals and used for the collection of toxic gases) may be used to collect a sample for later analysis.

Since there is no all-inclusive analyzer, the initial and preliminary data may be derived from detector tubes, OVAs, and PIDs. The analytical information generated by this equipment may provide the incident coordinators with information from which decisions can be made about evacuations from an area or when it is safe to allow residents/occupants to return.

**Training –** These technologies will require extensive knowledge and training in the hard sciences to be useful. Their use usually will be reserved for larger departments that have access to trained scientists.

**Costs –** These units can cost upwards of $100,000, and therefore are beyond the price range of most departments. The price of such technology has fallen in recent years, and it may continue to fall, meaning that these units may become affordable to emergency response agencies in the future.

**Future Trends –** It anticipated that as technology improves the time that is required to determine unknown substances will decrease. In addition, these units will continue to become smaller and decrease in price. Finally, the military has developed a mobile lab that is equipped with a biological detection suite which uses complementary technologies to detect biological agents.

### *Detector Tubes*

Colorimetric tubes provide a wide range of analyses for both organic and inorganic air contaminants. These devices are thin glass tubes filled with chemical reagents that react when exposed to a target compound. They produce a color change to indicate the presence and concentration of the contaminant in the air. The tubes are simple and easy to use, but they have a limited shelf-life and limited accuracy.

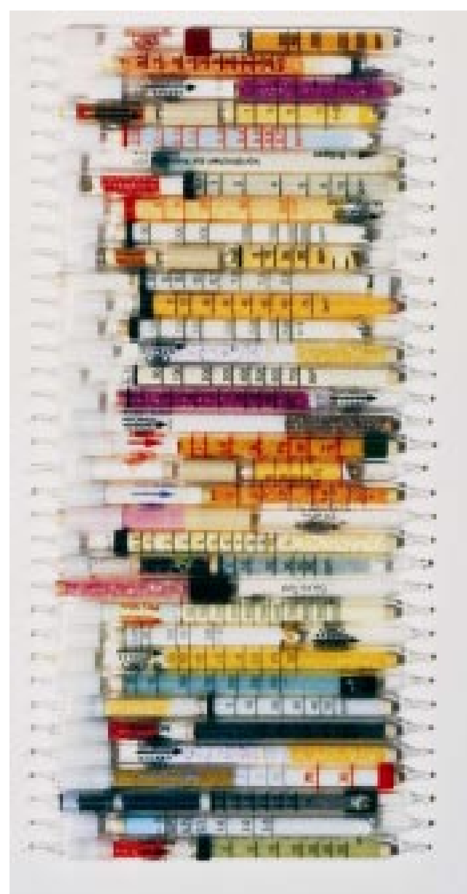


*Photo courtesy of Drager*

Detector tubes easily and rapidly provide the measurement results needed to decide which firefighting measures should be taken on certain hazardous materials incidents. Ideally suited for precisely measuring the concentration of noxious fumes, detector tubes can be used in a wide variety of hazardous materials incidents. Research has highlighted four principal indicator substances where this technology would be useful. Included in this are: carbon monoxide, hydrogen cyanide (prussic acid), hydrogen chloride (hydrochloric acid), and formaldehyde. This technology provides a simple, safe helping hand in risk analysis by hazardous materials teams. Detector tubes can also be used during fires involving large quantities of halogenated plastics such as PVC, low-temperature carbonization or decomposition of fertilizer, in warehouse fires where hazardous substances are stored and in fires in commercial enterprises and industrial plants.

The main advantages of these detection systems in firefighting are its ease of use and the its accuracy in its measurements. Most systems digitally display which hazardous substance have been detected and also indicate its concentration, thereby presenting the result of measurement as a direct aid in decision-making. Finally, most systems have relatively low sensitivities and offer high selectivity, preventing false alarms.

**Training –** This technology requires little training. Training is limited to tube use and understanding of the readings. Most companies that sell these products will provide classroom or videotape training to support their product.

**Costs –** Colorimetric tubes require a pump for use. This pump generally costs about $300. Pricing for colorimetric tubes depends on the nature of the gas being tested. Tubes range in price from $40 to $100. Each tube can be used only once.

**Future Trends –** With the development of electronic atmospheric monitors there has been a decreased use of colorimetric tubes. However, these tubes will continue to be needed to identify specific gases that can not be identified by atmospheric monitors.

### *Organic Vapor Analyzers*

The organic vapor analyzer (OVA) operates with a flame ionization detector (FID) to measure organic compound concentrations in air. The FID operates by ionizing the volatile organic with the energy of a hydrogen flame. The flame burns the organic substance to generate carbon dioxide and water. The carbon ions formed are measured by an electrical field. A small ion current flows when the charged carbons arrive at one of two electrodes and become neutralized. The ion current is amplified by an electrometer-type amplifier and presented to a meter. The FID gives some response to virtually all organic compounds. The OVA is easy to use, but it is limited by its supply of hydrogen as well as its battery charge. The OVA can measure contaminants as high as 10,000 parts per million (PPM) and as low as one PPM. This instrument measures the total organic presence, and does not identify individual compounds by species.

OVAs can be used in a variety of hazardous materials incidents. This technology is very useful in the stationary, continuous monitoring of the concentration of ethylene oxide, propylene oxide, ethene, propene, vinyl chloride, methanol, ethanol, acetaldehyde, butadiene, formaldehyde, vinyl acetate and iso-propanol in ambient air, particularly for the detection of leaks.

**Training –** This technology requires extensive knowledge and training in the hard sciences to be useful. Use of this technology can only be utilized by personnel trained to or above the Specialist level. These systems usually will be reserved for larger fire departments that will have trained scientists available to staff these units.

**Costs –** These devices generally cost about $9,000. The price can increase to $12,000, depending on the ancillary options that are purchased.

**Future Trends –** This technology is being merged with photoionization detectors into single units. These units will continue to become smaller and less expensive.

### *Photoionization Detectors*

The photoionization detector (PID) is a battery-powered portable instrument that operates using ultraviolet (UV) light. The PID consists of a sealed UV light source that generates photons which ionize specific molecules in the gas stream (chemicals considered pollutants, most hydrocarbons), but do not ionize the major components of air such as argon, carbon dioxide, oxygen, nitrogen, or water vapor. Molecules absorb the UV light leading to ionization and release of a certain amount of energy. The ionized molecules are subjected to a continuous electrical field between a pair of electrodes, (a collector and a repeller electrode). The ions move in the electrical field generating a current proportional to the chemical concentration in the detector cell. An electrometer circuit converts the current to a voltage, which is sent to the microprocessor for display as a concentration. The PID is more "user-friendly" than the OVA, and it requires less frequent calibration. It does not require hydrogen to operate. The PID can measure target compounds in a range from 0.2 to 2,000 PPM. Sensitivity and accuracy may fluctuate depending on the type of compound being monitored. The PID will measure the concentration of total organic in ambient air and displays concentration equivalent to the calibration gas, isobutylene.


*Photo courtesy of Enviro-Equipment*

PIDs can be used by hazardous materials response agencies to procure measurements of organic contaminants in the atmosphere. PIDs also provide fast and clear information. Finally, if calibrated accordingly, PIDs can even be used for quantifying an individual substance.

**Training –** This system will require extensive knowledge and training in the hard sciences to be useful. This system usually will be reserved for larger fire departments that will have trained scientists available to staff these units.

**Costs –** This system can be purchased for approximately $5,000. It also can be purchased in combination with OVAs for approximately $11,000. The price can increase significantly, depending on the options that are purchased.

**Future Trends –** This technology is being merged with OVAs into single units. These units will continue to become smaller and less expensive.

### *Radiation Detection*

Three basic types of radiation particles – alpha, beta, and gamma – have the capacity to harm those who are exposed to them. These particles can be found in a number of situations involving radiological exposures and spills. Alpha particles can be found at incidents involving uranium, plutonium and radon. Beta particles are a byproduct of some forms of carbon and sulfur. Gamma particles can be found in some forms of zinc and also in barium. Some ions such as phosphorus, magnesium, cobalt, sodium, and potassium sometimes give off combinations of both beta and gamma rays. The alpha particles emitted from any one type of radionuclide have a distinct energy. These energies are not sufficient to enable alpha particles to penetrate even the dead outer layer of the skin or a piece of paper. Because of this, they do not present an external radiation hazard. However, when alpha-emitting radionuclides are taken into the body, they become a serious internal radiation hazard.

Beta particles are much more penetrating than alpha particles. Very high-energy beta particles can penetrate tissue to a depth of about a centimeter. Eye and skin damage is possible if the source is strong; therefore, beta sources do present some external radiation hazard. They are, however, relatively easy to deal with by shielding. If beta-emitters are taken into the body (through inhalation or ingestion), they present a far greater hazard, though generally less so than the alpha emitters.

Unlike alpha and beta radiation, which are particles in nature, gamma radiation has no mass and is highly energetic. Gamma-rays have energies which are characteristic of the radioactive decay that produced them. Measurement of this energy provides a useful method of identifying the type of radioactivity in a sample. Gamma rays possess no electrical charge; therefore, they are not affected by electrical fields.

Since gamma rays have no mass, they are the most penetrating. A gamma ray can pass entirely through the human body and not be stopped. Gamma-rays will penetrate to great depths in materials. It takes 10 mm of lead to stop most gamma rays.

All radiation-measuring instruments consist of a radiosensitive detector and a means of recording the effects of radiation on the detector (i.e., the “response” of the detector). Detectors respond to radiation by producing various physical effects that can be measured. Ionization is one of these effects. The ion pairs can be collected to give an electrical signal which is related to the intensity of the radiation. Some detectors will emit light pulses in response to radiation, and the intensity of the radiation can be found by counting the pulses. Others will store the effects of radiation over long periods and then can yield the information at a later time. All of these devices respond in one way or another to the energy deposited in them by the radiation.

Instruments can be designed to indicate either the rate at which the radiation is being received or the integrated amount over a certain time. An ideal instrument would respond to all types and energies of radiation in terms of equivalent dose or equivalent-dose rate (i.e., it would be a universal equivalent dose meter). A good instrument should have the following characteristics:

- Accurate over a wide range of intensities.
- Intensity of measurement is independent of radiation energy.
- Capable of identifying the type of radiation.
- Signal proportional to dose or equivalent – dose rate.

By using different types of shielding on the detectors and specially designed electronic circuits, instruments can be made to approximate the above characteristics well. An instrument may indicate that the radiation field in a work location is 1mSv/h (milliSievert per hour). This is not enough information to enable us to assess the hazard. A practical instrument must tell us which type of radiation it is measuring, as well as the intensity.

Unfortunately, all radiation detectors do not respond to more than one type of radiation. Generally, in mixed radiation fields, a number of different instruments are required to measure the intensity of each radiation present.

When ionizing radiation passes through a gas it creates ion pairs. One method of measuring radiation is to collect the ions produced. There are three important instruments which use this type of detection. They are known as ionization chambers, scintillation counters, and Geiger counters.

### *Ionization Chambers*

Ionization chambers may have a number of electrode configurations and can be either sealed with a gas (or mixture of gases) inside or open to the atmosphere. A common construction is a sealed cylinder with a coaxial electrode which is electrically insulated from the cylinder. The body of the chamber thus forms one of the electrodes, and a rod or wire along the axis the other. A direct voltage is applied to the electrodes, positive to the center wire and negative to the body.

Radiation striking the gas will leave a trail of electrons and positive ions in its wake. The electrons are attracted to the positive electrode, and the heavier positive ions will drift more slowly to the negative electrode. When radiation strikes the detector at a steady rate, the electron flow to the positive electrode can be measured. This current will indicate the intensity of the radiation, provided that the detector voltage is high enough to attract all the electrons released by the radiation before they recombine.

Ionization chambers in their different forms are widely used as radiation measuring instruments. They are normally designed to respond to gamma radiation, but they also can be designed to detect and measure beta radiation and thermal neutrons.

Ionization chamber survey instruments have a response time of several seconds, and will respond to gamma radiation with- energy of 10 keV and above, and to beta particles with energy greater than 120 keV. For these measurements, the cap which usually protects a thin entrance window must be removed from the detector.

**Training** – Significant training or usage issues for the user are not foreseen for this type of system. While gathering information using these devices can be done by personnel trained to the Technician level, interpretation of the results of the information collected would probably require specialized training, perhaps even to the Specialist level.

**Costs –** Cost for these units generally ranges from $100 to $800.

**Future Trends –** These units will continue to decrease in both size and price.

### *Geiger Counters*

Among the oldest and most widely used portable radiation instruments is the Geiger counter. Fire departments may have old-style CDV-700 Geiger counters on hand. These were distributed under Civil Defense, and are recognizable by their distinctive yellow paint and Civil Defense stickers. The CDV-700 Geiger counter detects both low intensity beta and gamma radiation. Another ionization instrument distributed by the Civil Defense was the CDV-715. It measured only high-intensity gamma radiation.

The Geiger counter is a gas-filled tube with electrodes that attracts the electrons and ions to produce voltage pulses in external circuits. In a Geiger counter, the applied voltage is high enough to give the initial ions sufficient energy of their own to cause an avalanche of further ionization. The result is a large output pulse that is the same for all incident photons or particles. This causes the Geiger counter to register loud "snaps" as an audible indication of the presence of radiation.

*Photo courtesy of Ludlum Measurements*

Because the Geiger counter gives an output pulse each time a particle creates ionization in its detector tube, it is well suited for the detection of individual particles. If a Geiger counter is to detect beta as well as gamma radiation, the detector tube must have walls sufficiently thin for beta particles to penetrate. Such tubes are called "thin-walled-tubes" and often are used in portable survey meters. They may be fitted with a metal sheath which can be slid over the tube to prevent beta particles from entering. Measurements made with and without the sheath then will indicate the presence of beta radiation. These instruments usually are calibrated in counts per minute.

Particle detectors are not designed to measure anything other than the number of ionizing events that occur in the detector per unit time. They are generally used for monitoring surfaces, floors, hands, clothing, shoes, etc., for contamination.

Most portable instruments use a count-rate meter (rate-meter) to process the pulses from the Geiger detector. A rate-meter displays the rate at which pulses or counts are received by transforming a series of randomly arriving pulses into a smoothed-out direct current. This current is proportional to the rate at which the pulses arrive and is displayed on a meter calibrated in counts per minute.

The most important characteristic of a rate-meter is its response time. This is a measure of how long it takes the rate-meter to average out the pulse arrival rate and convert it to a steady reading. It will not give an instantaneous reading of the count rate.

Some rate-meters are equipped with a control which permits different response times to be selected. Long response times give a steadier reading, but the user has to wait longer for the reading to stabilize, whereas short response times may result in erratic readings. When the radiation level is low, a long response time is needed to smooth out the random rate at which the pulses arrive. For high levels, a short response time may be used. Radiation instruments fitted with rate-meters usually have response times in the 9 to 15 second range. The user must give the instrument enough time to reach its final reading. This is especially important when the user is monitoring other rescue personnel for low-level contamination.

A Geiger tube will not detect every particle or gamma photon that enters it. The percentage of the incoming radiation that is counted is known as the “efficiency” of the Geiger tube. The factors that affect the efficiency are:

- Type of radiation being detected – A Geiger tube detects beta particles much more efficiently than gamma rays which can pass right through without interacting. As a general rule, a tube will give a pulse for each beta particle entering it, but for only one percent of the gamma photons.
- Geiger tube construction – Geiger tubes made of different materials and of different sizes have different efficiencies. Generally, smaller tubes of the same type have lower efficiency.
- “Dead time” losses – After an ionizing event, the tube takes a short period of time to recover, and will not record anything during this interval, known as the dead time.

When surveying for radiation, it is important to start with the instrument switched to the highest range and then to select more sensitive ranges as required. Never walk into an area in which a high field may exist with the survey instrument set on a sensitive range. It may saturate and read very low or zero even though a high field is present.

In general, any Geiger counter is designed to account for the limitations of the detector by suitable design of the scale and by minimizing dead-time losses. The latter is achieved by using a tube suitable for the intensity of radiation. For this reason, many survey instruments are equipped with two Geiger tubes: a larger one for lower fields and a smaller one for high fields.

**Training –** Users must be trained on the operation of a Geiger counter, including how one measures "background" radiation. In addition, specific training is needed for each type of radiation being detected, and on the interpretation of readings.

**Costs –** Geiger counters can cost as much as $1,000 to $1,500 depending on the model, its specification, and the type of probe order.

**Future Trends –** No specific trends in the use or development of this technology have been identified.

*Scintillation Counters*

The detectors described so far all register the ionization produced by radiation in a gas. The scintillation detector works on quite a different principle: it measures radiation by detecting tiny flashes of light which radiation produces in certain materials. These light flashes, called scintillation, are converted to electrical pulses and, when fed into suitable electronics, can discriminate between different types of radiation and even between different energies of the same radiation.

There are several types of scintillation counters, but their detector systems always consist of two components which are optically coupled. The first is a scintillator. This is a solid or liquid which emits light pulses when radiation deposits energy in it. This is called the scintillation "phosphor." The second component is a photomultiplier which converts this light pulse into a pulse of electric current.

The scintillation counter is based on the emission by certain substances (such as those used to make the screens of television pictures tubes) of flashes of light when struck by ionizing radiation. The light flashes then are picked up by a photomultiplier tube which amplifies the initial output of photoelectrons from a suitable cathode by the secondary emission of further electrons at each successive dynode. A scintillation counter is more rapid in its operation than an ionization chamber or a Geiger counter.

There are several materials which are suitable for use as phosphors. To some extent, the type of radiation to be detected determines which material is chosen. One of the most commonly used scintillating materials for detecting gamma rays is activated sodium iodide. "Activated" in this context means that it is saturated with about one percent thallium to increase its efficiency as a scintillator.

The iodine provides most of the stopping power in the sodium iodide; it is the resettling of the orbital electrons of iodine after ionization which produces the blue, violet, and ultraviolet light of the scintillation. A scintillation is really a very brief shower of minute light flashes, each flash resulting from the resettlement of the electrons in an ionized atom. In a sodium iodide crystal, the whole process is completed in less than a microsecond, so that the shower appears as a single flash.

The more energetic the absorbed gamma photon is, the greater will be the number of atoms ionized in the crystal, and therefore the more intense the scintillation. In other words, we can measure the energy of the gamma photon by measuring the intensity of the scintillation.

The scintillator is optically bonded to a photomultiplier, and the assembly is encased in a thin aluminum can which allows gamma rays in, but excludes light from any source other than the scintillator. This also prevents moisture from damaging the sodium iodine crystal, which attracts water.

The photomultiplier has a light-sensitive electrode called the “photocathode” which emits electrons when photons strike it. These electrons are accelerated by a series of electrodes, called dynodes, towards a collector (or anode). The electrons produce several secondary electrons each time they strike a dynode, resulting in a multiplication of their number as they approach the anode. An external resistor chain connected to a stable power supply is used to produce the voltages which are applied to the dynodes.

The output from the photomultiplier is amplified and the signal fed into a discriminator. The discriminator is a circuit which is set such that only pulses in a small range of amplitude are allowed to pass. These pulses, of a selected energy range, then are fed into a rate-meter or scaler.

Typically, each electron which strikes a dynode will produce about four secondary electrons. This means that if one electron is released from the photocathode, a phototube with 10 dynodes will deliver $4^{10}$ (1,048,576) electrons to the collector. This gain, of about one million, is critically dependent upon the dynode voltages, which necessitates a very stable power supply.

It should be mentioned that particles also will produce scintillation in a phosphor. Alpha particles can be detected in the presence of other radiation by using very thin sheets of scintillating material. The phosphor may be a thin sheet of plastic scintillator or zinc sulphide embedded in a transparent tape. A very thin aluminized mylar foil is wrapped around this to exclude light but allow the alpha particles through. Because of their low penetrating power, alpha particles are stopped in the thin scintillator and so deposit all of their energy there. Beta particles and gamma photons will lose only a small fraction of their energy in the thin scintillator and so produce much smaller pulses. If the discriminator level is set to accept the larger pulses due to alpha radiation, and reject the smaller pulses produced by beta and gamma radiation, the instrument can be used for detecting alpha contamination, even when beta-gamma contamination is present, as is often the case.

Emergency responders in certain areas (e.g., laboratories) have been trained to use scintillation detectors when large amounts of alpha emitters are present (e.g., transuranic waste). Scintillation detection is used much less than other types of alpha detectors because they are larger, harder to use, and require specialized training. Scintillation detectors are more accurate Geiger counters but they are also more difficult to handle (e.g., the probe is much bigger and the detectors are more delicate because of the chemicals they use internally).

**Training –** Specialized training on the operation of the technology and interpretation of the measurement is required.

**Costs –** This technology can cost upwards of $1,000 per unit.

**Future Trends –** These units likely will decrease in size and price.

### *Dosimeters*

Dosimeters are widely used by personnel in a variety of environments where exposure to radiation is possible or probable. These small devices allow personnel and supervisors to know how much radiation an individual is exposed to over a short or long period of time. Dosimeters are used mainly to measure safe levels of radiation exposure in areas such as the nuclear industry and the medical field. Firefighters can use this same technology when operating on a scene where exposure to radiation is possible.

Dosimeters are small devices which register doses of radiation. Dosimeters can be made with radiation-sensitive materials which change color when irradiated, or can directly measure the accumulated dose or quantity of gamma and x-ray exposure.

**Training –** Users must be trained in how to read the dosimeter to determine the exposure risks, and also must be trained to wear or carry the dosimeters in any environment where radiation exposure is possible.

**Costs –** Dosimeters can cost from $100 to $250 per unit.

**Future Trends –** No specific trends in the use or development of this technology have been identified.

## CHAPTER V – REMOTE INCIDENT MONITORING

### Thermal Imaging Technology

Thermal imaging technology detects infrared energy produced by heat. Energy is given off in the form of heat by chemical and biological processes such as metabolism and oxidation; people, fires, and many chemical reactions release energy in the form of heat. Heat energy in the electromagnetic spectrum emits infrared waves not detectable by the human eye. Thermal imagery detects infrared energy and transforms the images so the human eye can visualize the heat energy through smoke and some obstructions.

Thermal imaging devices have previously been adapted to fire and EMS industry for firefighting and rescue applications. More recently, this technology has found an application in hazardous material incidents; because reacting chemicals may produce heat and detectable infrared energy waves. Thermal imaging may be useful for identifying escaping liquids and vapors as well as for determining the level of hazardous materials in many containers at emergency incidents.

Basic infrared (IR) technology has been used for many years by the military for night-vision surveillance of combat personnel. The night-vision equipment uses an electromagnetic spectrum wavelength unsuitable for the fire service because it can be obscured by smoke. The early IR detectors used pyroelectric vidicon (PEV) tube technology, which had the drawback of causing a "white-out" when pointed directly at a source of infrared energy, such as a fire. Some fire departments piloted these early units, but the sensitivity and white-out problems limited practical application.

What has made thermal imaging technology practical for the fire and rescue service is the focal plane array chips (FPAC) technology and microengineering. This technology relies on a heat-sensitive miniature ceramic chip, which responds to infrared energy and converts it to a video image visible to the human eye. This technology can detect temperature differences of 0.1° to 0.5° Fahrenheit, depending on the unit manufacturer.

Thermal imaging cameras are available through several manufacturers and in two basic configurations. The first is a handheld device that can be passed easily from person to person. This may be a benefit should a responder need to leave the "hot zone" to remove a victim or to replenish an air supply. The second type of device is a helmet-mounted unit. It allows hands-free operation, which has practical benefits for personnel attempting mitigation operations in a hot zone. It should be noted that it is rare for hazardous materials technicians and specialists to wear helmets into the hot zone and that departments looking into purchasing this technology should keep this in mind.

Some thermal imaging devices can transmit wireless video output. This allows the command post to see what the responder sees in real time, or to tape the event for later comparisons of the incident's progress or for training and critique purposes.

Because thermal imaging cameras have electrical components that are not certified as "intrinsically safe," they should be used at safe distances from flammable or explosive atmospheres.

### *Hazardous Materials Application*

The Atlanta, Georgia Fire Department has documented two incidents in which the thermal imager was used for hazardous-materials incidents. One incident involved a transportation accident where a truck spilled drums of hydrochloric acid on the ground during a light rain. The thermal imager was used to detect the chemical heat reaction and to determine the direction of the acid vapor cloud and liquid product flow. The resources and evacuation efforts then were adjusted accordingly.

On another hazardous materials incident, the thermal imager was used to determine if an overturned truck with spilled acetone had reacted with the oxidizer sodium hyperchloride also known to be in the cargo. The thermal imager allowed the hazardous materials personnel to determine, from a safe distance, that the two chemicals had not come in contact because no heat was detected.

Some fire departments around the country are using thermal imaging technology as powerful aids to assist fireground commanders to track emergency personnel, locate trapped victims, or do sizeups at incidents where heat signatures are not blocked by surrounding objects.

Thermal imaging devices may provide a number of tangible benefits during hazardous materials incidents where there are few heat-signature-blocking structures to limit the devices' effectiveness. One fire department has a standard operating procedure of using a thermal imaging camera to scan buildings or other areas for hazards, such as chemical reactions or unrecognized releases or runoffs prior to beginning operations.

*Photo courtesy of Raytheon*

### ***Thermal Imaging Cameras***

Thermal imaging cameras, which vary in size and power, can locate and monitor emergency personnel operating in smoke, fog, night, and other low-visibility conditions by locating the heat patterns of their infrared radiation signatures.

Thermal imaging cameras, which are especially sensitive to body heat, use infrared technology to sense very minute heat signatures. Typical thermal devices are able to discern differences of as little as 0.1° Fahrenheit between an object and its background. This "thermal contrast" is displayed on a monitor. Thermal imaging devices cannot see through most structures since infrared radiation cannot be detected through concrete, rock, brick, wood, drywall or other materials that block heat patterns.

The typical black and white image monitor, which varies in brightness depending upon an object's temperature, generally produces a silhouette-style image of a person, but will show neither detailed features nor colors. Most thermal imaging cameras available for use by the fire service use either a PEV unit or a FPAC. Some handheld thermal imaging devices contain PEV technology, which uses imagery that has a tendency to "white-out," or flood the entire display screen with light, when the unit is pointed directly at a high-energy heat source. FPAC technology is more expensive initially, but has lower maintenance costs over time. FPAC devices display a "virtual reality" image that does not white out when pointed at a high-energy heat source.

*Photo courtesy of Cairns*

### *Personal Thermal Imaging Cameras*

Personal thermal imaging cameras range from small handheld camcorder-like devices to helmet-mounted systems. Handheld units are designed for one-handed operation: firefighters simply lift the camera to eye level and look into the video display area. These offer the advantage of using the camera only as needed, which frees a firefighter's vision from constant obstruction.

Helmet-mounted units have a camera lens attached to the side of a helmet and connected to a video display anchored to the front of the helmet. Helmet-mounted units provide a constant thermal-enhanced image and allow unrestricted use of both hands, but are attached permanently to the helmet when in use. This means that helmet-mounted units cannot be passed among crew members while conducting interior operations or where ever helmets are worn.

Both types of personal cameras are ruggedly designed for limited use in, and exposure to, areas near fire or water, and usually can be used for several hours before the batteries run out of energy. Some units must be turned off hourly to cool down, since their airtight design does not allow for easy cooling of internal components.

**Training –** Initial in-service training is required for use of this technology. Proficiency with this, and most other resources in the fire/rescue service, is achieved through extensive training and experience, and departments purchasing this technology should keep this in mind.

**Costs –** Personal thermal imaging cameras cost $10,000 for base units and $20,000 for more expensive units which offer increased range and image clarity.

**Future Trends –** Thermal imaging devices of the future will be smaller, lighter, and more powerful. Experimental work has been done to build a firefighter helmet that incorporates a thermal imaging device, an SCBA facepiece, and an internal communication system into a motorcycle-like helmet. The growing popularity of thermal imaging cameras for use in a wide variety of roles will serve to stimulate further development of improved models.

### *Forward-Looking Infrared Radar*

*Photo courtesy of Raytheon*

Forward-looking infrared radar (FLIR) units, used by some search and rescue teams to scan for people over large areas, are very powerful and expensive thermal imaging devices that mount to vehicles such as helicopters or trucks. FLIRs commonly have a range measured in miles, depending on the lens, so they are ideal for vehicles capable of rapidly covering wide areas; some helicopter-mounted FLIRs have a range of ten miles. Sophisticated new tracking technology allows FLIR units to “lock on” and automatically track a thermal signature so long as it stays in range of the camera.

**Training –** Initial in-service training is required for use of this technology. Proficiency with this, and most other resources in the fire/rescue service, is achieved through extensive training and experience, and departments purchasing this technology should keep this in mind.

**Costs –** FLIR units are more expensive than handheld models, usually costing over $50,000.

**Future Trends –** The future of FLIRs will include enhanced resolution, increasing range and clarity, while the cost is expected to decrease.

### *Thermal Detectors*

Thermal detectors are similar to thermal imaging technology, but are much less sophisticated. Thermal detectors read only the temperature of the spot at which the detector is aimed. They can provide information about the thermal reactions of containers and products from approximately 30 feet. While gas monitors and detectors can provide lower flammable limits of the atmosphere, a thermal detector may indicate if ignition sources or rising temperatures as a result of a chemical reaction pose a threat.

Thermal detectors can measure from -20° to 2,000° Fahrenheit. They are very accurate. Some detectors use liquid crystal display (LCD) temperature readouts while others use different audible tones and colored liquid-emitting diodes (LEDs) to indicate intensity. Most handheld, compact units operate on a 9-volt alkaline battery.

One unit provides laser sighting, which allows the operator to target a specific area to be monitored. Another unit has a comparable feature which will compare the current reading with an earlier one to determine if the temperature is changing (or compare the temperature of one object with the temperature of surrounding objects).

**Training –** Significant training or usage issues are not foreseen for this type of system.

**Costs –** Thermal Detectors can cost from as low as $30 to $50 (for basic, non-scientific models) to as high as $5,000 to $10,000 (depending on the features they have).

**Future Trends –** These units will likely decrease in size and price.

## CHAPTER VI – ENVIRONMENTAL SURVEILLANCE EQUIPMENT

The breach of a hazardous materials container will allow the contents to come in contact with the atmosphere. A released material will produce a plume that is affected by humidity, wind speed, and direction. The direction of the plume indicates the potential threat to people and the environment; thus, it is important to monitor the weather conditions during hazardous materials incidents. It is also important to monitor the weather conditions in regard to the health and safety of the emergency responders.

### *Area Heat Stress Monitor*

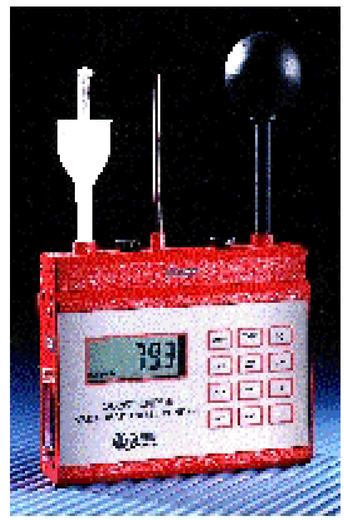


*Photo courtesy of Quest Technologies*

Area heat stress monitors generally measure three parameters: a dry bulb or ambient temperature (DB), natural wet bulb temperature (WB), and globe temperature (GT). From these the weighted average of all three (the WBGT index) is calculated in either degrees Celsius or Fahrenheit.

Perspiration is one way the body controls its internal temperature. As the perspiration evaporates, it has a cooling effect on the body. The natural wet bulb temperature simulates the effect of evaporative heat loss. The sensor achieves this by having an unshielded bulb covered with a wet cotton sock or wick. The evaporation from the wick cools the sensor in the same way that sweat cools the body. Because of this cooling effect, the natural wet bulb temperature normally is lower than the air temperature.

The GT indicates the amount of heat exchanged by the body due to radiation. DB is the dry-bulb temperature measured while shielded from radiation. Some units have the added capability of data storage and output to a serial or parallel printer. Ideally, these units should be placed four feet above the ground. The information these units provide is important to ensure the safety of personnel operating at a hazardous materials scene, especially those in level A suits.

Due to construction properties of turnout gear, there is virtually no exchange of water vapor (evaporation of perspiration) so DB will primarily serve as the main predictor of heat stress. In the presence of humidity, firefighters in turnout gear may also exhibit increased susceptibility to heat stress.

**Training –** Significant training or usage issues are not foreseen for this type of system. It may, however, require someone who is technically proficient to interpret the data. A basic understanding of human physiology and the effects of heat are required.

**Costs –** These units generally range in cost from $1,000 to $2,000.

**Future Trends –** There do not appear to be any major changes coming in the future for area heat stress monitors. These detectors may become integrated with portable weather monitors. These units generally will become smaller and less expensive.

### *Portable Weather Monitors*


*Photo courtesy of Coastal Environmental System*

Onsite monitoring of weather data is possible using commercially available technologies. Many fire department hazardous material teams use a system which employs weather sensors mounted on a tripod near the vicinity of the hot zone. The data are transmitted via radio telemetry back to a dedicated read-out display screen. The data also are entered directly into a host computer that can be updated every 30 seconds. The weather information can update any hazardous material plume modeling program, such as Computer Aided Management of Emergency Operations (CAMEO), and Aerial Location of Hazardous Atmosphere (ALOHA), which can display the plume and affected areas graphically on a computer screen.

Weather sensors can be mounted on a portable tripod and powered by batteries, or be vehicle-mounted and powered by 12-volt vehicle power. Included sensors can monitor wind, barometric pressure, humidity, air temperature, and direction (using an internal compass). More sophisticated models can measure ultraviolet radiation, evapotranspiration (evaporation from the soil and transpiration from the plants), and solar energy. The portable weather units transmit the information by radio telemetry. The vehicle-mounted units use direct cable wire to the readout display. The readout display and computer on either unit use 110/220 alternating current. The monitoring sensors are intrinsically safe.

**Training –** Significant training or usage issues are not foreseen for this type of system. It may, however, require someone who is technically proficient to interpret the data.

**Costs –** Portable weather monitors generally cost between $4,000 and $15,000 depending on the system configuration.

**Future Trends –** Future portable weather monitors will have enhanced capabilities that will provide users with the same capabilities that advanced dispersion modeling (see next section) programs have. In addition, these monitors will continue to become smaller and less expensive.

### *Dispersion Models*

Releases of vaporized or gaseous chemicals into the atmosphere results in clouds (or "plumes"). Predicting the size, altitude, and direction of travel of these plumes is extremely important in creating safe working zones and in determining the extent to which an evacuation will need to occur.

The atmosphere is a complex system in which chemicals – originating from various sources (called "point sources") – are dispersed by various mechanisms (e.g., heat, humidity, wind, topography, etc.). Models that accurately describe the dispersion process and the effects of chemicals will allow predictions of how man-made chemicals affect the environment. Special attention is being focused on how plumes are affected by factors such as the greenhouse effect, the thinning ozone layer, and the effect of industrial emissions on the biosphere.

When a hazardous material is released to the atmosphere, it is most concentrated at the source. For a gaseous material, the concentration in the air near the source depends upon the chemical's characteristics, including vapor pressure, which is the tendency of a substance to evaporate to the atmosphere.

Recent developments in the sophistication of geographic information system (GIS) application programming interfaces (API), combined with advances in the sciences of atmospheric dispersion modeling, communications, and computer hardware have provided the platform for development of an atmospheric modeling system for hazardous materials emergency response.

Computer modeling is a simulation of a real event (a hazardous materials release) using variable inputs (e.g., weather, topography, and the character of pollutant release) to predict and display effects (in this case, the chemical effects on the atmosphere). Models produce realistic plume paths for releases and spills. Sophisticated models will work even for the most complex terrain and can address plume spread, deposition, and health effects analysis, among other things.

Computers that predict the geographic extent of a hazard following a discharge of hazardous materials are an important tool for hazardous materials personnel. These predictions require the proper hardware, software, and a skilled operator to run the dispersion program.

Dispersion modeling is one of the tools that can be used to predict the spread of an air contaminant during an emergency response to a release of hazardous materials.

Because the atmosphere is turbulent, it mixes the air around a release site and spreads out and dilutes the concentrated slug of chemicals emanating from the source in a plume that moves in a downwind direction from the location where the chemical is leaking into the atmosphere. Even during relatively stable atmospheric conditions, known as "atmospheric inversions," some mixing occurs, carrying the pollutant away from the source of the release. The combination of winds and the tendency of warm air to rise will do two things to the pollutant that is released to the atmosphere:

1. *Dilute it.* The spreading out of the pollutant mixes it with a larger volume of air and the concentration is decreased.

2. *Spread it out*. The "plume" of pollution is carried away from the source and spreads out to cover a larger geographic area downwind from the release.

Five main weather factors determine how a given chemical will disperse in the atmosphere:

1. *Temperature*. The higher the temperature, the faster the substance will evaporate from the source of the release to the surrounding air.

2. *Wind speed*. The higher the wind speed, the greater the rate at which the chemical plume will spread downwind away from the release. The extent of the geographic area covered by a chemical plume is related directly to wind speed.

3. *Wind direction*. The direction of the wind will determine which geographic areas are affected by the chemical plume released to the atmosphere. Wind direction at the scene of a release is changeable. Localized winds can vary considerably in direction at any given time.

4. *Presence of an inversion*. The stability of the atmosphere refers to the degree of vertical mixing, which will affect the degree to which the pollutant is diluted. In the most stable atmospheres – known as "atmospheric inversions" – there is a "lid" on the atmosphere that causes minimum mixing of the atmosphere close to the ground. This results in a more highly concentrated plume of the chemical that stays closer to the source of the release. Atmospheric inversions require special modeling considerations.

5. *Humidity*. Some chemicals are soluble in water vapor; hence, the higher the humidity, the higher the concentration of the chemical in the atmosphere close to the ground.

The topography of the terrain downwind of the release also affects the way that the contaminant is spread and distributed into the environment. This consideration is referred to in models as "ground-roughness." In general, there are two extreme categories to be considered with regard to ground roughness:

1. *Obstructions*. The presence of hills, buildings, or other structures in the path of a chemical plume dispersing from a release will tend to keep a higher concentration closer to the source (with pockets of high concentration accumulating on the windward side of valleys or building walls). This condition sometimes is referred to as the "urban" condition.

2. *Flat terrain*. A flat, open terrain (e.g., Great Plains type of landscape) will carry the exude of chemical in the plume farther away from the source (affecting a greater area) and dilute it more (resulting in less dangerous concentrations). This sometimes is referred to as the "rural" condition.

In addition to categorizing ground roughness as one of the two extremes described above, some dispersion models allow the input of specific ground roughness factors determined in the field.

The following characteristics of the chemical involved in the release need to be considered in the running of the dispersion model:

1. *Chemical identity*. The specific identity of the chemical must be known, and the chemical must be present in the database of the model. It is important to note **that there are some substances that cannot be modeled**. Each dispersion software package has its own limitations on the database of substances that can be predicted by the model. For example, the ALOHA model uses a database of approximately 900 chemicals commonly involved in releases.

2. *Concentration*. The concentration of the chemical at the source of the release must be known. In general, the substance that is being released will be either fully concentrated (e.g., the release of ammonia at 100 percent) or some dilution of the chemical (e.g., 33 percent sulfuric acid in a puddle evaporating to the atmosphere).

3. *Physical state*. As the chemical is released to the atmosphere, is it a liquid or a gas? This is a fundamental question that needs to be entered into the model.

4. *Vapor pressure.* This characteristic determines how fast the substance evaporates into the atmosphere. This is not a specific parameter that needs to be entered into the model, as this characteristic is part of the model's chemical database.

5. *Toxicity and flammability limits*. The modeler needs to know the concentration of the chemical that is deemed to be hazardous. This is the key judgment that needs to be made by the modeler and requires a knowledge of which standard to use – for example, Immediately Dangerous to Life and Health (IDLH), Short Term Exposure Limit (STEL), Lower Explosive Limit (LEL), or some combination of health and flammability standards. This will be the key input, and it determines the limit of what constitutes a "hazardous atmosphere" that will be predicted by the dispersion run. Once the modeler knows what concentrations are to be set, it is simply a matter of entering this predetermined concentration as an input into the dispersion program.

Each dispersion model will have its own chemical database incorporated into the software. The specific conditions of the chemical release into the atmosphere need to be programmed into the model. The source circumstances include such factors as whether the chemical is being released as a gas from a broken valve or evaporating from a pooled liquid, the quantity of the release, temperature of the chemical being released, etc. Dispersion software programs will prompt the user through these data entry considerations.

All of the meteorological, topographical, and chemical considerations described above can be described by a complex equation. The equation, known as the "Gaussian Distribution Equation," integrates all of these factors – wind speed, wind direction, topography, chemical characteristics etc., and will provide the concentration profile in all downwind directions away from a release. The key word here is equation; the chemical dispersion model will calculate this equation for you with all of the inputs that you provide to the software. The output of the model is a predicted **estimate** of the spread of the plume: it provides the modeler with a snapshot of how far and in what specific direction a given concentration of the chemical will move. The differences among the various models available amount to specific procedures for providing these inputs and the degree of detail and accuracy in plotting the output predictions. The use of dispersion modeling requires software-specific training, as described below. There are three main applications of dispersion modeling for hazardous materials personnel:

*Predicting the hazard zone at the scene of a release.* Although this is an obvious application, predicting the geographic extent of the hazardous atmospheres at the scene of a release is a difficult undertaking. Onscene modeling requires quick determinations, and dispersion modeling often is cumbersome to set up, requiring onscene availability of a computer and real-time meteorological inputs to run the model. However, with a laptop computer, a process for constant updating of the model with weather conditions, a skilled operator, and plenty of practice, dispersion modeling can be a valuable tool for emergency personnel in determining the extent of the hazard zone.

*Prerun dispersion plumes for existing stationary sources.* Another application for dispersion modeling is preplanning. Stationary sources of hazardous materials (e.g., industrial facilities) have known inventories of each substance. Therefore, a "worst-case" plume can be generated, assuming an instantaneous release of the entire contents of the largest vessel of each substance, integrated with weather conditions that would cause the farthest geographic spread of the hazardous atmosphere from the source of the release. These plumes can be labeled, mapped, and made available to emergency response personnel, so that if a release of any substance from stationary facilities were to occur, responders could use the predetermined worst-case plume as an initial determination of the hazard zones. The obvious advantage of using prerun worst-case plumes is that it provides a way to determine a hazard zone without any input of time during the release. The limitations are that worst-case spreads probably will overestimate the areas affected by a release, since most releases will not be a worst-case circumstance.

The prerun releases need to be periodically (at least annually) updated, since industrial inventories are subject to change. A new Federal regulation, 40 CFR 63.112 of the Clean Air Act, requires certain industrial facilities to conduct these prerun worst-case models on their inventories of hazardous materials and to identify community receptors that would be at risk during a worst-case release. These dispersion predictions must be completed for most covered sources by 1999, and should be obtained by hazardous materials teams.

*Practice*. This often is an overlooked value of chemical dispersion modeling. Hazardous materials rescue teams that incorporate chemical dispersion modeling as a technique and practice the running of the plumes for different circumstances will develop a thorough understanding of the interactions of atmosphere, topography, weather, and chemical behavior. This understanding will enable emergency personnel to use this technique rapidly to determine the hazard zones around a release. If practiced routinely, the dispersion model can be a powerful tool that is more likely to be employed during an actual incident and can be of great value.

There are both hardware and software prerequisites for operating a chemical dispersion model. The specific hardware configurations are driven by the dispersion modeling software that is selected. Therefore, we will discuss software options and then generally describe hardware necessary to run the dispersion programs.

There are both public-domain and commercially available proprietary chemical dispersion models. Each model has its own strengths and disadvantages. A department considering dispersion modeling should investigate and evaluate the best model available for the budget available.

Specific hardware requirements vary with each model. Generally, most models are not keyed to a specific operating system and can be run in a Macintosh, DOS, or Windows environment. Most models will require a minimum of a 486 MHz computer with 12 megabytes of random access memory (RAM). It should be noted, however, that the faster the computer and the higher the RAM, the faster the system will be able to run the dispersion model. The best approach to consider current system requirements select the modeler that provides the best dispersion capabilities, and discuss the limitations (and possible hardware upgrades that may be required) with the distributors of the dispersion software.

The military currently uses remote tracking and infrared imaging capabilities to monitor atmospheric plume effects. Research shows that the centers of these plumes often (but not always) stabilize at an altitude between 2,500 and 7,200 feet. The military uses these data, along with atmospheric and meteorological conditions, to determine in what direction, at what speed, and with what concentration a plume will travel. By predicting such information, the military can give advanced warning to individuals in the targeted plume dispersion areas.

It is hard to determine when this military technology will be passed down to state and local hazardous materials agencies who may be faced with the need to calculate plume dispersion rates. Until then, there are several good models available – the ALOHA and the CAMEO models are among the most common and recognized.

**Training –** Operating a chemical dispersion modeling program requires training and experience. The type of training required depends upon the software that is selected and the level of proficiency that is desired in running the program and interpreting the results. For some of the simpler models (e.g., ALOHA), a one-half day introductory session may be sufficient to gain the ability to operate the program. The more advanced programs require more lengthy sessions and a higher level of background knowledge of Gaussian dispersion modeling. Beyond the initial introductory training, proficiency in operating a chemical dispersion model requires practice: Time must be devoted routinely for practice scenarios to keep the operators up-to-date on the intricacies of running the program and interpreting the results

**Costs –** In 1997, the Environmental Protection Agency (EPA) distributed a single free copy of one public domain chemical dispersion model, ALOHA, to each LEPC in the nation that requested it. The ALOHA dispersion model was designed by the National Oceanic and Atmospheric Administration (NOAA) specifically for predicting the geographic spread of a hazardous atmosphere resulting from accidental releases of hazardous materials. It is probably the dispersion model most widely used by hazardous materials teams across the country. For hazardous materials personnel who are just beginning to establish dispersion modeling capabilities, one approach may be to use the ALOHA model that is distributed by the EPA, and learn the general technique of modeling (ALOHA is relatively simple to learn and use).

When personnel have mastered the operation of ALOHA, they may then want to consider the selection of a different model as an alternative. Other computer models range in cost as high as $1,000 (not including training).

**Future Trends –** Future computer modeling programs will include larger hazardous material data bases. In addition, the price and system configurations are expected to change. There is a possibility of public release of other government modeling programs which could be available to fire and emergency service agencies in the future.

### *Weather Services*

Another option for monitoring the weather is through a weather service reporting real-time data. For a fee, a satellite receiver and satellite dish provide 24-hour service that can be customized for local and regional areas. This system provides information by satellite, including National Weather Service (NWS), and is updated instantly. This system can track storms and is similar to the system used by most television stations.

This system could be an advantage to a fire department with responsibilities for emergency preparedness. However, it would have limitations for specific onscene incident monitoring because it does not provide automatic updates to hazardous materials computer software.

The Internet also offers agencies another option for weather monitoring which may be less cost prohibitive. The Internet, also, may not offer real-time weather information, or may not be specific to a city or region.

**Training –** Significant training or usage issues are not foreseen for this type of system. It may, however, require someone who is technically proficient to interpret the data.

**Costs –** This service can be provided at an hourly rate or equipment can be leased on a monthly basis. The costs vary depending on the type of service selected. The cost of using the Internet is substantially less.

**Future Trends –** The Internet may be able to provide agencies with the important weather information they need as the use and sophistication of the Internet grows.

## CHAPTER VII – PERSONNEL MONITORING AND MEDICAL MANAGEMENT

Hazardous materials response personnel are constantly in a position of potential exposure to myriad toxic or hazardous substances. How to monitor the health of these individuals, and any effects of exposure on them, is a critical question. Both the acute and long-term effects of stress, heat, chemical exposures, and other factors must be considered. Recognition of this is necessary to develop a medical monitoring program for hazardous materials personnel. Accordingly, monitoring equipment that will provide the needed information in these areas must be selected. In addition, rescuers on the scene must be trained to be cognizant of the cardinal signs and symptoms of effects of hazardous materials exposure.

OSHA regulation 29 CFR 1910.120 mandates implementing a medical surveillance program if personnel are or may be exposed to hazardous substances. This includes emergency response personnel who respond to hazardous materials incidents.

There are three clearly defined periods of medical surveillance: pre-incident monitoring, incident monitoring, and post-incident monitoring.

Pre-incident monitoring (or pre-assignment monitoring) is performed at the time of initial assignment to a hazardous materials operational position to establish a baseline against which physiological changes can be observed. This is done through a thorough medical evaluation, which may include a medical history, physical examination, stress electrocardiogram (EKG), exercise pulmonary function test, complete blood count, a complete chemistry profile and urinalysis, and chest radiograph.

At present, incident monitoring usually consists only of pre- and post-entry physical examinations; however, as will be described later, technologies are emerging that will allow real-time monitoring of essential physiological functions and indicators.

During an actual hazardous materials incident, rescue personnel should be monitored by a designated safety officer or a medically qualified individual reporting to the safety officer. This individual should have expertise in hazardous materials and extensive familiarization with on-scene management and department administrative practices. These individuals ensure on-site safety and medical surveillance, contacting online medical control as needed for direction in providing medical care. A qualified expert in occupational medicine and toxicology should be consulted for known or potential exposures to any hazardous material. Complex issues must be addressed in defining the potential route of absorption, distribution, excretion, and kinetics of a given agent in the body. Vital signs and body weight should be taken at the onset of participation and as frequently as possible during the incident (e.g., at every SCBA bottle change, and when responders enter and leave the rehabilitation sector), paying particular attention to mental clarity, diaphoresis, pulse, respiratory rate, body temperature, and fine motor control.

Post-incident monitoring includes not only a re-evaluation of responders before they leave the incident, but also regular evaluations and any chemical-specific evaluations recommended by the chemical manufacturer, incident safety officer, or agency medical officer. Many departments require hazardous materials personnel to undergo a yearly physical examination to determine continued fitness for duty as a hazardous materials responder.

### *Medical Monitoring Technologies*

There are a number of medical monitoring technologies under development at this time. Many of these technologies suffer drawbacks that make them not entirely suited for use in the fire service; however, as these problems are overcome, these technologies may become more frequently used in the field. Drawbacks include the need to put on extra equipment under PPE, difficulty with monitoring signal acquisitions during exercise and sweating, and difficulty transmitting biomedical data due to structure construction, frequency issues, and the size and weight of transmitters to give sufficient power. Additionally, there is little medical research to provide a guide on what biomedical data should be monitored during hazardous materials operations. Nonetheless, medical monitoring of responders is an emerging practice that may provide hazardous materials personnel with an extra margin of safety.

Many of the technologies that could be used for medical monitoring during a hazardous materials incident were designed for military use. They may have significant fire/EMS applicability as well. These devices are either carried or worn. They provide continuous information on the physical condition and status of the wearer. Sensors include devices that can fit on a wrist, are attached to various body parts, or even are worn as a vest. (In the case of the vest, this monitoring capability has been combined with some sort of protective function as well, such as protection against fragments, bullets, and other projectiles common in military situations.) The sensors in these devices are connected remotely by radio, satellite, or other means, to a monitoring facility, which may be at headquarters, or simply one person with a computer.

Medical monitoring encompasses four basic modalities. The first is the measurement of an actual chemical in a body fluid. The detection of blood lead is an example of this type of monitoring. A second monitoring modality is the measurement of a metabolite (or breakdown product) in a given body fluid. An example of this type of monitoring is carbon monoxide levels in exhaled air (or carboxyhemoglobin levels in the blood) for methylene chloride exposures. Measurement of these metabolites provides an indicator of exposure but not an exact level of the chemical in the body. The determination of indirect biochemical parameters is the third biological monitoring modality. An example of this is the determination of cholinesterase levels for exposure to organophosphates. The final modality method of biological monitoring is the determination of a pathological event. An example of this would be the determination of pulmonary function tests for asbestos exposure.

In general, medical monitors transmit data about the person wearing the monitor back to a control center. Most of these devices are able to measure pulse, blood pressure, and respiration. More advanced models are able to measure perfusion and oxygen saturation.

Higher quality models that integrate real-time movement, position, and status data are being developed for the military. These systems also may integrate visual and audio transmitters that are worn by those out in the field, and provide images and sounds to whoever is monitoring and receiving the data. In some cases, a transparent "heads-up display" is integrated into the wearer's visor, providing information about the whole scene. This information can be tailored to individual needs by the control center. As technology is transferred from military to civilian application, this type of equipment may become available to emergency response agencies.

At present, these instruments are relevant to hazardous materials settings in a way that may not be considered mainstream. While these devices cannot, at present, indicate the precise location of an individual, they do still have a valuable role and are important to hazardous materials responders. Used in an appropriate system, they can provider commanders, safety officers, and medical personnel with essential physiological data that will assist in determining the health of each responder. They also can be used to determine who is in trouble or in imminent danger of becoming so. Should a person need help, these devices would alert a commander to that fact, and allow a search and rescue effort to be mounted.

In the future, it is expected that advances in positioning technology, such as GPS or radar, will be combined with these devices to provide a more complete picture of the location and status of any individual or group. Future models also are expected to be able to tell when an injury occurs or a wound is inflicted.

### *Sensor Vest*

This is essentially an elastic vest embedded with sensors and processors that both collect and disseminate information about the wearer. These vests are designed to detect torso penetration as well as areas of major bleeding. They also may be able to detect wounds and their location. The sensor vest monitors the wearer's heart rate, blood pressure, and respiration rate. The capacity for these devices to monitor such items as blood oxygenation, blood loss (through changes in body weight), dehydration, electrocardiogram (EKG), motion, and position also is being developed.

**Training** – Significant training or usage issues are not foreseen for this type of system. Using the vest at a hazardous materials incident may, however, require someone who is technically proficient to operate the monitoring station and interpret the data. For the most part, however, this technology operates on a stand-alone basis and does not interfere with what the wearer is doing. Good communication still will be required for optimum performance.

**Costs** – The costs of such systems may be prohibitive to fire and EMS agencies for the foreseeable future. Should a civilian application warrant commercial production, the costs could be expected to drop significantly. This, of course, would take place after the technology for such devices becomes more refined.

**Future Trends** – Future versions of this vest may integrate more sensing capability, such as EKG's, with an increased ability to provide location data. The vests may provide a protective element and allow greater communication opportunities.

### *Non-Invasive Medical Sensors (Personal Status Monitors)*

Noninvasive medical sensors are sound navigation and ranging (SONAR) used on the human body for medical purposes. These types of devices are used to monitor respiration, circulation, blood pressure, and central nervous system (CNS) function. Sensors can be worn on the body in several locations, as they are the size of a silver dollar and can fit into grooves such as those around the carotid arteries. Once in place, the sensors monitor pulse, perfusion, and blood pressure. They relay their data to a transmitter worn on the belt, which then sends the data back to the monitoring station.

**Training** – These devices are easy to use and wear. Basic medical training can assist in the ability to interpret the data being sent adequately and promptly, and to maintain communication among those wearing the sensors, those monitoring them, and those in overall command of the operation.

**Costs** – Such devices may be prohibitively expensive until a reasonable commercial application necessitates that they be priced competitively.

**Future Trends** – In the future, this type of technology will be able to provide a more complete picture of an individual’s status, however, it is unlikely that these devices will be able to provide positional information.

### *Silicone Rubber Optical Fibers*

Silicone rubber optical fibers are elastic materials that attach around the torso. They are sensitive to expansion and contraction, allowing them to monitor respirations. Presumably, they also can detect heart rate, skin temperature, and other vital signs. This type of a system is especially desirable in areas where alternate monitoring is not possible due to electromagnetic interference, etc.

**Training** – No significant training or usage issues appear. These systems require basic capabilities for monitoring purposes.

**Costs** – Because this technology is still emerging, cost is unknown at this time.

**Future Trends** – Silicone rubber optical fibers will provide an increased ability to collect information about vital signs and other physiological factors. This will enhance other technologies that have potential hazardous materials application.

### *Foot Force Sensors*

Foot force sensor systems use a special insole to detect foot pressure. The sensors can be calibrated individually to transmit data. The system is limited in its ability to provide essential physiological data, but it can monitor movement of victims. This system acts as a motion sensor that could be used to track the movement of emergency responders.

**Training** – No significant training or usage issues appear. This system would require basic monitoring capabilities.

**Costs** – Because this technology is still emerging, cost is unknown at this time.

**Future Trends** – No specific trends in the use or development of this technology have been identified.

### *Heart/Lung Sound Project*

The heart/lung sound project is an acoustic detection and classification system that is being developed by the military to detect heart and lung abnormalities. This system will allow onsite supervisors and paramedics to make diagnostic decisions based on physiological function. The advancement of computing, signal processing, and acoustic sensing technologies has made it possible to collect and analyze short-duration signals on inexpensive and portable off-the-shelf equipment. This system is being developed using a portable laptop as the computing platform. The initial system will have the following attributes:

Two acoustic, one ECG, and two reference channels. The acoustic channels will have a bandwidth from 20 Hz to 2 KHz with a variable prewhiting filter to emphasize different detection of selected signal components.
Background noise subtraction for detection of quiet sounds in noisy environments.
EKG for time-referencing cardiac events and detection of arrhythmias.
Multiple time/frequency analysis and display screens.
Automatic detection of selected signals.

**Training** – Because this technology is still emerging, training requirements are unknown at present.

**Costs** – Because this technology is still emerging, cost is unknown at this time.

**Future Trends** – No specific trends in the use or development of this technology have been identified.

### *Hands-Off Arrhythmia Monitor*

The hands-off arrhythmia monitor is a small, non-invasive sensor that can detect arrhythmia (abnormal heart beats) in the wearer. The device can uplink to a distress transmitter that will notify monitoring personnel of the occurrence of any dangerous arrhythmia. The sensors also can transmit data to a control center or hospital.

**Training** – Anyone using this system would have to be trained in cardiac rhythm interpretation, and possibly in arrhythmia intervention techniques.

**Costs** – Because this technology is still emerging, cost is unknown at this time.

**Future Trends** – Perhaps in the future, this type of instrument will be able to provide other information about a wearer's status, or even have the capability to deliver antiarrhythmic electrical shocks.

### *Portable Blood Analyzers*

Whole-blood analyzers are a new technology that will become more available to prehospital personnel in the future. There are a number of "point-of-care" devices already available, which come in three designs: transportable, portable, and handheld. Their use presently confined to hospitals and clinics. With a couple drops of blood, these devices accommodate multiple tests, such as sodium, potassium, chloride, urea, nitrogen, glucose, hematocrit, blood gases, pH, $PCO_2$, $PO_2$, and ionized calcium. Training to interpret of most the values is not part of the National Highway Traffic Safety Administration (NHTSA) National Standard Curriculum: EMT-Paramedic; however, most prehospital professionals are capable of performing the test. This information could be sent via radio or computer to medical professionals (physician or toxicologist) who can provide analysis and recommend treatment.

**Training –** Significant training or usage issues are not foreseen for this type of system. It may, however, require someone who is technically proficient to interpret the data (physician or toxicologist).

**Costs –** Most handheld analyzers cost about $4,000 to $5,000. Additional equipment is required, such as cartridges ($3 to $8 per use), to use this technology what will increase the cost.

**Future Trends –** Future whole-blood analyzers may be able to test exposed blood for common toxins and hazards.

### *Ear Temperature Probes*

Ear temperature probes are lightweight and durable thermometers that are placed inside the ear canal to monitor the core body temperature. The reading is provided on a LCD screen. These monitors accurately (to one one-hundredth of a degree) record body temperature in approximately 60 seconds. The accuracy of body temperature is unaffected by eating, drinking, smoking, and breathing through the mouth unlike the traditional oral thermometer. Some probes even are able to store and display temperature data. These probes would be suitable for use in the pre- and post-entry examinations.

**Training –** There is no significant training involved with this technology.

**Costs –** Costs for these units range from $50 to $100.

**Future Trends –** This type of device will have an increased ability to provide information about vital signs and other physiological categories. As the technology improves, these units will become smaller and more affordable.

### *Personal Heat Stress Monitor*

*Photo courtesy of Quest Technologies*

Personal heat stress monitors are lightweight, durable monitors that use sensor technology. An expandable earplug is placed inside the ear canal to monitor the body's core temperature. The instrument stores and displays temperature data, and warns rescuers of internal body temperatures that exceed a preset level via a small speaker mounted just outside the ear. This will provide hazardous materials responders operating in high-heat environments with advanced warning of impending heat stress. After recording the exposure data with personal heat stress monitors, the data can be downloaded into a PC where it can be monitored.

**Training –** Significant training or usage issues are not foreseen for this type of system. Usage during emergency operations may interfere with hearing in the ear into which the personal heat stress monitor is placed. Users need to train with the device in place to become accustomed to any communications impairments they may cause. It may, however, require someone who is technically proficient to interpret the data.

**Costs –** These units generally cost around $1,500.

**Future Trends –** As the technology improves, these units will become smaller and more affordable.

## CHAPTER VIII – DECONTAMINATION PRODUCTS

Decontamination reduces the level of hazardous materials contamination so it is no longer a hazard to living things or the environment. Decontamination is completed for three important reasons. First, it is intended to protect all onsite personnel by sharply limiting the transfer of hazardous materials from the contaminated area into the clean zone. Second, it protects rescuers by reducing the contamination and resultant permeation or degradation of their protective clothing and equipment. Finally, it protects the community by preventing transportation of hazardous materials from the incident to other sites in the community. Decontamination is broken down into two main groups: technical and personnel.

This report does not assess hazardous material PPE. However, rescue personnel who will work in areas contaminated with hazardous materials need appropriate PPE to ensure they do not come in contact with harmful chemicals. Equally as important as the appropriate level of personal protection is that response and support personnel are not exposed to harmful contamination while taking off protective equipment in an area expected to be safe.

For these reasons, safe hazardous-materials operations require that a decontamination area is established in the warm zone immediately adjacent to the hot zone. Everyone (and everything) leaving the hot zone must be decontaminated in the warm zone. This should include all personnel, victims, and equipment that have been in the hot zone. Personnel who leave the hot zone without having undergone the proper decontamination procedures can contaminate ambulances, hospital facilities, and other people.

The determination of the decontamination methods necessary for the incident is just as important as the decisions about what level of protection is necessary for entry into the hot zone. This decision must be undertaken once the product has been identified, and in consultation with experts knowledgeable about that product. The decontamination operation should be planned and set up before rescue personnel are placed in situations where contamination of equipment can occur.

Decontamination requires an organized area with a single point of entry at the “contaminated zone” and a multiple-station progression to the “clean zone.” Personnel enter the dirty end, progress toward the clean, and the PPE is cleaned and removed.

The sides of the decontamination area also are established as a “dirty side” and “clean side.” Clean equipment and solutions are brought in from the clean side, and dirty equipment is removed and runoff cleaning solutions are retained at the dirty side. This organization prevents additional contamination.

It is always preferable to have contaminated victims decontaminated in the field, but, sometimes, for any number of reasons, contaminated patients do arrive at hospitals. The transport ambulance crew may not recognize that the patient is contaminated, or they may not have the materials or expertise needed to perform decontamination. In addition, private automobiles may transport people contaminated by hazardous materials to hospital emergency rooms. In these cases, hospitals may need to perform decontamination;

therefore, some of the technologies described here may be of interest to fixed medical facilities.

### *Decontamination Solutions*

Acceptable procedures for decontaminating people and equipment exposed to hazardous-materials products should include four solutions: wash solutions A and B, and rinse solutions C and D.

**Wash Solution A –** A mixture of five percent sodium carbonate and five percent trisodium phosphate. Mix four pounds of commercial grade trisodium phosphate with ten gallons of water.

**Wash Solution B –** A mixture containing ten percent calcium hypochlorite. Mix eight pounds with ten gallons of water.

**Rinse Solution C –** Use after both A and B solutions. Mix five percent solutions of trisodium phosphate with 10 gallons of water.

**Rinse Solution D –** This is a dilute solution of hydrochloric acid (HCl) into ten gallons of water (acid to water only). Stir with a wood or plastic stirrer.

These solutions are used for specific types of chemicals. All four solutions are used for the chemicals in the DOT 49 CFR hazard classes. Solutions A, B, and C are used for unknown products.

Either the "homemade" or commercially available, ready-mixed solutions can be applied with a compressed air sprayer. Solutions are brightly colored and cling to protective ensembles. The distinct color helps to ensure that all areas are covered completely and evenly. A scrub brush with a hose connection and water control valve allows the solution to be scrubbed off and well rinsed.

*Photo courtesy of Indian Springs*

Just as it is important to decontaminate the PPE, it is also important to prevent runoff of decontamination solutions and rinses. This means that decontamination solutions must be collected and disposed of properly. Decontamination runoff can be collected using a child's wading pool or a commercially fabricated shower and runoff collector system.

The wading pools are constructed of polyvinyl plastic material and usually are three to four feet in diameter. Disposable decontamination pools constructed of polyethylene are available.

Commercial decontamination wash systems usually include a shower assembly and containment pool. These units usually are easy to store, and come in many configurations. Some shower units are enclosed assemblies, which is an advantage in colder climates where the decontamination area must be in a portable shelter such as a tent. The enclosed shower assemblies also contain water spray, thus reducing the potential of contaminating decontamination area assistants with the shower spray. Commercially designed decontamination water showers are very effective for complete head-to-toe, front, side, and rear coverage.

Consideration must be given for protection from heat stress during hazardous materials incidents. This is of particular importance in the decontamination area because response personnel are finishing up in the hot zone and may be at the limits of their endurance. Therefore, the decontamination should be thorough but quick, so the hot and heavy equipment can be removed. The decontamination area should include benches for the response personnel to sit on while in the different stages of decontamination.

Comfort is important and necessary in areas with seasonal cold and hot extremes. Response personnel should not be exposed to extreme temperatures when protective suits and equipment are removed. If necessary, the undressing areas should be in climate-controlled shelters. A climate-controlled shelter also provides privacy for decontaminating victims and response personnel in stages of undress. A section of this manual specifically addresses shelters and the climate control of them.

After decontamination is complete, medical personnel should evaluate the vital signs of personnel or victims completing decontamination. This area should be equipped with standard medical evaluation and treatment equipment (also discussed later in this manual).

Hazardous materials incidents can injure citizens as well as public safety personnel. Nonambulatory victims must be carried from the scene, decontaminated, and then transported to the appropriate medical facilities for needed care. Field decontamination of victims will prevent contamination of ambulances and medical facilities, and safeguard the EMS caregivers.

Emergency medical equipment used for patient transport must be durable enough to allow for cleaning with decontamination solutions and repeated showering with water. All such equipment should be made of sealed materials and constructed so as not to trap contaminated runoff.

***IMPORTANT NOTE:*** *New decontamination research is being done at the Chemical and Biological Defense Information Analysis Center at the Aberdeen Proving Ground in Maryland. This research has indicated that a vital element in decontamination is the speed and timing in which it is completed. Bleach and water decontamination does not appear to be as effective as high volumes of water rapidly after contamination. For chemical warfare agents, there is a 10-minute window in which decontamination is effective. The study suggests that using large volumes of water with low pressures (fog nozzles) is an effective* *decontamination tactic. Soap and water decontamination solutions are actually a better option, but because of the increased time required to make the solution, it may not be as efficient. Look for future information about changes in chemical decontamination in the future based on these studies. Because these studies are not yet complete and distributed, this report still presents information on other methods of decontamination.*

*Photo courtesy of North American Rescue Products*

### *Decontamination Stretchers for Nonambulatory Victims*

This stretcher is similar in design to the fold-up military pole stretcher. Decontamination stretchers are constructed of a chemical-resistant woven monofilament polypropylene mesh fabric. The honeycomb weave allows decontamination solutions to drain through the stretcher without allowing the pooling of liquids under the patient. The mesh design permits decontamination from above and below the stretcher.

The metal parts of the stretcher are constructed of stainless steel or aluminum alloys, coated with chemical-resistant epoxy coatings. These coatings prevent chemical reactions between the hazardous material and the metal. All straps and handles are made of materials resistant to hazardous materials.

The Jefferson County (Kentucky) Emergency Medical Response Team has practiced removing injured hazardous materials personnel from the hot zone. The team found that rescue personnel in PPE are difficult to position on stretchers and backboards because of the breathing apparatus. Personnel wearing SCBA must be put on the stretcher on their sides. They also found it is cumbersome to balance personnel wearing SCBAs on stretchers.

Based on its findings, the Jefferson County Emergency Medical Response Team modified a wire basket litter (Stokes basket) with wheels and handles, creating a wheelbarrow-type device that allows the rescuers to roll a fallen hazardous materials technician out of the hot zone to decontamination. This device solves many problems associated with carrying injured people considerable distances from the hot zone to the decontamination area.

**Training –** Significant training or usage issues for the user are not foreseen for this technology.

**Costs –** The stretchers generally range in cost from $200 to $500.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Patient Decontamination Tables*

These tables are available commercially and are designed to allow the patient to be decontaminated while in a prone or supine position on the table. The wash and rinse runoff is drained to a collection container under the table. These units are portable and fit on most hospital tables or stretchers as well as on standard ambulance gurneys.

**Training –** Significant training or usage issues are not foreseen for this technology. Proper decontamination skills are required to ensure personnel and environmental safety.

**Costs –** Decontamination tables usually cost between $500 and $1000.

**Future Trends –** There do not appear to be any future trends associated with this technology.

### *Patient Decontamination Kits*

Prepackaged kits containing materials needed for decontamination of patients are available commercially for EMS, industrial, or hospital personnel. They include the solutions, instructions, and equipment to apply localized or full-body decontamination. While these kits are suitable for EMS units and hospitals for a limited number of patients, they are not recommended for hazardous materials response teams because of the potential for needing to treat large numbers of victims.

**Training –** Significant training or usage issues are not foreseen for this technology.

**Costs –** These kits generally range in cost from $50 to $100.

**Future Trends –** As more attention is directed toward chemical and biological counterterrorism, more commercial kits will become available to decontaminate patients with injuries from these agents.

### *Decontamination Shelter*

The decontamination shelters come in various styles. Newer models use an airframe-supported shelter with an inner canopy and floor. The canopy protects the airframe during decontamination operations. Canopies come in various configurations that can include extra doors, window, shower stall and a heater/air conditioner connection sleeve. The airframe can be inflated with a standard breathing air bottle, an air compressor, or the electric inflator. Once an air source is connected, the shelter will deploy automatically in less than two minutes.

*Photo courtesy of Zumbro*

**Training –** Significant training or usage issues are not foreseen for this technology.

**Costs –** Decontamination shelters generally cost $500 to $1,000 depending on style and size.

**Future Trends –** As the technology becomes more common it is anticipated that the price will decrease.

### *Decontamination Suits*

Hazardous materials decontamination suits are available commercially for prehospital EMS providers and hospital personnel. Decontamination suits are appropriate for EMS personnel to wear after their patients have completed decontamination, but not as primary protection against cross-contamination from patients who have not yet been decontaminated. These garments can be used for responders or patients in conjunction with the decontamination table and stretcher systems. Most decontamination personnel protection kits generally contain:

- *Zipper-front coverall constructed of a splash-resistant material with attached hood, boots and elastic wrists;*
- Tape strips for wrists, legs, and zippers;
- One pair of inner latex gloves;
- One pair of chemical-resistant outer gloves;
- One pair of chemical-resistant goggles; and
- One pair of latex boots.

While these suits are adequate for use by responders in many decontamination situations, they do not include respiratory protection. These kits should be used in conjunction with a full-face shield, which is not provided in the kit.

Many fire departments allow their firefighters to wear turnout gear to decontaminate hazardous materials personnel in Level A and Level B PPE going through the decontamination corridor. Other departments choose to require their personnel to wear commercially available decontamination suits for this purpose.

**Training –** Significant training or usage issues for the user are not foreseen for this technology.

**Costs –** These suits generally cost from $25 to $100, depending upon the kit design.

**Future Trends –** New fabrics that are resistant to chemical and biological agents are presently under development. In addition, new suits will provide a more comfortable atmosphere for workers and reduce exhaustion from heat and humidity.

### *Wipe Bags*

Wipe bags are commercially available cleanup bags that have absorbent material on the outside. The user puts a chemically protected, gloved hand in the wipe bag, and wipes to absorb the hazardous substance, biological, or infectious spill. The bag is turned inside out and sealed. The sealed bag is color-coded to indicate a biohazard. These bags can be of benefit during patient decontamination and or treatment as well as hazardous materials cleanup. These waste containment bags meet OSHA's Bloodborne Pathogens Final Rule, 29 CFR 1910.1030, personnel equipment standards as well as certain EPA regulations.

**Training –** Significant training or usage issues are not foreseen for this technology.

**Costs –** Wipe bags are very inexpensive. Their cost depends on the size and number of bags desired. The majority of costs associated with their use will be assigned to proper disposal of the bags after use.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Cleanup Technologies*

After the decontamination operation is finished, the dirty and contaminated reusable equipment must be decontaminated. Portable decontamination systems are available with high-pressure washer systems which use decontamination detergents that are biodegradable. The washer uses 65 gallons-per-minute of water and discharges it at 700 psi. It is mounted on wheels for portability and uses 220 volts. The unit is available with a rotating brush for flat surfaces, high-pressure wand, and an under-vehicle body attachment. The high-pressure decontamination unit is also a hose washer.

**Training –** Significant training or usage issues are not foreseen for this technology.

**Costs –** This technology generally ranges in price from $500 to $1,000.

**Future Trends –** The military has developed a system that allows water to be heated before use.

# CHAPTER IX – CLIMATE-CONTROL EQUIPMENT

## Personnel Cooling

About 90 percent of the body's heat is produced in the torso by the major organs and muscle groups. The amount of heat generated increases as the body works harder, especially during hazardous materials incidents. In order to maintain a constant core temperature, the body must either give up or retain this heat, as necessary. How this is accomplished depends greatly on the ambient temperature and humidity around the rescuer.

## How the Body Maintains Normothermia

In order to understand how climate-control technologies operate, it is helpful to understand how the human body maintains "normothermia" (98.6° Fahrenheit).

### *Convective Body Cooling*

Under normal conditions (60º to 80º Fahrenheit ambient temperature), the circulatory system carries core heat toward the skin's surface. Since heat always travels from hot to cold, rather than from cold to hot, the body heat is carried away as the cooler outside air passes over the skin. This process is known as convective cooling, since the heat is removed by the movement of air.

### *Evaporative Body Cooling*

As the temperature outside begins to rise, the difference between normal skin temperature (90º Fahrenheit) and the ambient temperature narrows. As the ambient temperature rises above 80º Fahrenheit, this difference is not great enough to allow the body's internal heat to flow away from the body by convection.

Instead, the body reacts by cooling itself through a process known as evaporative cooling. When water is exposed to warm, dry air, it will evaporate into water vapor. This change of state is called a phase change, and it produces a tremendous cooling effect. The body creates this phase change by producing perspiration from sweat glands to the surface of the skin.

When the air surrounding the skin is warm and dry, this is an extremely efficient process. But as the humidity rises, perspiration can no longer evaporate to water vapor, as the air is already saturated. This is a dangerous condition, since the body has no other natural mechanism to give up heat. This is what occurs inside of PPE, where a high humidity micro-climate is produced when evaporative loss of sweat to the outside environment is prevented by the textile characteristics of the encapsulating suit.

### *Vasoconstriction and the Brain*

When the outside temperature drops below 60º Fahrenheit, the body needs to reverse the process and retain its internally generated heat. This is accomplished by a process called vasoconstriction. Vasoconstriction is the restriction of blood flow to the skin surface by constriction of blood vessels. Since the body's organs always must have a flow of blood, vasoconstriction is applied only to those vessels carrying heat to the skin's surface.

When the brain is fooled into thinking the temperature is cool – for example, when ice is applied to the body – vasoconstriction occurs in an effort to prevent loss of heat, even though the core temperature actually may be rising. This can lead to dizziness and fainting. More dangerous is the fact that the cool skin temperature physiologically feels comfortable, so one actually may work harder, creating an even faster rise in core body temperature and the risk of cardiac arrest.

Thus, cooling technologies are not without their dangers. Cooling technologies must be coupled with adequate medical monitoring to ensure personnel safety.

## *The Danger of Heat Stress*

OSHA considers heat stress to be a major concern. As such, OSHA increasingly has cited employers who fail to provide adequate controls to reduce heat stress and who fail to have an adequate heat stress management program in place. Before discussing the types of controls that are available, it is important to explain what is involved in assessing the hazardous materials incident for potential causes of heat stress. Without a proper assessment, it is impossible to select the right controls.

## *Assessing the Incident*

The most accurate way to ascertain the heat levels present in a hazardous materials incident is through the use of periodic wet bulb globe temperature (WBGT) index readings. Industrial hygienists use a WBGT thermometer to make this measurement, because it provides not only the temperature of the air, but also the amount of humidity present and the degree of radiant heat.

The WBGT index (also known as the "heat index") takes into account factors that can affect significantly how heat actually "feels" to us. The following heat index chart provides an idea of the role relative humidity plays in determining the actual effect of a given environmental temperature.

### *Heat Index*

| Relative Humidity (%) | Environmental Temperature (°F) 70 | 75 | 80 | 85 | 90 | 95 | 100 | 105 | 110 | 115 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0% | 64 | 69 | 73 | 78 | 83 | 87 | 91 | 95 | 99 | 103 | 107 |
| 10% | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 105 | 111 | 116 |
| 20% | 66 | 72 | 77 | 82 | 87 | 93 | 99 | 105 | 112 | 120 | 130 |
| 30% | 67 | 73 | 78 | 84 | 90 | 96 | 104 | 113 | 123 | 135 | 148 |
| 40% | 68 | 74 | 79 | 86 | 93 | 101 | 110 | 123 | 137 | 151 | |
| 50% | 69 | 75 | 81 | 88 | 96 | 107 | 120 | 135 | 150 | | |
| 60% | 70 | 76 | 82 | 90 | 100 | 114 | 132 | 149 | | | |
| 70% | 70 | 77 | 85 | 93 | 106 | 124 | 149 | | | | |
| 80% | 71 | 78 | 86 | 97 | 113 | 136 | | | | | |
| 90% | 71 | 79 | 88 | 102 | 122 | | | | | | |
| 100% | 72 | 80 | 91 | 108 | | | | | | | |

At temperatures of 90º to 104º Fahrenheit, heat cramps and heat exhaustion are possible. It is possible for hazardous materials personnel to work in temperatures of 105º to 130º Fahrenheit. At these temperatures, heat cramps and heat exhaustion are likely; heat stroke is possible. At temperatures of 131º Fahrenheit or higher, heat stroke is highly likely. The body functions most effectively within a limited temperature range. If the temperature rises too high, the body's metabolic rate increases and its efficiency decreases. When the body loses fluid through perspiration, the blood vessels dilate in an attempt to cool the body.

Heat cramps are cramps caused by too little water and salt in the body, and occur after vigorous physical exertion in very hot weather or in conditions which cause heavy sweating and loss of body fluids and salts. Personnel experiencing heat exhaustion can exhibit general weakness, dizziness, nausea, muscle cramps, and fainting spells and is caused by low levels of body fluid and salts resulting from exposure to intense heat or the inability to adjust to heat. Finally, heat stroke is a severe and sometimes fatal condition that results from the failure of the body to regulate its temperature after being exposed to high levels of heat.

Note that a temperature of 90º Fahrenheit combined with a humidity reading of 90 percent can yield a heat index reading of 122º Fahrenheit. That is a dangerous heat index. If full sun exposure or PPE is added to the temperature/humidity mix, the heat index can rise even higher.

### *Avoiding Heat Stress Injuries*

In addition to personal cooling technologies available for responding to hazardous materials incidents, there are some more fundamental things personnel can do to avoid heat stress injury:

- Drink fluids often.
- Gradually build up tolerance for warmer conditions.
- Stay physically fit.
- Be aware of any medical conditions or medications that may affect heat tolerance.
- Dress appropriately within the guidelines of safety.

### *How Personal Cooling Technologies Work*

Today more than ever, hazardous materials responders have a wide range of personal cooling technologies from which to pick. It is important to keep in mind the requirements of a particular application when reviewing the following technologies.

### *Umbilical Systems*

Some technologies actually are connected to the responder. These are loosely termed “umbilical systems.”

#### *Fluid-Chilled Systems*

Fluid-chilled systems consist of a garment, a fluid reservoir, a circulating pump, and connecting hoses. The fluid in the reservoir is chilled by ice to 33º to 34º Fahrenheit, then circulated by the pump through tubing passages in the vest-like garment. The chilled fluid will rise 6º to 7º Fahrenheit while moving from the pump to the garment. As the fluid passes over the skin, the body transfers heat toward the cooler fluid, which then carries the heat back to the reservoir. As the fluid re-enters the reservoir, it is chilled back down by the ice and the circulation process begins again.

The circulation pump is operated by either batteries or an AC adapter (batteries are used when mobility is required). The battery life is typically four to five hours between recharges. This can create a problem when long-duration cooling is needed.

The temperature of the fluid at the body can be controlled somewhat by changing the speed of the pump motor. This regulates the rate of flow, which determines the amount of heat drawn from the body.

Fluid-chilled systems are efficient and work well, but mobility is limited because the reservoir and pump are separate from the garment. Some systems operate with a hip pack containing an umbilically attached reservoir and pump. These systems allow greater mobility but add weight to the body and have limited space for ice, which limits the length of operation.

Another concern with fluid-chilled systems is that they can promote the formation of condensation due to their cool operating temperature range. This can cause some efficiency loss and dampness to the body.

*Advantages*

- Garments are available in all sizes and fit most areas of the body.
- Can be worn against the skin and are generally close fitting; uniforms easily fit over garments.
- Long-duration cooling.

*Disadvantages*

- Limited mobility due to umbilically connected circulating reservoir and pump.
- Formation of condensation can cause efficiency loss and dampness.
- More expensive than other technologies.
- Requires electricity or batteries to operate.

**Training –** The training for using these devices is not significant. These devices are easy to use and wear.

**Costs –** This body cooling system costs between $1,000 and $2,500.

**Future Trends –** It is anticipated that the cost of this technology will decrease in the future.

### *Prechilled- or Forced-Air Systems*

Prechilled- or forced-air systems consist of a torso garment, a compressor, and an umbilical line. The compressor forces prechilled air through the umbilical line and into a bladder in the garment. The air is then forced against the body through a series of orifices in the inner surfaces of the garment. As the cooler air passes near the surface of the skin, it convectively draws heat away from the body and into the atmosphere.

These systems are lightweight and provide efficient cooling, but mobility is restricted by the length of the umbilical. They also employ many moving parts in the compressor and require regular maintenance.

*Advantages*

- Garments are available in all sizes and fit most areas of the body.
- Provides a comfortable cooling temperature range.
- Lightweight garment construction.

- Long-duration cooling.

*Disadvantages*

- Mobility is limited and encumbered by the umbilical, which must be attached to a fixed compressor location.
- More expensive than most technologies.
- Requires electricity to operate.
- Moving parts require regular maintenance.

**Training –** The training for using these devices is not significant. These devices are easy to use and wear.

**Costs –** This body cooling system costs from $1,000 to $2,500 per system with a number of personal units. In addition, some costs for maintenance must be considered.

**Future Trends –** It is anticipated that price of this technology will decrease in the future.

### *Passive Systems*

Some technologies maintain the responder's temperature indirectly. These are referred to as "passive systems."

#### *Ice- or Gel-Pack Vests*

Ice- or gel-pack vests consist of a torso garment containing pockets, surrounding the chest cavity, that hold ice packs. Body heat, carried to the surface of the skin by the circulatory system, is absorbed by the ice packs.

The garment fully loaded with packs is heavier than an umbilical-type garment, but is completely unattached to any external devices, making it much more portable. Typical weight is nine to 11 pounds. Cooling duration is approximately 1 to 1¾ hours between recharges, based on average workload and metabolic rate. The packs recharge in five hours in a freezer, and can be recharged literally thousands of times. When considering whether an ice or gel pack vest is the right choice, first determine how easily the wearer will be able to change packs on the job. After all, once the packs lose their cooling charge, they do nothing but add weight to the wearer.

A concern with this technology is that the ice packs condense, since their temperature is below the typical dew point. The condensation generates heat, which then is absorbed by the pack, reducing the duration before another recharge is needed. Also, the condensation is absorbed by clothing, causing discomfort and adding weight, which creates a greater load on the body.

Ice technology provides a reduction of body core temperature when used for short periods. However, with prolonged exposure (several hours of continuous use) the core temperature actually can begin to rise. This is due to vasoconstriction that occurs in the blood vessels carrying core heat to the surface of the skin. The vasoconstriction is caused by the 32º Fahrenheit temperature of the packs. The continued cold exposure of the packs to the skin fools the brain into thinking it is cold outside. The body then attempts to retain heat when, in reality, it should be giving up heat.

Since workload continues to generate even more heat, the core temperature rises. This condition can cause fainting and dizziness. If full workload continues, there is a serious risk of heat stroke.

In addition to vasoconstriction and the resultant physical problems, extended cold exposure to the skin can cause harm to skin tissue and the development of flu-like symptoms.

*Advantages*

- Inexpensive.
- Portable; no umbilical device needed.
- Rechargeable.

*Disadvantages*

- Fools body into thinking it is cold, which could be potentially dangerous.
- Packs condense; uncomfortable to wear.
- Undergarments required to avoid direct contact with skin; defeats purpose of cooling.
- Bulkier to wear than umbilical systems.
- Requires freezer to chill.
- Limited-duration cooling.

**Training –** The training for using these devices is not significant; they are easy to use and wear.

**Costs –** Depending on the style and length of cooling this technology generally cost $100 to $500.

**Future Trends –** Future models will become less bulky and the duration of cooling will be increased.

### *Phase Change Material Technology*

Phase change material (PCM) vests consist of a torso garment with chest pockets that hold PCM packs, similar to ice and gel pack vests. Body heat, carried to the surface of the skin by the circulatory system, is absorbed by the PCM packs, which operate at either 65º or 85º Fahrenheit.

The garment fully loaded with packs is heavier than an umbilical-type garment, but is completely unattached to any external devices, making it much more portable. Typical weight is three pounds for a 100º Fahrenheit product and nine pounds for a 125º to 130º Fahrenheit product. Cooling duration is approximately 1½ to 2 hours between recharges based on average workload and individual metabolic rate. The packs recharge in 20 minutes in ice water or a freezer, and can be recharged literally thousands of times.

Because the temperature range of the packs (65º or 85º Fahrenheit) is well above the typical dew point, the packs will not condense and will remain dry against the body. Further, a wicking-type material on the body side of the garment absorbs perspiration and carries it away from the body, reducing irritation from dampness.

The temperature of PCM packs is within the comfort range of the body, so the garment can be worn for extended periods of time without the risk of vasoconstriction or skin tissue damage.

PCM packs cannot absorb as much heat as ice packs, but this limitation is offset by a lower loss of cooling potential to the ambient air temperature (because the differential between the ambient and the 65º or 85º Fahrenheit packs is less than the differential between the ambient and 32º Fahrenheit ice). An insulation material in the outer portion of the garment helps further reduce loss to the ambient.

*Advantages*

- Comfortable temperature against the skin; no undergarment required.
- Inexpensive.
- Portable; no umbilical device needed.
- Packs will not condense; no irritating moisture against the skin.
- Wicking action removes perspiration.
- Easy to recharge in ice water; no freezer needed.

*Disadvantages*

- Bulkier to wear than umbilical systems.
- Limited-duration cooling.

**Training –** The training for using these devices is not significant; they are easy to use and wear.

**Costs –** Depending on the style and length of cooling, this technology generally costs $150 to $400.

**Future Trends –** Future systems will be less bulky and the duration of cooling will be increased.

### *Evaporative Cooling*

Evaporative technology consists of a garment and a water-absorption material. The garment is extremely lightweight and the technology is inexpensive.

To use the garment, simply soak it in water and put it on. The crystals in the cloth swell up and contain water held closely against the body. The process simulates the body's evaporative cooling system as it evaporates the water held in the garment to the atmosphere. The phase change from water fluid to water vapor creates a tremendous cooling energy. There is some efficiency loss over natural perspiration evaporation because the water is not in actual conductive contact with the skin, but is actually cooling air between the absorption crystals and the skin.

The concept is simple, but has several drawbacks. Most obvious is that evaporative technology works well only in warm, dry air. When the humidity is high and the air already saturated with water vapor, the technology cannot work. There is a hybrid version of this technology, which suggests placing the water-saturated crystals in a freezer to solidify. The frozen crystals provide some absorption cooling in high humidity, but only for a very short duration, since the total amount of retained water is minimal.

Another drawback is that the garment is always damp, which can cause skin irritation, bacterial growth, mold, and odor.

*Advantages*

- Most inexpensive.
- Extremely lightweight.
- Portable; no umbilical device needed.
- Longer-duration cooling.

*Disadvantages*

- Requires the movement of warm, dry air to be effective; completely ineffective under any type of protective garment.
- Will not work in high humidity.
- Tends to be damp against the body; can cause skin irritation, bacterial growth, mold, and odor.

**Training –** The training for using these devices is not significant; they are easy to use and wear.

**Costs –** Depending on the style this will cost between $50 and $250.

**Future Trends –** Future models will protect against skin irritation, bacterial growth, mold and odor.

### *Environment Cooling*

There are many methods of conditioning and ventilating the air around rescuers. If rescuers operate in a closed, contained space, it is possible to provide spot environment cooling. There are a number of methods available, and results will vary based upon the ambient temperature, humidity, and mobility of rescuers.

The simplest method is to provide good ventilation and a flow of fresh outside air. This can be an effective method against lower temperatures of 80º to 90º Fahrenheit, as the air movement will induce evaporation of perspiration. When the temperature rises above 90º Fahrenheit, however, this method no longer is effective, as the differential between circulating air temperature and skin temperature is too small, so body heat can no longer be drawn away.

Another method is to use spot air prechillers. This is effective for cooling a small group of rescuers in higher heat, but is an expensive approach and limits rescuers' mobility to the cooled area. Also, as rescuers constantly move back and forth between hot and cold areas they can develop flu-like symptoms over extended periods of exposure.

In addition to the initial expense of these types of environment cooling systems there will be an ongoing maintenance cost, plus the utility cost to run them.

*Advantages*

- Allows good worker mobility, but only within cooled area.
- Temperature is controlled easily.
- Can be turned off when not required.

*Disadvantages*

- Most expensive.
- Not effective for outdoor situations.
- Not effective for large groups of rescuers

**Training –** Significant training or usage issue issues for the user are not foreseen for this type of body cooling system.

**Costs –** Environmental cooling systems cost between $250 and $5,000.

**Future Trends –** The future of this technology is uncertain, however, the price is expected to decrease.

### *Selecting the Right Technology for the Hazardous Materials Incident*

Before selecting the right technology, several factors must be considered:

1. How much mobility will the incident require?
2. Will rescuers be operating or using tools while standing still or sitting?
3. Will they worn in the hot, warm or cool zone?
4. Will rescuers need to wear protective gear over their cooling garments?
5. How long will rescuers be working?
6. How hot and humid is the weather?

Consideration must be given to the amount of physical mobility required of the rescuers. The products that are attached umbilically or provide spot cooling allow very limited mobility. There is a need to consider how long rescuers will need to stay cool without interruption, keeping in mind that passive technologies cannot be recharged without removing the suit.

Not all types of cooling technologies work with all types of protective gear. For instance, umbilical-type cooling systems are not appropriate for chemical suits, which require full enclosure. Neither are evaporative cooling systems, since there is no movement of air, and humidity is high within the suits.

Passive systems must be recharged periodically. In addition, a freezer, refrigerator, ice water, or a special plug-in charger needs to be handy throughout the hazardous material incident. Before selecting a technology, check how long it will provide cooling between recharges, what device is needed to recharge, and how long a recharge takes. If necessary, spot coolers and umbilical types provide extremely long continuous cooling.

The temperature range and humidity affect the duration and use of cooling technologies. In fact, high humidity may render certain products substantially less effective.

## CHAPTER X – ABSORBENT, CONFINEMENT, AND CONTAINMENT

Absorption can be a physical and/or chemical event. Absorbents are a general classification of products that can wick or soak up a released product. They bring the spilled material into the matrix of the absorbent. Each absorbent has an inventory of chemicals that it can absorb without undergoing an adverse reaction. Some are effective on oils, coolants, solvents, and water. Others are designed for acids, bases, and unknowns. Many absorbents will pick up many times their own weight in spilled product. Absorbents come in many forms – pads, mats, rolls, pillows, dikes, and socks.

They can be placed in areas where leaks are active or expected. They speed the clean up process and are a natural fit in the decontamination program. These products are permeable backs stuffed with loose absorbent filler. Many of these products are made of polypropylene which naturally absorbs oil and repels water.

### *Booms*

Oil booms are solid floating barriers that contain oil spills in the ocean, in harbors, rivers, streams, lagoons, etc. A range of booms in different types and sizes are available for use in these different locations; the most common are fence and curtain booms. Fence booms have foam buoyancy, while curtain booms may be foam or air filled. Special-purpose booms, such as tidal booms, have been developed for specific conditions that cannot be met satisfactorily with a fence or curtain boom. Special connectors on the ends of all booms allow multiple boom sections to be joined together easily. Booms are stored and deployed from storage bags, cages, or reels.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** These products generally range in price from $50 to $1,000 depending on size, type of absorbent, and quantity.

**Future Trends –** No major advances are foreseen for booms, however, future models will be smaller, lighter, and easier to handle and deploy.

### *Socks*

Socks (or tubular pillows) also are used as absorbent booms. Socks employ a tubular shaped, permeable fabric wall stuffed with loose absorbent filler. The tubes can be purchased in lengths of 2 to 50 feet. Socks are especially valuable in diking, diverting, and retaining spills.

Pillows and socks designed to select and capture petroleum products only are frequently used to contain spills on water. Both pillows and socks are used for picking up large volumes of liquid in a short period of time. They are used much like a sponge to capture the contaminant. Pads and rolls are easy to place for fast and easy cleanup and are also excellent for skimming oil off water.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** The price of pillows and socks depends directly on the amount of units and the type of absorbent used. Traditionally, the units cost between $100 and $1,000.

**Future Trends –** No major advances are foreseen for socks, however, future models will be smaller, lighter, and easier to handle and deploy.

### *Sewer/Drain Blockers*

Sewer/Drain blockers provide unsurpassed protection against accidental spills into drains and manholes. Most are flexible mats that allow the user to seal the opening quickly without costly, time-critical adjustments. Some mats are reusable and resist water, oil, and most chemicals.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** These products generally range in price from $50 to $1,000 depending on size, type of absorbent, and quantity.

**Future Trends –** No major advances are foreseen for drain blocker, however, future models will be smaller, lighter, and easier to handle and deploy.

### *Granules*

Granules are, for the most part, all-natural, nontoxic products that have the ability to absorb and encapsulate hydrocarbons, while acting as a catalyst for the bioremediation of hydrocarbon-contaminated soil. Studies have shown that granules are a remarkable natural oil absorbent, absorbing up to 2,000 times their own weight.

Granules can be used as a sweeping compound on hard surfaces in all spill situations from residential garages to refineries. Most granules can be tilled into contaminated soil where they enhance the process of bioremediation, thus eliminating the need for soil removal and reducing disposal costs. Most granules can be applied safely to spills on water, as they remain on the surface for a long period of time (allowing for easy recovery). Also, granules provide an extra measure of safety when used as a filler in packing and transporting oil and chemical drums. If kept dry, granules have a virtually unlimited shelf life.

Some granules do not require prior EPA or Food and Drug Administration (FDA) approval as they are considered a Non-hazardous Oilfield Waste (NOW) as per 29 CFR 1910.120. This allows them to be tilled into the soil with no disposal required. Some granules have passed the EPA's LC-50 test successfully, which is mandatory for any product to be used on water. These properties make granules easier, less costly, and less time-consuming to use than other products for oil spills and hazardous waste sites.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** Most granule products are inexpensive, packaged in various sized containers ranging in cost from $1 to $50 depending on the amount and type desired.

**Future Trends –** No specific future trends in the use of development of this technology have been identified.

### *Skimmers*

Skimmers are designed to absorb and encapsulate hazardous materials (usually hydrocarbons) by floating directly on the water. As oil-polluted water flows into the skimmer it filters out and absorbs hydrocarbons without inhibiting water flow. Most skimmers are made of oil-absorbing copolymers, packaged in flexible mesh containers that are available in a variety of sizes. These innovative products also are capable of removing oil sheen and will not leak or leach encapsulated oil back into the environment.

**Training –** Specialized training on the use of skimmers is required. Maritime hazardous materials response programs should cover the use of skimmers. Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** These products generally range in price from $1,000 to $5,000.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Weir*

A weir skimmer floats in water and is used to remove oil from the water. A weir skimmer has three connected floats supporting a central shallow dish. The top of the dish sits 1 mm to 20 mm below the surface of the water. Upon starting the skimmer, the water in the dish is sucked away by a pump. As the dish empties, the surface oil and some water fall into the dish and are pumped to shore if the oil is not thicker than 10 to 20 mm. A special floating ring joined to the top of the dish automatically will readjust the skimming depth to 10 to 20 mm in choppy water. Weir skimmers can process from 5 to 100 tons per hour. The larger capacity skimmers (greater than 40 tons per hour) have hydraulic-driven, onboard pumps. Smaller skimmers have external suction pumps.

**Training –** Specialized training on the use of skimmers is required. Maritime hazardous materials response programs should cover the use of weir skimmers. Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** These products generally range in price from $1,000 to $5,000.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Disc Skimmers*

Disc skimmers are used to remove oil from water. They pick up oil with less than 2 percent water intake. The skimmer floats on water and has a number of rotating discs that sit half in and half out of the water. As the discs rotate, they pass through the oil that is sitting on top of the water. The oil adheres to the disc, and then is scraped into a sump before being pumped to shore. The smallest floating skimmer usually has five discs and a maximum pick-up capacity of 1.5 tons per hour. The larger 40-disc skimmer usually has a capacity of 15 tons per hour with a 300 mm disc and 30 tons per hour with a 450 mm disc.

**Training –** Specialized training on the use of skimmers is required. A program that covers maritime hazardous materials response programs should cover the use of skimmers. Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** These products generally range in price from $1,000 to $5,000.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Rope Skimmers*

Rope skimmers are used for removing oil and fuel at an oil spill or to remove oil from a sump at a mine site or industrial complex. The skimmer operations are similar for both applications. A specially designed, highly oil absorbent polypropylene rope, is pulled through the oil before being squeezed between two rollers. The oil is collected in a drum or sump at the bottom of the skimmer. The oil pickup capacity is determined by the rope size and speed at which the rope is pulled through the oil. Ropes have a capacity of between 1.5 tons and 6 tons per hour. When skimming oil from a sump, the skimmer usually is positioned directly over the sump with the rope directly into the sump. However, at an oil spill the rope is pulled horizontally, requiring floating anchored pulleys to position it correctly. The rope may run directly out and back to a single pulley or pass around two or three pulleys to create a triangle.

**Training –** Specialized training on the use of skimmers is required. Maritime hazardous materials response programs should cover the use of rope skimmers. Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** These products generally range in price from $1,000 to $5,000.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Neutralizers*

Neutralizers chemically alter a contaminant so that the resulting compound is harmless. A color change indicator reflects neutralization for safe and fast cleanup in a manageable gel form. For example, adding soda ash to an acidic solution can increase the pH, making it chemically harmless. One advantage is that by rendering the material harmless, one reduces the problem of disposal.

Many neutralizers present hazards of their own. Chemical reactions can result in the release of heat and energy.

Acid neutralizers are specifically formulated to treat spills of common mineral and organic acids. Laboratory and field tests have shown these agents to be effective at neutralizing and solidifying spills of many acids, including sulfuric, hydrochloric, nitric, phosphoric, perchloric, formic, acetic, chlorosulfonic, 70 percent hydrofluoric, and oleum.

**Training –** Only specially trained personnel should use neutralizers. In some states, response personnel are required to be certified to use neutralizers.

**Costs –** These products come in a number of different delivery systems (i.e., bottles, boxes, etc.). They generally range in cost from $25 to $200, depending on the size and amount desired.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Fuel Solidifier*

Fuel solidifiers easily clean up fuel or oil-based solvent spills. These products act like a dike to encapsulate and rubberize liquids and permanently solidify fuel. They can be used on land or water.

**Training –** Significant training or usage issues are not foreseen for this type of system. Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** Most fuel solidifying products are inexpensive, packaged in various containers ranging in cost from $1 to $50, depending on the amount and type desired.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Overpack Drums/Cylinders*


*Photo courtesy of Indian Springs*

Overpack drums are used to contain spills from breached containers. Overpacking is accomplished most commonly by rolling or placing a smaller container into a larger one. The overpack drum then is turned upright (if necessary) and sealed. Overpacking materials must be selected for compatibility with the spilled product.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product. Personnel trained to the Operations may deploy this technology under certain circumstances (i.e., they have been trained to do so, they do not come into contact with the product, the atmosphere is not immediately dangerous to life or health, and no Technician-level personnel are available).

**Costs –** Depending on the size of the containers desired, overpack drums generally range in price from $50 to $300,

**Future Trends** – No specific future trends in the use or development of this technology have been identified.

### *Patches, Plugs, and Wedges*

Wedges, plugs, and patches are used to reduce or temporarily stop the flow of materials from small holes, rips, tears, or gashes in cylinders, tanks, gas lines, pipe runs, and similar containers. Patches, plugs, and wedges come in various sizes and materials. The plugs work to seal holes to control liquid, gas, and bulk material leaks up to 5 inches in diameter. Most plugs and wedges are manufactured from soft woods, and when exposed to a liquid will absorb it and swell to seal the opening tightly. A hardwood mallet is used to drive the plugs and wedges into place. Most plugs and wedges come in kits that contain various sizes and make storage easier.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product.

**Costs –** These products generally range in price from $10 to $200, depending on size and quantity.

**Future Trends** – No specific future trends in the use or development of this technology have been identified.

### *Inflatable Drum Sealers*

Inflatable drum sealers are the fastest, most effective way to stop hazardous, messy, and expensive liquid and granular drum leaks. Most inflatable drum sealers are made of a Teflon®-coated bladder that is resistant to virtually all chemicals. The bladder is inflated using a carbon dioxide cartridge, and the bladder immediately seals leaks. These sealers fit steel, plastic, and fiberboard 55-gallon drums. These devices eliminate tipping or pegging. Most sealers are effective at temperatures from 0° to 140° Fahrenheit, and have a shelf life of about five years.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product.

**Costs –** These products generally range in price from $300 to $500, depending on size and quantity.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Pipe-Plugging Kit*

A pipe-plugging kit allows responders to plug a broken or disconnected pipe to stop the flow from the pipe. Most of these kits contain neoprene plugs in various sizes that will occlude pipes from ½ inch to 4 inches. Included in most kits are shutoff values that are used with pipe plugs. With the valve installed on the plug in the open position, the plug can be installed on the pipe end, while the flow is maintained to reduce the pressure. With the installation completed, the valve can be closed to stop the flow. If removal of the contents of the pipe is required, the tubing can be connected to the valve and the contents removed to another container. These kits are usually packed in a heavy-duty plastic toolbox for easy storage and use.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product.

**Costs –** Most kits generally cost between $100 and $500, depending on the number and size of the plugs in the kit.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Dome Clamp*

In a hazardous materials operation involving tankers with hazardous or flammable cargo, it is necessary for the response unit to safeguard the tanker dome covers to prevent a leak, or stop or slow existing leaks. With dome covers in place, a greater margin of safety is provided for the members as they complete the remainder of the mitigation and salvage operations.

Dome clamps are constructed of steel or aluminum. Aluminum clamps are lighter in weight compared to the steel clamps, which allows for ease of handling and reduces the possibility of creating a spark during handling or placement on the dome.

Clamps are adjustable for domes from 4½ to 22½ inches in diameter. They should fit both inside- and outside-lipped dome covers without removing the locking screws.

**Training –** Personnel using this technology should be trained to the Technician level in accordance with NFPA 472, if they will be coming in contact with the product.

**Costs –** Dome clamps generally are priced between $200 and $500, depending on the material they are made of.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

## *CHAPTER XI – FIRE SUPPRESSION FOAM AND APPLICATORS*


*Photo courtesy of Task Force Tips*

Firefighting foam is a mixture of water under pressure, foam concentrate, and air. The concentrate is mixed with flowing water through a proportioning device. Then the mixture is aspirated with air to produce the characteristic finished foam. By incorporating air into the foam-water mixture, foams expand many times beyond the combined volume of water and concentrate.

Firefighting foam might be used at a hazardous materials incident to prevent or extinguish a fire, especially where flammable liquids are involved. Low-expansion foams, used primarily on flammable liquid risks, have expansion ratios of 10:1. Mid-expansion foams, for suppressing the release of hazardous or ignitable vapors, have ratios between 20:1 and 200:1. High-expansion foams, with ratios of 200:1 to 1000:1, are used primarily for confined-space firefighting.

Foams are designed to work in four ways:
- Exclude air from flammable vapors;
- Eliminate vapor release from the fuel surface;
- Cool the fuel surface; and
- Cool the surrounding exposures.

Foam concentrates are specially formulated depending on the nature of the risk (i.e., hydrocarbon, polar solvent, etc.). Selecting the right foam for the risk is critical to success, whether the task is extinguishment or prevention. Foam selection is the key to effectiveness.

### *Class A Foam*

Class A foam is formulated of specialty hydrocarbon surfactants. Surfactants reduce the surface tension of the water in the foam solution. This provides better penetration of the water, thereby increasing its effectiveness. When used with compressed-air foam systems (CAFS), Class A foam has outstanding insulating qualities. CAFS entrain large amounts of compressed air and small amounts of water into the concentrate to make foam.

Class A foam may be used with medium- and high-expansion devices and compressed-air foam systems. Class A foam may be used with almost any nozzle, including solid-stream, fog, and aerating nozzles.

The shelf life of Class A foam concentrate can be as long as 20 years. Because this type of foam is used in such small percentages in solution, harm to the environment may not be a concern under ordinary fire suppression conditions. There is some evidence that the concentrate may affect aquatic life slightly, so direct application into bodies of water is not recommended. Class A foams approved by the U.S. Forest Service have been tested for biodegradability and environmental impact. Class A foam concentrate has corrosive or supercleaning characteristics; however, fire apparatus components exposed to Class A foam are not affected by its corrosive characteristics because of the low percentages of foam concentrate used in solution. Additionally, following recommended procedures for flushing application equipment after use should minimize any adverse effects.

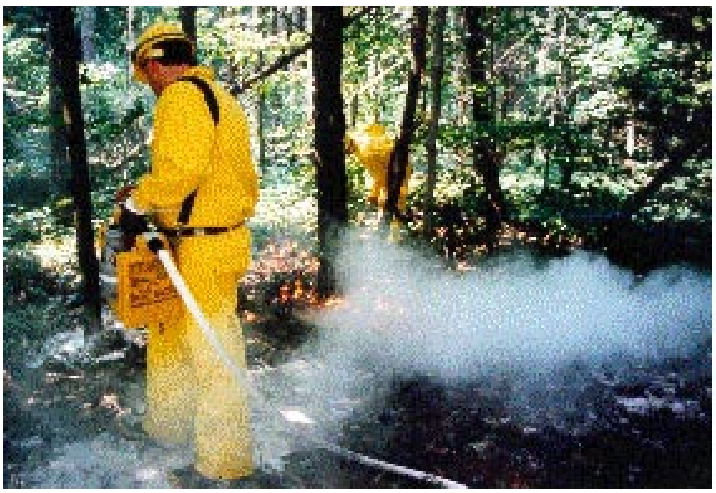


*Photo courtesy of Task Force Tips*

Class A foam concentrates are mixed in proportions of 0.1 to 3.0 percent; however, most commonly used concentrates are mixed in proportions of 0.2 to 1.0 percent. There are no performance enhancements to be gained by proportioning Class A foams above their recommended levels; this only drives up the cost of the operation. There are some common rules of thumb for Class A foam proportioning:

- Fire attack and overhaul with standard fog nozzles – 0.2 to 0.5 percent;
- Exposure protection with standard fog nozzles – 0.5 to 1.0 percent;
- Any application with air-aspirating foam nozzles – 0.3 to 0.7 percent; and
- Any application with compressed-air foam systems – 0.2 to 0.5 percent.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Foams are sold by container size. Generally, the larger the container the lower the cost of the foam. Class A foam costs approximately $3 per gallon.

**Future Trends –** There is trend in the foam industry to develop a “universal foam.” This may eliminate the need for carrying and deploying various kinds of foam depending on the nature of the incident. The universal foam will have an increased capacity to emulsify and break down flammable hazards while reducing run-off. In addition, foams will continue to become more environmentally friendly.

### *Class B Foam*

Class B foam is used to extinguish fires involving flammable and combustible liquids. Class B foam also is used to suppress vapors from unignited spills of flammable and combustible liquids. Several types of Class B foam concentrates are available.

*Photo courtesy of Task Force Tips*

Class B foams used today are mixed in proportions from one to six percent. The proper proportion for any particular concentrate usually is listed on the outside of the foam container. Some multipurpose foams designed to be used on both hydrocarbon and polar solvent fuels are intended to be used at different concentrations, depending on the fuels they are used on. These concentrates normally are used at a three percent rate on hydrocarbons and six percent on polar solvents. Newer multipurpose foams may be used at three percent concentrations regardless of the type of fuel they are used on.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Foams are sold by container size. Generally, the larger the container the lower the cost of the foam. Class B foam costs approximately $3 per gallon.

**Future Trends –** There is trend in the foam industry to develop a “universal foam.” This may eliminate the need for carrying and deploying various kinds of foam depending on the nature of the incident. The universal foam will have an increase capacity to emulsify and break down flammable hazards while reducing run-off. In addition, foams will continue to become more environmentally friendly.

### *Protein Foams*

Regular protein foam is derived from naturally occurring sources of protein such as hoof, horn, or feather meal. The protein meal is hydrolyzed in the presence of lime and converted to a protein hydrolysate that is neutralized. Other components, such as foam stabilizers, corrosion inhibitors, antimicrobial agents, and freezing-point depressants then are added. Regular protein foam generally has very good heat stability and resists burnback but is not as mobile or fluid on the fuel surface as are other types of low-expansion foams.

Special freeze-inhibiting additives permit use down to a concentrate temperature of -20° Fahrenheit. Protein foam causes extinguishment in two ways. The foam blanket excludes oxygen from the fuel's surface, and the water in the foam provides cooling. The protein base provides a stable, long-lasting foam blanket highly resistive to the effects of heat. This prevents reignition and enhances burnback resistance. Standard features of these foams include

- Stable, long-lasting foam blanket provides excellent burnback resistance.
- Highly resistant to fuel contamination.
- Suitable for use with fresh or sea water.
- Compatible with standard-proportioning and air-aspirating foam-making equipment.
- Suitable for use with foam-compatible, dry-powder/chemical extinguishing agents.

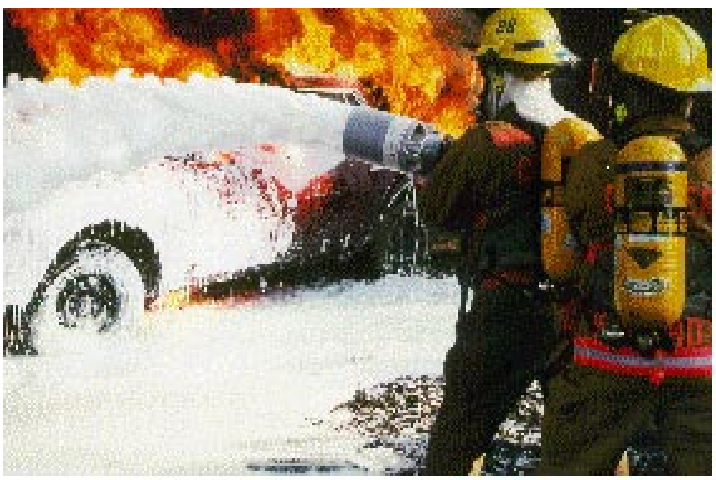


*Photo courtesy of Task Force Tips*

Protein foam is used in fire suppression systems and manual applications to fight fires involving hydrocarbon fuels such as crude oil, gasoline, and fuel oils. It is not suitable for use on polar solvents or water-miscible fuels such as alcohols, ketones, esters, and ethers. Typical storage tank systems include surface (topside) application. It is not suitable for subsurface application, a process by which foam is pumped into the bottom of a burning petroleum tank and allowed to float to the top to form a fire extinguishing blanket. Other uses include loading racks, docks, process areas, marine tankers, spills, etc. For best performance, protein foam concentrates should be used with aspirating nozzles and foam-making equipment.

Protein foam ideally is stored in its original shipping container, in tanks, or in other containers which have been designed for such foam storage. Recommended construction materials are carbon steel, high-density cross-linked polyethylene, or reinforced fiberglass polyester (isophthalic polyester resin) with a vinyl ester resin internal layer coating (50 to 100 mils).

Protein foam concentrates are subject to evaporation which accelerates when the product is exposed to air. Storage tanks should be sealed and fitted with a pressure vacuum vent to prevent free exchange of air. The recommended storage environment is within the UL-listed temperature range of -20° to 120° Fahrenheit (-29° to 49° Celsius).

It is not recommended that protein foam be mixed with any other type of foam concentrate in long-term storage. Such mixing could lead to chemical changes in the product and a possible reduction in or loss of its firefighting capability. Most expanded foams are compatible for side-by-side application during an incident.

The shelf life of any foam concentrate is maximized by proper storage conditions and maintenance. Factors affecting shelf life are wide temperature changes, extreme high or low temperatures, evaporation, dilution, and contamination by foreign materials. Properly stored protein foam has been tested and shown no significant loss of firefighting performance, even after 25 years. Annual testing of all firefighting foams is recommended in NFPA 412.

Most protein foams are biodegradable. However, as with any substance, care should be taken to prevent discharge from entering ground water, surface water, or storm drains. With advance notice, some protein foams can be treated by local biological sewage treatment systems. Since facilities vary widely by location, disposal or discharge of concentrate or foam solution should be made in accordance with federal, state, and local regulations.

Tests for acute oral toxicity and primary skin irritation have failed to show any dangers. Repeated skin contact will remove oils from the skin and cause dryness. Protein foam is a primary eye irritant, and contact with the eyes should be avoided. Users are advised to wear protective equipment. If protein foam enters the eyes, flush them well with water and seek immediate medical attention.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Foams are sold by container size. Generally, the larger the contain the lower the cost of the foam. Protein foam costs approximately $3 per gallon.

**Future Trends –** There is trend in the foam industry to develop a “universal foam.” This may eliminate the need for carrying and deploying various kinds of foam depending on the nature of the incident. The universal foam will have an increase capacity to emulsify and break down flammable hazards while reducing run-off. In addition, foams will continue to become more environmentally friendly.

### *Fluoroprotein Foams*

Fluoroprotein foam is a combination protein- and synthetic-based foam. It is derived from protein foam concentrates to which fluorochemical surfactants are added. These fluorochemical surfactants are similar to those developed for aqueous film-forming foam (AFFF) agents (described later) but are used in much lower concentrations. The addition of these chemicals produces a foam that flows more easily than regular protein foam. Fluoroprotein foams are well suited for subsurface injection. Fluoroprotein foam provides a strong “security blanket” for long-term vapor suppression. Vapor suppression is especially critical with unignited spills of flammable substances.

Fluoroprotein-based foams are designed to extinguish fires in hydrocarbon fuels only. The superior performance has been proved by independent testing agencies for use on methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether (ETBE), tertiary amyl methyl ether (TAME), and gasoline/MTBE-blended motor fuels. Fluoroprotein foam extinguishes fires in two ways. First, the foam blanket excludes oxygen from the fuel's surface, and second, the water in the foam cools the fuel. Standard features of these foams include

- Stable, long-lasting foam blanket provides excellent burnback resistance.
- Highly resistant to fuel contamination.
- Suitable for use with fresh or sea water.
- Compatible with standard proportioning and air aspirating foam making equipment.
- Suitable for use with foam-compatible, dry-powder extinguishing agents.

Fluoroprotein foam is manufactured using a unique process which produces protein hydrolyzate to form the foundation for the concentrate formulation. The protein base provides a stable, long-lasting foam blanket that is highly resistive to the effects of heat. This prevents reignition and enhances burnback resistance. Fluorochemical surfactant additives are combined with the protein base to increase fluidity of the foam and enable it to seal around obstructions.

Fluoroprotein foam concentrations generally are suitable for use with most types of proportioning systems and Venturi-type proportioners (eductors). Fluoroprotein foam is used in fire suppression systems and manual applications to fight fires involving hydrocarbon fuels such as crude oil, gasoline, and fuel oils. It is not suitable for use on most polar solvents or water-miscible fuels such as alcohols, ketones, esters, and ethers. However, fluoroprotein foam has been found suitable for use on slightly polar fuels such as MTBE, ETBE, TAME, and MTBE/gasoline motor fuel blends. Typical storage tank systems include surface (topside) or subsurface application. Other uses include loading racks, docks, process areas, marine tankers, spills, etc. For best performance, fluoroprotein foam concentrates should be used with aspirating nozzles and foam-making equipment.

Fluoroprotein foam ideally is stored in its original shipping container or in tanks or other containers which have been designed for such foam storage. Recommended construction materials are carbon steel, high-density cross-linked polyethylene, or reinforced fiberglass polyester (isophthalic polyester resin) with a vinyl ester resin internal layer coating (50 to 100 mils).

Foam concentrates are subject to evaporation which accelerates when the product is exposed to air. Storage tanks should be sealed and fitted with a pressure vacuum vent to prevent free exchange of air. The recommended storage environment is within the UL-listed temperature range of 20° to 120° Fahrenheit.

It is recommended that fluoroprotein foam not be mixed with any other type of foam concentrate in long-term storage. Such mixing could lead to chemical changes in the product and a possible reduction in or loss of its firefighting capability. Most expanded foams are compatible for side-by-side application during an incident.

Fluoroprotein foam is suitable for use in combination with foam-compatible, dry-chemical extinguishing agents.

The shelf life of any foam concentrate is maximized by proper storage conditions and maintenance. Factors that reduce shelf life are wide temperature changes, extreme high or low temperatures, evaporation, dilution, and contamination by foreign materials. Properly stored fluoroprotein foams have been tested and have shown no significant loss of firefighting performance, even after 25 years.

Most fluoroprotein foams are biodegradable. However, as with any substance, care should be taken to prevent discharge from entering ground water, surface water, or storm drains. With advance notice, fluoroprotein foams can be treated by local biological sewage treatment systems. Since facilities vary widely by location, disposal or discharge of concentrate or foam solution should be made in accordance with federal, state, and local regulations.

Tests for acute oral toxicity and primary skin irritation have failed to show any dangers. Repeated skin contact will remove oils from the skin and cause dryness. Fluoroprotein foam is a primary eye irritant, and contact with the eyes should be avoided. Users are advised to wear protective equipment. If fluoroprotein foam enters the eyes, flush them well with water and seek immediate medical attention.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Foams are sold by container size. Generally, the larger the container the lower the cost of the foam. Fluoroprotein foam costs approximately $3 to $4 per gallon.

**Future Trends –** There is trend in the foam industry to develop a “universal foam.” This may eliminate the need for carrying and deploying various kinds of foam depending on the nature of the incident. The universal foam will have an increased capacity to emulsify and break down flammable hazards while reducing run-off. In addition, foams will continue to become more environmentally friendly.

### *Aqueous Film-Forming Foam*

AFFF (commonly pronounced “A-triple-F”) is the most common foam used today. AFFF is completely synthetic and consists of fluorochemical and hydrocarbon surfactants combined with high-boiling-point solvents and water. Fluorochemical surfactants reduce the surface tension of the water to a degree that is less than the surface tension of the hydrocarbon so that a thin aqueous film can spread across the fuel. AFFF is available in one, three, and six percent concentrations and in alcohol-resistant formulations. When alcohol-type AFFF is applied to polar solvent fuels, it creates a membrane rather than a film over the fuel. This membrane separates the water in the foam blanket from the attack of the solvent. The blanket acts in much the same way as a regular AFFF. AFFF also is suited for subsurface injection and may be premixed in portable fire extinguishers and apparatus water tanks.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Foams are sold by container size. Generally, the larger the container the lower the cost of the foam. AFFF foam costs approximately $3 per gallon.

**Future Trends –** There is trend in the foam industry to develop a "universal foam." This may eliminate the need for carrying and deploying various kinds of foam depending on the nature of the incident. The universal foam will have an increased capacity to emulsify and break down flammable hazards while reducing run-off. In addition, foams will continue to become more environmentally friendly.

### *Film-Forming Fluoroprotein Foam*

Film-forming fluoroprotein foam (FFFP) concentrate is based on fluoroprotein foam technology with AFFF capabilities. FFFP incorporates the benefits of AFFF for fast fire knockdown and the benefits of fluoroprotein foam for long-lasting heat resistance. FFFP is available in three and six percent concentrations and also in alcohol-resistant formulations. Premixed FFFP may be stored in fire extinguishers or in apparatus water tanks. It also may be used for subsurface injection applications.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Foams are sold by container size. Generally, the larger the container the lower the cost of the foam. FFFP foam costs approximately $3 per gallon.

**Future Trends –** There is trend in the foam industry to develop a "universal foam." This may eliminate the need for carrying and deploying various kinds of foam depending on the nature of the incident. The universal foam will have an increase capacity to emulsify and break down flammable hazards while reducing run-off. In addition, foams will continue to become more environmentally friendly.

### *High-Expansion Foam*

High-expansion foam is a special-purpose foam that has a detergent base. Because it has a low water content, it minimizes water damage. Its low water content also is useful when runoff is undesirable. The major uses for high-expansion foam are as follows:

- In concealed spaces such as basements, in coal mines, and in other subterranean spaces;
- In fixed-extinguishing systems for specific industrial uses, such as rolled or bulk paper storage; and
- In Class A fire applications.

High-expansion foam may be expanded in ratios ranging from 200:1 to 1,000:1. This type of foam typically is proportioned at rates between one and a half and three percent. The use of high-expansion foam outdoors generally is not recommended because the slightest breeze may remove the foam blanket in sheets and reexpose the hazard to stray ignition sources.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Foams are sold by container size. Generally, the larger the container the lower the cost of the foam. High-expansion foam costs approximately $4 per gallon.

**Future Trends –** There is trend in the foam industry to develop a "universal foam." This may eliminate the need for carrying and deploying various kinds of foam depending on the nature of the incident. The universal foam will have an increased capacity to emulsify and break down flammable hazards while reducing run-off. In addition, foams will continue to become more environmentally friendly.

### *Foam Proportioners*

Proportioning is the process of mixing water with foam concentrate to form a foam solution. Most foam concentrates are intended to be mixed with fresh or salt water. Many firefighting foam concentrates are intended to be mixed so that the solution is 94 to 99.9 percent water. For example, when using three percent foam concentrate, 97 parts water are mixed with three parts foam concentrate to equal 100 parts foam solution. For six percent foam concentrate, 94 parts water are mixed with six parts foam concentrate to equal 100 parts foam solution.

For maximum effectiveness, foam concentrates must be proportioned at the specific percentage for which they are designed. This percentage rate for the intended fuel is marked clearly on the outside of every foam container. Failure to follow this formula, such as trying to use six percent foam at a three percent concentration, will result in poor-quality foam that may not perform as desired. However, Class A foams are an exception to this rule. The proportioning percentage for Class A foams can be adjusted (within limits recommended by the manufacturer) to achieve specific objectives. A higher proportion produces a dry (thicker) foam that is suitable for exposure protection and firebreaks. A lower proportion results in a wet (thinner) foam that sinks more rapidly into a fuel's surface.

The selection of a proportioner depends on the following:

- foam solution flow requirements;
- available water pressure;
- cost;
- intended use (vehicle or fixed); and
- agent to be used.

The selected proportioner must be compatible with the delivery device; proportioners and delivery devices (foam nozzle, foam maker, etc.) are engineered to work together. Using a foam proportioner that is not compatible with the delivery device (even if the two are made by the same manufacturer) can result in unsatisfactory foam or no foam at all.

Foam can be proportioned by four basic methods: induction, injection, batch mixing, and premixing.

- Induction – The induction (eduction) method of proportioning foam uses the energy of the pressure of the water stream to induct (draft) foam concentrate into the fire stream by passing the stream of water through a device (called an eductor), which has a restricted diameter. Within the restricted area is a separate orifice that is attached via a hose to the foam concentrate. The pressure differential created by the water going through the restricted area and over the orifice creates a suction that draws the foam concentrate into the fire stream. In-line eductors and foam nozzle eductors are examples of foam proportioners.

- Injection – The injection method of proportioning foam uses an external pump or head pressure to force foam concentrate into the fire stream at the correct ratio in comparison to the flow. These systems are employed in apparatus-mounted or fixed fire protection system applications.

- Batch Mixing – Batch mixing is the simplest method of mixing foam concentrate and water. It is the most accurate method of proportioning foam. This method is used to mix foam within a fire apparatus water tank or a portable water tank. Batch mixing is a common practice with Class A foams but should be used only as a last resort with Class B foams. Batch mixing may not be effective on large incidents. When the tank becomes empty, the foam attack lines must be shut down until the tank is filled completely with water and more foam concentrate is added. Another drawback is that the concentrate and tank water must be circulated to ensure thorough mixing before it is discharged.

- Premixing – Premixing is one of the most commonly used methods of proportioning. With this method, premeasured portions of water and foam concentrate are mixed in a container. Premix systems are limited to a one-time application. When used, they must be emptied completely and then refilled before they can be used again. Typically, the premix method is used with portable extinguishers, wheeled extinguishers, skid-mounted twin-agent units, and vehicle-mounted tank systems. In most cases, premixed solutions are discharged from a pressure-rated tank using a compressed inert gas or air. An alternative method of discharge uses a pump and nonpressure-rated atmospheric storage tank. The pump discharges the foam solution through piping or hose to the discharge devices.

There are three types of foam proportioners:


Graphic courtesy of Task Force Tips

*Line Eductor*

These are the simplest and least expensive proportioning device. They have no moving parts in the waterway. The line eductor may be attached to the hoseline or may be part of a nozzle. The are two types on line educators, an in-line eductors and self-educting nozzles. Both types use the Venturi principle to draft foam concentrate into the water stream.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Line educators generally range in price from $500 to $1,300.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

*Balanced-Pressure Proportioners*

The balanced-pressure proportioner is built into the apparatus fire pump. There is a foam concentrate line connected to each discharge outlet. The separate line is supplied by a foam concentrate pump separate from the main fire pump. The foam concentrate pump draws the concentrate from a fixed tank on the apparatus. The pump is designed to supply foam concentrate to a desired outlet at the same pressure at which the fire pump is supplying water to that discharge.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Balanced-pressure proportioners generally range in price from $2,500 to $6,000.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

*Around-the-Pump Proportioning System*

The around-the-pump proportioning system consists of a pick-up line from the discharge side of the pump back to the intake side of the pump. An in-line eductor is positioned on the pump bypass to deliver foam.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Around-the-pump-proportioning systems generally range in price from $800 to $1,200.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Foam Makers*

Nozzles designed to discharge foam are called foam makers. There are three common types of foam makers.

#### *Air-Aspirating Foam Nozzle*

Many foam discharge devices are air-aspirating; they are designed to mix air with the foam solution to form an expanded mass of bubbles. When used with AFFF and Class A foams, they develop a thick foam blanket which has better extinguishing ability and is longer lasting than foam from nonaspirating nozzles. Air-aspirating foam nozzles are the most effective appliance for the generation of low-expansion foam. They are specially designed to provide the aeration required to make the highest quality foam.

*Photo courtesy of Task Force Tips*

Air-aspirating foam nozzles are designed to be handheld (30 to 250 gallons per minute) or monitor mounted (250 gallons-per-minute or more). Monitors allow a single person to control the horizontal and vertical directions of large-capacity discharge streams. They are stationary devices that are fed foam solution or water from permanent piping or hose. Some monitors are maneuvered manually using a rear-mounted handle to swivel the monitor horizontally and vertically. Other monitors can be operated using electric remote control tied into a hydraulic system. Still others will oscillate automatically from side to side using water pressure as the energy source.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** Air-aspirating foam nozzels generally range in price from $150 to $700.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Standard Fixed-Flow Fog Nozzle*

Standard fixed-flow fog nozzles are used with foam solution to produce a low-quality, short-lasting foam. These nozzles use the agitation of water droplets moving through the air to achieve the foaming action; they are best used with AFFF and cannot be used with protein and fluoroprotein foam. These nozzles are available in a wide capacity range and can be either preset at the factory or set in the field. The fog pattern also can be changed easily at the installation site.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** This technology ranges in price from $100 to $500.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Automatic Nozzles*

Automatic nozzles require an eductor to deliver foam; they are designed for use with most types of foam concentrates, including protein, fluoroprotein, and AFFF. These nozzles may experience problems if the eductors is operated at a lower pressure than that recommended by the manufacturer or if the nozzle is gated down.

**Training –** Personnel using foam should be trained in accordance with NFPA 11.

**Costs –** This technology ranges in price from $500 to $800.

**Future Trends –** No specific future trends in the use or development of this technology have been identified.

### *Universal Foam Container Wrench*

The universal foam container wrench is a fairly economical aluminum wrench designed to allow full 360 degree rotation to open most foam containers while protecting firefighter’s knuckles.

**Training –** Significant training or usage issues are not foreseen.

**Costs –** The universal foam container wrench is an inexpensive tool ranging in price from $10 to $50 depending on the quality.

**Future Trends –** With the development of new and stronger alloys, it is expected that the tool will last longer and decrease in price.

# CHAPTER XII – COMMUNICATIONS EQUIPMENT

Clear, concise communications, which are understood by both the message transmitter and receiver, are an essential component of any effective hazardous materials incident response. A wide variety of communication systems are available to keep emergency personnel informed and connected to the incident command and personnel accountability systems in which they operate. Clear lines of communication are fundamental to an emergency hazardous materials incident.

Communications technology can transmit a signal via radio frequency waves or through a hardwired cable. Radio signals can be blocked by walls and metal, and are limited by distance and other barriers. By contrast, hardwired communications equipment is nearly 100 percent reliable; however, it is not as versatile since communication signals must travel through a physical wire.

## *Radio Frequency (RF) Systems*

Conventional radio frequency (RF) systems, which are widespread in the emergency services sector, convert a voice message into a specific radio wave frequency, measured in megahertz (MHz), and transmit those waves to other radio units operating on the same frequency. RF systems, standard for fire department handheld and mobile communication units, transmit messages in the 25 MHz to 800 MHz radio frequency range. A general rule associated with radio waves is that lower frequency waves will travel a greater distance than higher frequency waves, but lower frequency waves will not be able to penetrate barriers as well as higher frequency waves. For example, a 40 MHz signal from a standard mobile radio can travel 50 miles or more without a signal repeater, whereas an 800 MHz signal would have difficulty traveling the same distance, even under ideal conditions. An 800 MHz signal, however, can transmit through a concrete enclosed room that would block a 40 MHz signal.

Many RF communications systems rely on repeating stations to increase a network range. Repeaters simply take an incoming signal and relay it back out to the radio network, sometimes at an increased strength. Repeating stations located at strategic points in an emergency response area increase the range of any one particular radio by decreasing the total distance that a radio signal must travel.

## *Trunked Radio Systems*

RF technology, already ubiquitous throughout the emergency response services, offers advantages to a wide variety of emergency incidents, since it can transmit over a large area and depending on the frequency, through a number of obstacles. RF technology does, however, have certain limitations. Obstructions such as concrete, metal, tunnels, static interference, similar high-powered frequencies, and atmospheric disturbances like electrical storms can interfere with radio signal transmissions. RF signals are not able to pass below the surface of water and are frequently blocked in many confined space emergencies.

Trunked radio systems allocate 20 or more channels to a particular radio frequency. Trunked radio systems do not require one frequency for every one channel. Instead, the system picks an unused frequency when the user transmits over a channel. Trunked systems work on the concept that even though there are a multitude of channels available to users, it is extremely unlikely that more than a few of them will be in use simultaneously.

At the heart of a trunked system is a computer that assigns a user an open frequency. The computer selection process is invisible to the user. The multiple-channel capability of a trunked radio system offers many advantages at small- and large-scale rescue or fire incidents. Typically, there are many high-priority operations occurring simultaneously at an emergency incident. Coordination of the operations is very difficult if only one or two channels are available to emergency response personnel. RF trunking technology offers multiple channels. For instance, each sector in an incident command could use a separate channel, while the commanders could use another channel for communications and coordination among themselves. Incident commanders, however, would have to monitor ongoing operations on the separate channels to ensure that they remain coordinated.

A trunked system is designed to allow communications among multiple agencies, allowing fire, police, public works, and other agencies to communicate with one another, which facilitates communications during a major incident. The technology also allows communications with other jurisdictions' radio systems so that no patching of frequencies is necessary. One limitation with the trunked system is that if the signal does not reach the central trunked system receiver, the transmission will not reach other radios that are connected to the system.

### *Hardwired Systems*

Hardwired systems are considered to be one of the most reliable media communications available because users are connected directly by a wire or a cable. Some systems use a console to interconnect several users. This allows for duplex communications, which allows multiple rescuers to talk simultaneously while ensuring that everyone hears them (similar to a conference call). The systems generally use headsets, sometimes with throat microphones, which are attached to the wire that runs to a central console. The headsets and microphones are very compact, and the transmit button can be held in a rescuer's palm or the system can be voice activated. These features facilitate movement within a confined space or inside a chemical-protective suit.

Hardwired systems can be used effectively at incident locations where RF signals cannot penetrate, such as heavy concrete construction factories, because the wire carries the signal; this virtually ensures that a rescuer can be heard at any time. Many rescuers find the greatest advantage of these systems to be the psychological reassurance of knowing that they always will be able to communicate, especially when they are out of visual contact with nonentry personnel.

Some hardwired units have emergency buttons that can be activated if a rescuer needs assistance. Some are intrinsically safe, making them useful at hazardous materials incidents where the atmosphere may be flammable or explosive, such as incidents occurring in silos, sewers, vats, storage tanks, or ship hulls. The main power supply for intrinsically safe units remains outside the explosive environment. A fully shielded communications wire carries only a few millivolts. Newer hardwired systems are insulated from outside electrical signals that can create interference or static.

The major limitation with any hardwired system is the length of the wire. Depending on the system, the wire generally is limited to between 500 and 1,500 feet. For longer distances, a repeater may be necessary to boost the signal. Most hardwired systems also are limited to four or five users, unlike RF systems, which can accommodate many more users; however, sometimes additional hardwired systems can be connected at the control console to increase the number of users. Users of hardwired systems also must deal with dragging a communications wire, which may become snagged or tangled.

**Training –** Many departments are already familiar with the use of radio communications. However, they may not be used to the tether of a wire and the safety hazards it creates. Further, they may need to be trained how to lay down the wires and connect them properly.

**Cost –** Multi-user hardwired systems range from $5,000 to $10,000.

**Future Trends –** As long as wireless communications continue to face interference from a host of electrical and physical barriers, hardwired communications should provide a reliable option to ensure that messages are sent and received in emergency situations.

### *Communications Wire/Rope*

Many rescue incidents require a safety line (tag line) to be attached to rescuers at all times. Rescuers involved with confined space entry, diving, rappelling, or swiftwater entry often must use safety lines. Sometimes rescuers also need to take a hardwire communications line with them and they also may have to take an air-supply line with them (for SABA units). The three separate lines may present a hazard to rescuers if they become tangled, twisted, or caught.

*Photo courtesy of Ocean Technology Systems*

Communications wire/rope is a technology that combines two of these lines into one, to reduce the risk of tangling. It usually is constructed as a kernmantle rope, with the communications wire running through the inside of the kern (the rope's inside core). Rope strength is not compromised by the encased wire, allowing the combination rope/

communications wire to serve as a safety line. Each end of the wire/rope has a locking coaxial-type connection so that it can be attached to a radio, headset, or other communications console.

Most communications wire/rope has a breaking strength of around 5,000 pounds; military-grade wire/rope is rated as high as 9,000 pounds. The rope is made from synthetic fibers and is waterproof. Since the wire runs through the center of the rope, it is intrinsically safe for rescue operations in flammable environments. Under high stress, the wire portion of the rope could be damaged by the greater elasticity of the rope. Communications wire/rope is available in various widths and lengths.

**Training –** Rescuers would have to be aware of the dangers of their lines getting tangled and other dangers inherent in working in confined spaces.

**Cost –** Communications rope generally costs approximately $3 per foot, if it is encased in kernmantle rope.

**Future Trends –** Since wireless radios often cannot be used during confined space rescues, this could be a reliable way to ensure communication. Hardwired systems may become less expensive and more reliable in the future.

### *Water Resistant Communications Equipment*

*Photo courtesy of Ocean Technology Systems*

Because hazardous materials responders must undergo decontamination (which generally requires water), communications equipment may be exposed to water. Watertight bags can be attached to the rescuer’s chest or waist to hold a portable radio. The sound quality of the bags does not distort communications. Waterproof headsets with the microphones or throat mikes with palm push-to-talk buttons are ideal for a rescuer who cannot use his/her hands to activate a radio.

**Training –-** Training beyond care and maintenance of waterproof radios is not necessary, as most emergency response personnel already will be familiar with the operation of portable communications equipment.

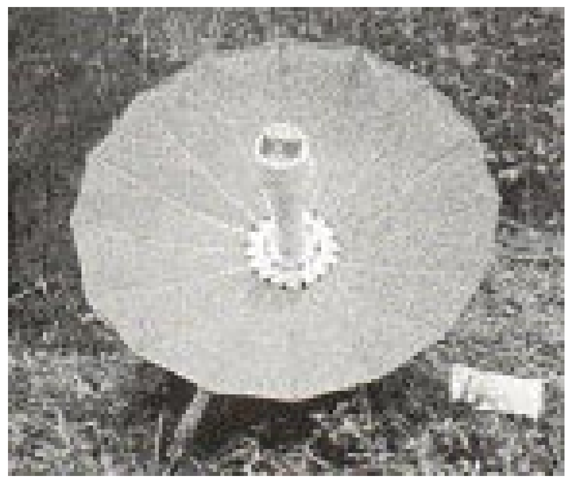
**Cost –-** Radio manufacturers often charge a considerable premium (as much as $3,000 per radio) for waterproof models. A more affordable alternative is to use existing USCG-approved marine band portable radios, which often can be purchased for under $200 each. These radios use FCC-approved public frequencies and are not limited to use by fire/rescue personnel.

**Future Trends —** As this technology is developed, it likely to become less expensive and therefore more readily available to the fire service.

### *Cellular and Satellite Telephones*

In areas not served by hardwired telephone systems, cellular telephones provide an alternative means of communication. Because hazardous materials incidents sometimes take place in remote areas not served by telephone, and because communication with CHEMTREC or hazardous materials manufacturers or shippers often is necessary at the scene of a hazardous materials incident, cellular telephone technologies are playing an increasingly important role in hazardous materials response.

During a hazardous materials incident, several disadvantages to cellular transmission may be experienced. Cellular transmission may not get through if the user is in an area where signals cannot reach a receiving cell. Cellular systems may become overloaded during the incident. In multiple unit or multiple agency responses, it can be difficult to coordinate multiple cellular users in the field because users cannot monitor each other's transmissions. In addition, cellular communications are not secure, and information may be intercepted by unauthorized individuals.



Another option is to bypass the local telephone system entirely with a satellite telephone. These expensive units are the size of a suitcase-but particularly useful for rescuers in remote areas where neither hardwired telephones nor cellular receiving sites are available.

**Training –** While many people are familiar with the use of cellular phones, minimal training might be required to familiarize rescuers with the setup and positioning of a satellite phone.

**Cost –** Cellular phones are commercially available, and rates vary according to the region, the service providers, and whether government service plans are available. Satellite telephones can cost more than $10,000.

**Future Trends –** Additional cellular (and digital cellular) coverage will enable communications even in the most remote areas of the United States. Digital cellular will enable more secure communications.

### *Laser Communication*

The military uses a secure laser communications system that is able to relay data at high speeds digitally in real time over distances of up to five miles.

**Training** – This system would require some training as to proper usage, although it is unclear how much training would be needed for nonmilitary applications.

**Costs** – Such a system probably would be prohibitively expensive for fire and EMS agencies for the foreseeable future.

**Future Trends** – Future applications of this type of technology might provide personnel with individual communications equipment that could potentially replace radios (and the attendant problems such as range and overlap of transmission).

### *Amateur Radio*

Amateur radio operators are able to communicate with thousands of other licensed operators throughout the United States and the world. More than 600,000 radio operators are licensed in the Amateur Radio Service by the Federal Communications Commission (FCC). Amateur radio operators must have the proper FCC license appropriate to the tested knowledge and skill levels to operate an amateur radio station.

#### *The Amateur Radio Emergency Service (ARES)*

The Amateur Radio Emergency Service (ARES) is a volunteer radio communication service available to Federal, State, county, and local emergency management agencies. It is a nonprofit volunteer organization of more than 25,000 amateur radio operators nationwide, who have registered their service voluntarily and formed an organized pool of operators to provide reliable primary and secondary emergency communication links for governmental agencies and/or nonprofit organizations. ARES provides radio communications support to disaster preparedness, response, and recovery within local communities. Communications provided may be in the form of voice, digital, analog, television, and other modes.

*Photo courtesy of SPC*

### *Real-Time Video Transmitter*

Damage assessment following a hazardous materials incident can be handled in many different ways. Usually hazardous materials teams send assessment teams out on foot or by vehicle to assess an area. They also watch video footage taken by news helicopters, or use photographs from military airplanes and satellites to assess damage. A new technology that is used currently by the military allows real-time transmission of video from a remote camera to a receiving video monitor.

The system comprises two briefcase-sized instruments: one a transmitter and the other a receiver. The transmitter unit takes a video from a standard or FLIR camera and transmits it to a receiving unit equipped with a portable video monitor. This technology is used most often to send video from a helicopter to a ground assessment point. The unit can transmit sharp video pictures for eight or more miles, depending on the wattage of the transmitter. However, its transmission distance decreases when used at lower altitudes (below 1,000 feet) and on the ground.

**Training –** Personnel would have to be trained to set up and monitor the device as well as how to transmit and receive images.

**Cost –** The system costs approximately $40,000.

**Future Trends –** For now, the cost of this technology may prohibit it from becoming widely used in the fire service. However, if it were to become more affordable and more widely available, it might have many uses in the fire service. In the future, these technologies may be incorporated into rapidly evolving robotic systems for remote assessment of container damage, spill status or assessment inside structures.

## CHAPTER XIII – RESPONSE/SUPPORT VEHICLES

Today, hazardous materials response and support vehicles appear very similar to heavy-rescue apparatus.  These vehicles carry various forms of equipment for hazardous materials response including PPE, breathing apparatus, monitoring tools, absorbents, etc., but often lack incident command center and conferencing capabilities.  Although it is not possible (in the context of this manual) to develop generic specifications for a hazardous materials response vehicle, the following items offer some considerations to help departments formulate vehicle specifications appropriate for the jurisdiction and hazards covered.


*Photo courtesy of Chicago Fire Department*

Hazardous materials response and support vehicles come in four general categories:  custom box on a cab and chassis, school-type bus, semi trailer, and trailer or other non powered design.  Most vehicles are manufactured with high-strength, all-aluminum construction and are available in body sizes ranging from 10 to 20 feet.  If fiberglass is used rather than metal, additional roof inserts for a radio antenna ground plane may be required. These vehicles should be designed to carry all the equipment needed for emergency mitigation and remediation of chemical spills and releases.

Prior to developing specifications for a hazardous materials response vehicle, the following factors/ decisions should be addressed:

*Funding* – Funding, budget, grants, cost sharing, and the relative proportions and limitations of each contributor must be established and documented.

*Continuity* – There must be documented ongoing financial commitment for maintenance, repairs, and future upgrading of the vehicle.

*User Agencies* – Input on minimum operational requirements should be obtained from the hazardous materials team.

*Management Structure* – The management structure/system (e.g., Emergency Site Management, Incident Command System, etc.) to be employed by each hazardous materials team should be established, as it may have an effect on the interior layout.

*Usage/Function* – There must be an understanding as to the specific use, control, operation, and activation of the vehicle, and agreement by all user agencies, to ensure proper design criteria.

*Readiness* – A designated agency must be responsible for daily upkeep, readiness, dispatch, and movement of the vehicle to the incident site

*Fuel* – Local availability (in all areas to be serviced) of the intended motor fuel (e.g. gasoline, diesel, propane) should be established.

*Range* – The potential operational range of the vehicle, relative to the availability of the selected fuel, should be considered in determining optimum fuel tank size.

*General Functions* – The general function(s) of the vehicle should be identified, as these will have an impact upon design criteria. These include:

- incident communications/dispatch;
- command and control;
- decision making and planning;
- conference; and
- first-line response.

*Interior* – The need to include the following interior amenities must be considered:

- cabinets, storage, desks, and work surface;
- lighting;
- seating;
- flooring, walls and ceiling;
- telephone jack;
- power outlets, 110 and 12 volt;
- air conditioning and heating; and
- doors and window.

*Additional Capabilities* – The need to include the following additional capabilities must be considered:

- computers;
- meteorological equipment;
- electricity; and
- telephone communications.

*Storage* – Storage of the vehicle should be considered. Where indoor storage is contemplated, vehicle dimensions, including roof-mounted lights, air conditioners, antennas, etc., must fit existing space and doorways. Where outside storage is contemplated, engine block heaters, and shore power connections must be planned, as well as the impact on onboard water systems and holding tanks. Effects on sensitive electronic equipment also must be considered. Proper security must be provided.

*Roof Platform* – If roof-mounted platforms or catwalks are planned, a reinforced roof design must be sufficient to hold personnel and/or heavy equipment; this loading factor must be determined and specified.


*Photo courtesy of Chicago Fire Department*

*Roof Design* – A curved roof design, which may offer increased roof strength, can reduce the storage space of interior cabinetry mounted near the ceiling.

*Winch* – If a winch is contemplated, power and structural mounting must be considered.

*Consistency in Components* – As far as is feasible, all interior parts should be of like design, to reduce the number of spare parts and tools needed to ensure readiness. This includes such items as switches, hinges, light fixtures and bulbs, fasteners, etc.

*Exterior Lighting* – The role of exterior lighting on the vehicle should be considered high intensity scene lighting, or merely security for the vehicle. The type, style, and weight of lighting envisioned may impact on roof/sidewall design/strength.

*Industrial Grade* – "Heavy-duty" or "industrial grade" should be specified in all applications, (e.g., cabinets, hinges, fastenings, flooring, tabletops, etc.). Standard recreational vehicle materials may not withstand the heavy use to which the vehicle may be subjected.

*Exterior Doors* – The number of access doors (other than the driver's door) should be considered. One-door access will permit better control of unauthorized entry, but will increase the disruption caused by the entry and movement of personnel to other areas of the vehicle.

*Vehicle and Component Selection* – To reduce downtime, select a vehicle which will have parts readily available for repair and maintenance, as well as access to service facilities. This applies equally to interior design components, as well as to electrical and communications hardware.

*Vehicle Operators* – The personnel who will be operating the vehicle should be considered, as specific training may be indicated. Availability during off-hours, possession of the appropriate drivers license, and familiarity with emergency response driving should be considered.

*Vehicle Configuration* – Consideration should be given to:

- underbody ground clearance;
- wheelbase/turning radius;
- angle of approach; and
- departure angle (relative to the anticipated operating environment).

*Primary Operational Environment* – The operating environment of the vehicle should be identified, because it will affect vehicle design/configuration.

*Legislated Restrictions* – Preliminary designs should be reviewed to ensure compliance with Federal and or State highway traffic laws, including height, width, gross weight, and length.

*Manufacturer's Limitations* – Preliminary design should ensure that:

- anticipated gross vehicle weight does not approach the manufacturer's Gross Vehicle Weight Rating (GVWR) for the chassis selected; and
- manufacturer's warranty is not voided by the intended use.

*Power-to-Weight Ratio* – Deliverable power, appropriate to the total weight of the vehicle, must be considered to ensure adequate performance.

## CHAPTER XIV – ROBOTICS

Robotics is a fundamental tool for most bomb squads. Robots operate in dangerous areas under the control of an operator at a safe, remote location. The Prince Georges County (Maryland) Fire Department operates the county bomb squad and has used the bomb squad robot with success on hazardous materials incidents.

Robots may have all-terrain wheels or tracks and even can go up and down steps. They are battery powered and are either radio controlled or tether controlled. Radio controls are reliable to about 200 yards. Tether controls are limited to the length of the cable. The tether wire control ensures that the robot is not moved beyond the radio range. Prince Georges County's robot is equipped with 1,000 feet of cable. The robot is equipped with video cameras that allow it to record or transmit pictures of container labeling or to view the scene close up without risking personnel.

Robots weigh approximately 500 pounds and can pull a vehicle with the transmission in neutral or drag a victim out of a "hot zone." Prince Georges County's robot has an arm with enough reach to open the rear roll-up doors on trucks. The hazardous materials team has used the robot to open cargo doors and view the contents and container labels from remote locations. This allows the team to develop an action plan with the least risk to personnel.

Robots also can be used to monitor personnel working in the hot zone visually and audibly or to shuttle needed tools and equipment to the hot zone. Robots can be equipped with sensing equipment and can be adapted with thermal imaging video cameras, night vision, and 3-D vision. Since these units are custom-built, sensing monitors and the ability to lift 55-gallon drums can be designed into the robot.

Two limitations of using robots on hazardous materials incidents are that they are not water-tight or intrinsically safe. Normal decontamination procedures using water spray will harm robots not designed for washing.

**Training –** Operators must be skilled in their use, and practice is very important to develop proficiency. The unit can be hard to operate remotely using one-dimensional video images.

**Costs –** Robotic vehicles have important applications in hazardous materials incidents but may be cost prohibitive for many fire departments.

**Future Trends –** In order to be used for hazardous materials response, robots must be equipped to detect obstacles in their path. Obstacles are detected by using range sensors to observe the geography of the environment. Then the geography is analyzed to find passable routes for the vehicle. However, range sensors have not been available that meet the cost and performance requirements of most fire department applications. A major step forward in this area has been taken by demonstrating the first practical range-sensing system to be based on stereo vision.

Stereo vision uses two cameras to observe the environment, finds the same object in each image, and measures range to the object by triangulation; that is, by intersecting the lines of sight from each camera to the object. Finding the same object in each image is called "matching" and is the fundamental computational task underlying stereo vision. Matching objects at each pixel in the image produces a range estimate at each pixel; together, these range estimates form a range image of the scene. Geometric analysis of the range image identifies passable routes. For robotic vehicle applications, the primary alternatives to stereo vision-based range estimation use acoustics, radar, or scanning lasers. Compared to these alternatives, stereo vision has the significant advantage of high resolution and simultaneous acquisition of the entire range image without energy emission or moving parts. The key issue in making stereo vision practical is to find a combination of algorithms and processors that lead to reliable, real-time range estimation with a computer system small enough and inexpensive enough to use on robots.

# CHAPTER XV – FUTURE TECHNOLOGY IDEAS

With the real and growing threat posed by the proliferation of biological and chemical weapons in the world, the military has stepped up its research and technology development within this domain. The military already has developed several technologies that could be used by civilian emergency personnel to identify and help mitigate a hazardous materials incident. Presently, most of these devices are not available to civilian jurisdictions. Under the Nunn-Lugar-Domenici Act, many of these technologies could be transferred from the military to the civilian sector.

Because most of the technology listed in this section is still under development or reserved for military use only, it is impossible at this time to provide training, costs, and future trend information. As these technologies become available to the civilian sector, these issues will be addressed by the manufacturer and the military.

## Chemical Detection and Warning

The military has developed technologies to sense the presence of certain chemicals and to give visual or audible warning of their presence. While some of these technologies are capable of measuring levels of contaminants, others provide only an indication that such contaminants are present.

### Chemical Agent Detector Kit

The Chemical Agent Detector Kit is a portable, expendable item capable of detecting and identifying hazardous concentrations of nerve, blood, and blister agents. The kit is used after a chemical attack to determine if it is safe to unmask. Each kit consists of 12 disposable sampler-detectors, one booklet of chemical agent detection paper, and a set of instruction cards. Each sampler-detector contains laboratory filter paper test spots for the various agents. The technology uses wet chemistry enzymatic substrate-based reactions where the presence of agents is indicated by a specific color change. Response time is about 15 minutes. Engine exhaust, petroleum products, and high temperatures may produce false readings. It cannot be used to detect agents in the water. The kit can be used to check an area before personnel enter an area or to define clean areas or routes. Some chemical ingredients in the kit are considered possible carcinogens and should be handled as such; the manual provides the necessary information for handling these chemicals.

### Chemical Agent Monitor/Improved Chemical Agent Monitor

Chemical Agent Monitors (CAM, also referred to as “CAM-V”) are handheld, service-member-operated devices designed for monitoring chemical agent contamination on personnel, equipment, and surfaces. They use ion mobility spectrometry technology to detect and differentiate between mustard and nerve agent vapor. The units are simple to operate. They can be held in either hand while wearing chemical protective equipment, and operate during the day or night. Relative vapor hazard and malfunction information is displayed on a liquid crystal display. It is a point monitor only (meaning it does not provide reading for areas, but rather for smaller "points") and cannot give an assessment of an area vapor hazard. The CAM may give false readings when used in enclosed spaces or when sampling near strong vapor sources such as a dense smoke, aromatic vapors, cleaning compounds, exhausts, and fumes from some munitions. Since it is a monitor, it can become saturated and must be cleared; it cannot give precise concentration readings, only relative readings.

### *Automatic Chemical Agent Alarm*

The Automatic Chemical Agent Alarm is an automatic detection and warning system designed to provide real-time detection of the presence of nerve agent vapors or inhalable aerosols. It consists of the detector, which is an ionization product diffusion/ion mobility-type detector and up to five alarms which will provide both an audible and a visible warning. It will give a false alarm when heavy concentrations of engine exhausts are present. The alarm usually is placed no more than 150 meters upwind from the perimeter of the area to be monitored.

### *Chemical Agent Water Testing Kit*

The Chemical Agent Water Testing Kit is designed to detect and provide colorimetric identification of hazardous levels of nerve, mustard, lewisite, and blood agents in treated or untreated water. A full kit contains enough supplies to perform 25 tests for each agent. About 20 minutes is required to perform all four tests. All bodily contact should be avoided with the kit chemicals, since some can be very harmful. Kit contents should be handled only by personnel wearing protective gloves and equipment.

### *Chemical Agent Detection Paper*

Chemical Agent Detection Paper comes on a single roll and has an adhesive-backed and coated tape which contains a suspension of an agent-sensitive dye in a green-colored paper matrix. It will turn pink, red, reddish-brown, or red-purple when exposed to hazardous chemical agents, but does not identify the specific agent. The paper also reacts to a wide range of interferents such as petroleum products, brake fluid, insect repellent, defoliant, and antifreeze. The paper is used by attaching strips to the individual overgarment and equipment.

### *Remote Sensing Chemical Agent Alarm*

The Remote Sensing Chemical Agent Alarm (also referred to as RASCAL) uses an automatic scanning, passive infrared (IR) sensor which detects nerve and blister agent clouds based on changes in the background IR spectrum caused by the presence of the agent vapor. The alarm scans a horizontal 60-degree arc and can recognize agent clouds at line-of-sight ranges of up to five kilometers. Normally, the alarm, placed looking into the wind, measures and stores a background spectrum which then is compared to contemporaneous readings by an onboard microcomputer. The computer decides whether an agent is present, based on ambient readings. Response time is one minute or less.

### *Automatic Chemical Agent Alarm*

The Automatic Chemical Agent Alarm is a portable, advanced point-sampling chemical agent alarm system that works on ion mobility spectroscopy. It detects standard blister and nerve agents, and is able to operate unattended after system startup. It provides audio and visual alarms and can be connected to a communications interface to provide warning to remote monitoring sites.

## *Biological Detection and Warning*

Biological detection and warning devices are similar in purpose to chemical detection and warning technologies; however, they are designed to alert users to the presence of harmful biological agents such as viruses and bacteria. The military has been working on these devices with limited success, because detection of biological agents is much more difficult than detection of chemicals.

### *Biological Integrated Detection System (BIDS)*

Meant for point detection, the Biological Integrated Detection System (BIDS) is composed of a lightweight multiple purpose shelter mounted on a high-mobility, multiple purpose wheeled vehicle. It is equipped with a biological detection suite which uses complementary technologies to detect large-area biological attacks. Within 15 to 30 minutes, the BIDS can detect and identify between five and 25 agent-containing particles per liter of air over the range of two to 10 microns. Some of the equipment in the detection suite are commercially available. These include a particle counter, particle sizer, and flow cytometry, as well as antibody-based identification devices. These combine to provide a warning of a distinct change in the normal atmosphere. The BIDS also includes sample preparation equipment, meteorological instruments, environmental control, and communications equipment. The features used in the biological arena by the BIDS network include basis for warning of a biological attack, a confirmation that a biological attack has occurred, a safety configured sample for laboratory analysis at a later time, and a basis for appropriate medical actions.

### *Integrated Virus Detection Systems*

The Integrated Virus Detection System detects viruses and virus-like materials in fluids, water, and the air. A breakthrough technology, the system has the capability to detect, identify, and give virus concentrations in approximately 15 minutes for all known viruses, without the use of complicated chemistry. The five main parts of the system are collection stage, separation stage, concentration stage, counting stage, and data reporting stage. The system is free of false positives associated with background material, and from false negatives associated with viruses that mutate, due to its ability to separate all the virus-like particles, count them, determine a concentration, and report this in relationship to other known virus particles.

### *Joint Biological Point Detection System*

The Joint Biological Point Detection System is being developed to detect and identify bacteria, viruses, and toxins by using an automated, fixed-air sampler and analyzer. The concept for the detection system includes a trigger to warn of the presence of biological material, a sample collector, a detector to announce the presence of the agent, and an identifier to label the specific agent.

## ***Decontamination***

The military has recognized the need to conduct field decontamination of its personnel, and has invested time and money in the development of technologies to accomplish this. The military has designed two different skin decontamination kits.

### *Skin Decontamination Kit*

The Skin Decontamination Kit is designed to neutralize and remove liquid chemical agents on the skin. It consists of three “number one” liquid packets and three “number two” liquid packets. The “number one” packets will neutralize G-series nerve agents by hydrolysis, and the “number two” packets will neutralize VX and mustard agents by oxidation. The contents of the kits are highly caustic, hence they should not be used for decontamination of wounds or near the eyes or mouth.

The second kit is a soft package consisting of two flexible pockets, each of which contains three decontamination packets. Each packet contains a black resin which is a mixture of a carbonaceous adsorbent, a polystyrene polymeric compound, and an ion exchange resin which is both reactive and adsorbent. The decontamination pad is made from a nonwoven fiberfill impregnated with the dry resin mixture. The decontamination is accomplished merely by opening the packet and scrubbing the skin surface with the applicator pad until an even coating of resin is achieved.

### *Lightweight Decontamination System*

This system is designed to draw water from any source and deliver it at pressures up to 100 psi and at temperatures up to 120° Fahrenheit to two installed spray wands. The system can be used to provided pressurized hot water before or after application of decontaiminant at regulated pressures and temperatures. It has a liquid soap siphon hose attachment for removal of mud, dirt, or grease which may have absorbed chemical agent. It has a 3,000-gallon collapsible water tank which can be prepositioned and filled for hot water showers.

## *Miscellaneous Equipment*

### *Biological Agent, Vaccines, and Toxoids*

A number of vaccines and toxoids have been used to protect military troops against a biological attack. For the most part, however, these must be administered in advance of an exposure. Licensed products are now available for anthrax, plague, and smallpox. Vaccines in an investigational status include Tularemia; Western, Eastern, and Venezuelan Equine Encephalomyelities vaccines; Q fever vaccine; Pentavalent Botulinun Toxoid vaccine; and Botulism Immune Globulin (Human). Some of these vaccines are in investigational status with the Food and Drug Administration (FDA) and require special administrative procedures for use. Several courses are offered to provide health care personnel with training in medical management of chemical and biological casualties. Some of these courses are presently available through CD-ROM and distance learning.

### *Mark I Nerve Agent Antidote Kit*

The military has developed an easily used nerve agent antidote kit that consists of two "autoinjectors" held together by a plastic clip. One autoinjector contains atropine, a well-recognized treatment for nerve agent poisoning. The second injector contains 2-pralidoxime chloride (2-PAM) which also provides therapy against nerve agent poisoning. These antidotes are either to be self-administered or given by "buddy-aid." The device is activated by removing the cap, placing the injector against the outer thigh, and pressing.

### *Patient Protective Wrap*

To protect a patient during evacuation, after protective garments have been removed and the patient has received medical treatment, the military has developed a patient protective wrap. A protective mask is not needed inside the wrap, but should be sent with the patient, who can remain in the wrap for up to six hours. The wrap is for one patient only. It weighs approximately six pounds and is constructed of a camouflage-pattern material similar to battle dress overgarments. The wrap has a continuous zipper along the outer edge for ease of patient insertion and a large transparent window in the top to view the patient or for him/her to see out. A pocket for medical records also is provided.

### *Robotic Helicopter*

A robotic helicopter may offer a new option for hazardous materials response teams. NASA and the U.S. Army have developed a remote-controlled helicopter that could be used for a wide range of tasks including hazardous spill inspection, fire surveillance, and emergency medical delivery. Called the Free Flight Rotorcraft Research Vehicle, the robotic helicopter can carry a movie camera, a still camera, video downlinks, night vision, or infrared cameras. The prototype helicopters are powered by a modified gasoline engine, are about six feet long including the rotor diameter, and can fly at speeds up to 60 mph.

### *Noninvasive, Noncontact Optrodes for Electrocardiography*

The military is researching a noninvasive, noncontact optical electrode (optrode) for determining a person's vital signs rapidly at or near the scene of battlefield trauma. In particular, a sensor is proposed that uses fiber optic and integrated optic technologies for rapid determination of an electrocardiogram (EKG). Heart rate also can be determined from the EKG signal. The fiber-optic-based EKG sensor (optrode) can be integrated within a suite of other small, low-powered, noncontact sensors supported by hand-held, PC-based computers. The sensor will process the EKG signal and communicate the information by a local area network embedded in the soldier's uniform. This information is transmitted to command and medical personnel who will be able to monitor the physiological threats to health and life of a soldier operating in a realistic field environment. The optrode consists of a miniature electro-optic crystal-based intensity modulator mounted at the end of an optical fiber. The optical interface uses the electro-optic effect to convert weak bioelectric potentials, produced at the skin surface, to measurable electrical signals. Common-mode rejection of unwanted electrical signals is provided by applying the outputs of the optrodes to remote differential amplifiers connected to conventional physiological recording devices interfaced to a personal computer.

This system would eliminate the need for time-consuming and troublesome electrode attachment and allow medical personnel to routinely monitor various important physiological parameters routinely. The system would allow for a wide spectrum of monitoring capabilities for patients outside of a hospital setting.

### *Noninvasive Hematocrit Monitor*

The military is currently in the animal testing stage of developing a high-precision, non-invasive technology for hematocrit monitoring.  A need exists to have an automated, continuous, and noninvasive method of measuring hematocrit directly on the patient as a way to gauge the blood loss in trauma victims and to evaluate the success of resuscitative efforts. The monitoring approach is based on near-infrared absorption and will provide a low-cost and man-portable device for rapid and accurate hematocrit measurement. The effort will be to develop a prototype instrument to be evaluated with human subjects. The instrument response will be calibrated against conventional capillary hematocrit measurements. The near-infrared device will be extremely valuable for measuring hematocrit in emergency situations such as the medical evaluation of combat casualties in the field, or accident victims in an ambulance or emergency room. The device should find a large market, since hematocrit is one of the most common blood tests used by physicians.  The proposed instrument will provide improved hematocrit measurement capabilities over current systems in the areas of improved accuracy/precision and portability.

### *Manportable Chemical and Biological Sensor*

The military is researching a rugged, solid-state laser-based, Manportable Chemical and Biological Sensor (MCBS) for the purpose of detecting biological and chemical warfare agents in the field. The MCBS will be capable of operating at a 50 Hz pulse repetition rate, will occupy less than 0.5 cubic foot in volume, and will have a weight of less than 20 pounds. The MCBS will be capable of simultaneous operation in the eyesafe (1.5-1.6 micron) band, and in the 8-12 micron band, and will have the capability of rapidly switching wavelengths within these bands at a 50 Hz, or greater, rate. The MCBS will provide topographical measurements out to several kilometer range, and will have a range capability of at least 8 kilometers for aerosol clouds.

### *Ambulatory Muscle Fatigue Monitor*

The military is designing a complete ambulatory muscle fatigue monitor that will use wireless telemetry and advanced signal processing techniques to allow researchers to record and monitor muscle fatigue in soldiers without the need to be tethered to a cumbersome electromyography (EMG) monitor. Fatigue is a phenomenon that accompanies repeated muscular exertion. The ability of the muscle to produce force is reduced as fatigue occurs. Local muscle fatigue is manifested in EMG signals by a shift in the EMG power spectrum from high to low frequencies. By using this phenomenon, it is possible to monitor local muscle fatigue in soldiers as they perform mission-related tasks. The device will be a small, lightweight, unobtrusive three-channel differential EMG amplifier/transmitter using proven wireless technology to digitize and transmit the EMG data to a PC-compatible computer for storage and data processing. The mean power frequency of the EMG signal will be calculated and used to indicate local muscle fatigue.

### *High-Impedance, Dry Physiological Recording Optrode*

This military project will develop a dry, high-impedance electrode for physiological monitoring in operational environments. In particular, a device is proposed that uses optical-fiber-based voltage-sensing technology to provide an optoelectronic interface to standard electrical recording devices. This optical-based-electrode (optrode) can be placed in contact with the skin and record physiological signals without requiring any special skin preparation. When placed in the helmet, a suite of such optrodes would provide the high-impedance, high-sensitivity interface needed to monitor the physiological status of various personnel, including aviators, in battlefield scenarios. The optrode consists of a miniature electro-optic-crystal-based intensity modulator mounted at the end of an optical fiber. The optical interface uses the electro-optic effect to convert weak bioelectric potentials, produced at the skin surface, to measurable electrical signals. Common-mode rejection of unwanted electrical signals is provided by applying the outputs of the optrodes to remote differential amplifiers connected to conventional physiological recording devices. Because the electro-optic crystal presents a very high impedance and very low capacitance, the optrode need not be in good physical contact with the head. Therefore, the points of contact can be dry. It should thus be feasible to obtain routine, real-time physiological recording with the minimum of setup time (the need for time-consuming and troublesome electrode attachment) and allow medical personnel to monitor various important physiological parameters routinely. The system would allow for a wide spectrum of monitoring capabilities for patients outside of a restrictive hospital setting.