NIOSH

# Personal Protective Equipment for Hazardous Materials Incidents:

## A SELECTION GUIDE

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

# PERSONAL PROTECTIVE EQUIPMENT FOR HAZARDOUS MATERIALS INCIDENTS: A SELECTION GUIDE

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A MAN IN ARMOR IS HIS ARMOR'S SLAVE.

Robert Browning

## ABSTRACT

Selection algorithms have been developed for respirators, protective clothing, and accessories for the protection of employees engaged in the control of hazardous materials incidents. These algorithms are based upon the environmental, physiological, chemical, and physical interaction of numerous factors which influence protective equipment performance.

Step-by-step guides are presented for the selection of respirators, chemical protective clothing, and ancillary equipment which comprise a PPE ensemble necessary to protect workers who encounter a hazardous material incident.

Methods of calculating tolerance times based upon heat stress are offered, as well as several methods of calculating protective equipment service life or duration.

Model training, administrative, and emergency programs are offered for adoption.



Key Words: Chemical protective clothing, Hazardous materials, Hazardous material incidents, Personal protective equipment, PPE, Respirators

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## INTRODUCTION

This document is intended to provide guidance in the selection of personal protective equipment (PPE) for use by individual workers and organizations involved in control and/or cleanup operations during hazardous materials incidents (emergencies).

## SCOPE

This guide is specifically intended for use by the individual responsible for planning a mission involving an individual or team effort to contain or clean up hazardous materials. Optimum use of this guide requires that time and circumstances permit the mission planner to make rational selections of required equipment; therefore, the selection guide is recommended for use under a limited set of conditions. These conditions are established in order to differentiate the selection and use of personal protective equipment for hazardous material incidents from the selection and use of protective equipment for routine exposures.

Specifically, the selection guide only addresses:

1) Acute exposures. The acuteness of the exposure contemplated by this guide is the cardinal element which distinguishes this approach from the more traditional techniques and philosophies of occupational health. Exposures of hours, days, or even weeks may be considered acute in this context, as long as these exposures are differentiated from the lifetime exposure concept of section 6(b)(5) of the OSH Act [1]. Employees with current acute exposures, fire fighters on hazardous materials teams or clean-up contractors for example, are specifically included.

2) Planned entry. This selection guide addresses those situations when entry into and escape from a hazardous material incident are on a planned basis; i.e., when adequate time is available for the rational selection of the appropriate personal protective equipment. Excluded are escape only situations in which process workers, for instance, are forced by a hazardous material incident to escape from their normal workplaces.

3) Emergency response or remedial action teams. This selection guide applies to those workers who are specifically employed and trained to provide remedial action in the event of a hazardous material incident. On site workers engaged in cleanup or remedial activities related to hazardous materials are also specifically included. Excluded are any off site workers, even those responsible for landfill or disposal operations.

4) Effective personal protective equipment programs. Effective personal protective equipment programs must exist in all the operations to which the selection guide is applied. No selection or use of personal protective equipment can be viewed as appropriate or safe in the absence of an effective program which includes criteria for:

1) material identification
2) environmental surveillance
3) medical surveillance
4) selection of equipment
5) training in and fitting of equipment
6) decontamination and cleaning
7) inspection, maintenance and storage
8) written program
9) program review and evaluation
10) operational use

A discussion of these 10 factors to consider in establishing a personal protective equipment program may be found in Appendix A.

## HAZARDOUS MATERIALS

Hazardous materials may be defined as any materials capable of causing an acute or chronic human illness or injury as result of an acute exposure. Such materials may exist as solids, liquids, vapors, or gases, and exhibit a plethora of toxicological, chemical, physical, radiological, or etiological properties that can be considered potentially hazardous to humans.

The use, handling, and disposition of hazardous materials is increasing [2]. Every year, the number of materials considered hazardous to humans grows larger [3]. Concurrently, the probability of incidents of uncontrolled release of hazardous materials increases. The threat always exists that hazardous materials may be released from control to the extent that real hazards to human health and safety exist.

## HAZARDOUS MATERIALS INCIDENTS

A release of hazardous materials to the extent that human exposure could result in acute or chronic injury or illness is known as a hazardous materials incident (HMI). Such an emergency can occur at any stage of hazardous materials processing, handling, transport, or disposal, as well as during periods of storage or waste containment. The release initiating a hazardous materials incident can be abrupt, such as an explosion, or gradual and over a long period of time, as through slow leakage, or leaching from a waste impoundment. Other typical modes of hazardous materials release are vessel ruptures, spills, fires, and transportation accidents.

## SCOPE OF HAZARDOUS MATERIALS PROBLEM

Estimates of waste sites containing hazardous materials range as high as 32,254 to 50,664 with some 1,200 to 2,000 posing significant problems [4]. A more conservative estimate is 4,802 sites, with 431 considered potentially hazardous [4]. The Environmental Protection Agency (EPA) has recently announced a cleanup priority list of 418 U.S. sites [5].

Manpower estimates likewise vary considerably, but a conservative estimate is that more than one million people are potentially exposed to hazardous materials incidents as members of active emergency services (200,000 as paid firefighters [6]; 500,000 as volunteer firefighters; and 300,000 as law enforcement officers). Additionally, scores of hazardous materials handling and cleanup companies employ hundreds to thousands of full-time employees and numerous part-time employees.

NIOSH estimates that 1,400 people were injured in hazardous materials transportation incidents in 1978, and that 45 died from their injuries [7]. National Safety Council figures for 1980 indicate that 3,358 deaths from hazardous materials accidents (other than drugs and medicaments) occurred in all categories of poisoning, ignition of highly flammable materials, explosive materials, and radiation [8]. We are unable to state how many of these deaths could have involved hazardous materials incidents as defined above, or how many might have been prevented by the proposed PPE selection and use guidelines offered herein. It should be recognized that these deaths attributed to hazardous materials exceeded all deaths attributed to surgical and medical complications and misadventures, and far more than those attributed to poisoning by drugs and medicaments [8].

## HAZARDOUS MATERIALS CONTROL TECHNOLOGY

Hazardous materials control technologies in current use are inadequate to protect the group of workers who are occupationally exposed during hazardous materials incidents [9]. Those workers involved in emergency response, investigation, and cleanup, such as fire-fighters on hazardous materials teams or employees of cleanup contractors, are the focus of Federal government interagency efforts to develop effective hazardous materials control programs [10].

Currently available control technology for hazardous materials incidents is based upon traditional industrial safety and health procedures and fails to consider the unique, dynamic, evolving, and interactive elements of an emergency situation [9].

The traditional industrial approach proceeds from the identification (recognition) of the hazardous material(s) to environmental surveillance (evaluation). Then, based upon the surveillance, recommendation of personal protective equipment, for control purposes, is made. This procedure is the basis for most current hazardous materials incidents control systems, such as:

- o NIOSH/OSHA "Occupational Health Guidelines for Chemical Hazards," (1981) [11]
- o Department of Transportation (DOT) "Hazardous Materials, Emergency Response Guidebook," (1980) [12]
- o EPA "Hazardous Materials Spill Monitoring: Safety Handbook and Chemical Hazard Guide," (1979) [13]
- o USCG "Chemical Hazard Response Information System," (1978) [14]
- o NFPA "Fire Protection Guide on Hazardous Materials," (1978) [15].

Unfortunately, the weakest link of this chain of procedures (materials identification, environmental surveillance, and PPE selection), the identification of the hazardous material(s), is also the most critical. Specific recommendations regarding methods of environmental surveillance and selection of PPE are retrievable only by substance name [11-15]. Currently, there is no comprehensive materials identification scheme in practice.

In the identification of hazardous materials, the following three scenarios are probable:

1) Material identification can be made easily on site, and a traditional industrial hygiene protective program can be used.

2) Material cannot be identified on site, but a broad useful classification can be made based upon chemical and physical properties; e.g., inorganic acids, amines, or ketones.

3) Material cannot be identified on site and no useful classification can be made. Protection is selected by assuming anything and everything is present in toxic concentrations and eliminating (by chemical tests) those substances or conditions for which the predetermined protective program is ineffective.

The first scenario suggests an in-process spill, where ready identification is probable, or an incident involving a single substance which is clearly labeled or otherwise identifiable. As material moves further along the process chain toward ultimate disposal, and as additional, perhaps uninitiated workers become involved with its handling, the necessity for field identification and characterization increases. At a hazardous waste site, where all material identification may be erased by time, complete reliance on chemical and physical analysis for identification may be necessary. Materials identification may be further confounded by the potential mixture of different hazardous substances. It is unfortunate that no comprehensive system exists by which PPE constructed from appropriate materials may be selected for protection against specific hazardous substances. Thus organizations purchase chemical protective clothing (CPC) before being required to respond to a hazardous materials incident. This is compounded by the fact that testing methods currently used in environmental evaluation do not ensure against suit failure due to penetration by a substance which cannot be successfully identified prior to exposure.

For example, if a volunteer fire department purchases two chemical protective suits of Saranex/Tyvek composite, no current system will tell them that identification and quantification of toluene is required [16], or that the detector tube set they carry may have difficulty distinguishing toluene from kerosene [17], or why this is important (because toluene rapidly penetrates the suit, kerosene doesn't).

Labeling and placarding of materials containers and transporters have not proven to be effective means of ensuring hazardous materials identification in the event of emergency. One study of trucks used to transport such hazardous materials revealed that 40% were not placarded when they should have been, or were incorrectly placarded [18].

Even if correct marking is effected by the recently adopted DOT system (effective in November 1981), the DOT "Hazardous Materials, Emergency Response Guidebook" [12] must be consulted to identify the substance, and a second or third source is necessary to determine what type of PPE and what methods of environmental surveillance are recommended [11].

## PERSONAL PROTECTIVE EQUIPMENT

In 1981, the National Institute for Occupational Safety and Health (NIOSH) developed a safety profile of hazardous materials incident control which identifies seven areas for possible NIOSH investigation and action:

1) materials identification
2) environmental surveillance
3) medical surveillance
4) operations
5) personal protective equipment
6) fire and spill control
7) contamination control [19].

Of the seven areas, personal protective equipment was selected for initial development.

The purpose of personal protective equipment (suits, gloves, boots, respirators, etc.) is to prevent illness or injury to the wearer by reducing contact with the hazardous material(s) to the extent that exposure remains within safe limits. No one piece of protective equipment is capable of providing protection against all threats; neither is any ensemble omnifarious in its protection. In fact, no protective equipment is capable of providing absolute protection against even one threat, or for prolonged periods of time at a given level of threat. In light of these limitations, the object of any PPE program development must be to enhance, to the greatest extent possible, wearer protection from environmental threats (such as hazardous materials), as well as from injury which could result from incorrect use or the malfunction of PPE.

Hazardous materials control personnel must be aware of less obvious and perhaps more critical dangers, in the use of PPE, than the substances to be encountered.

For example, vapor barrier protective clothing used by workers during hazardous materials incidents can prevent evaporation of sweat [20-22], the primary means the body has of dissipating excess metabolic heat [23-25]. Metabolic heat must be stored in the body if not transferred, creating the threat of heat injury [25-29]. The effects of heat stress can substantially alter the length of time (duration) a hazardous materials worker can continue working [29]. Therefore, this internal threat to worker safety can, in some instances, be a greater threat than potential exposure to the substance involved. Most existing hazardous materials control measures do not adequately address the complex, interactive, and evolving system formed by hazardous materials, PPE, and the hazardous materials worker. It is not enough to know that a worker has 30 minutes of air supply, or a specific duration (say 45 minutes) of protection before a substance permeates his protective suit and invades his body, if he suffers a debilitating heat stress 20 minutes into the mission due to metabolic heat buildup.

The selection and use of PPE was chosen for initial development because more usable information is currently available on the subject than, for example, materials identification. Further, such human physiological factors as metabolic heat buildup and acclimatization are critical in terms of mission duration and heat injury.

Selection of PPE for hazardous material incidents involves the balancing of several dozen competing factors all of which must be considered if a rational selection is to be made. These factors are briefly discussed in Part I of this document, which presents a description of PPE components, as well as discussion of the ensemble, environmental, human, and mission factors that influence the selection of PPE for use during hazardous materials incidents.

Part II presents a step-by-step decision logic for selection of respirators, protective suits, and ancillary equipment. In this section a series of structured questions are asked. The specific questions and the order in which they are asked are dependent upon the preceeding answers. Part III provides a worksheet for estimating the air/oxygen supply and the amount of cooling capacity required based on a specific task, and the environmental and human factors which are anticipated for a given mission. Detailed worksheet instructions and look-up tables are provided to be used in completing the calculations.

This document also contains appendices addressing the establishment of a PPE program (Appendix A) and an emergency rescue program (Appendix B). The culmination is the selection of the appropriate PPE for a given set of conditions.

## Part I: PPE SELECTION FACTORS

### A. COMPONENT FACTORS

### 1. Respirators

Respiratory protective equipment or respirators used in hazardous materials incidents fall into one of three classifications which depend upon the method of supplying respirable air to the facepiece or hood of the respirator.

#### a. Air-purifying respirators

Air-purifying respirators use a filter, sorbent, or combination of filter and sorbent to remove the airborne contaminants from otherwise respirable air [30]. Their use, of course, assumes that there is sufficient oxygen in the ambient atmosphere to support life at high workrates [30]. Since the sorbent materials used in respirators cartridges or canisters operate upon chemical and/or physical mechanisms, they are quite selective in their capacity to absorb or otherwise retain specific materials [31]. Thus, their efficiencies vary considerably, even for closely related materials [31]. The temperature, relative humidity, concentration, and workrate all affect the duration for which the sorbents may effectively remove a specific contaminant from the air [31]. Selection of air-purifying respirators for hazardous material incidents must be based upon a complete and thorough understanding of all factors involved. The mission to be performed, its duration, and the anticipated workrate are all factors which influence the duration of effective respiratory protection when using air-purifying respirators [31].

The most fundamental factor in the selection of an air-purifying respirator is the substance, specifically its chemical identity, which is to be removed from the ambient atmosphere [31]. Current NIOSH approval practice for air-purifying respirators for organic vapors is based upon the use of a single challenge substance, carbon tetrachloride, at a given temperature and over a narrow range of flowrates and relative humidities [32]. The assumption that a cartridge determined to be efficient against carbon tetrachloride will be efficient againct another substance is unwarranted [31]. Therefore, only a moderate degree of confidence can be established for the efficiency of the respirator against a single substance, i.e., carbon tetrachloride. Additional specific approvals are available for materials such as formaldahyde, methyl iodide, ammonia, monomethylamine, hydrogen chloride, chlorine, and sulfur dioxide [33]. Special approvals have been granted to certain respirators for use against vinyl chloride under carefully controlled conditions [33].

Sorbent efficiency studies of equivalent validity can be used to extend the use of air-purifying respirators beyond those few substances which NIOSH tests.

Another series of air-purifying respirators suitable for use against carbon monoxide operates by catalyzing the reaction of carbon monoxide to carbon dioxide [34]. This is a highly specific reaction and while the material used as the catalyst has an affinity for some acid gases and organic vapors, they are not tested nor approved for use against substances other than carbon monoxide [33].

Certain gas mask canisters previously called "all service," "universal," "type N" or "all purpose," are universal only in the sense that the canisters contain layers of the different sorbents commonly used in the individually approved canisters [34]. Even when canisters or cartridges are approved by NIOSH/MSHA for more than one substance, the canisters or cartridges are tested independently against a single substance. For example, an organic vapor and acid gas canister which is approved for organic vapors and hydrogen chloride will be tested against carbon tetrachloride, and another, new canister will be tested against hydrogen chloride [32]. No tests are made against both substances in combination or in the same canister with the substances challenging the canister sequentially [32]. That is, a canister which in NIOSH testing lasts 12 minutes against hydrogen chloride at 2% concentration under the specific flowrates, temperatures and humidities of the test may not last 12 minutes in a combination of hydrogen chloride and sulfur dioxide equivalent to 2% by volume. Likewise, the challenge of the canister with 2% of hydrogen chloride for 6 minutes followed by a subsequent challenge to the canister with 2% of sulfur dioxide for an additional 6 minutes does not necessarily result in the protection of the wearer against this combination for 12 minutes. The selection of air-purifying respirators for use during hazardous material incidents would, therefore, require a thorough characterization of the conditions of use including, but not limited to: the specific contaminant or contaminants and their interaction, the concentration or concentrations, the anticipated workrates, the flowrates, the temperatures, and the relative humidities. If all of these factors match the test conditions under which the sorbents were tested and a high degree of confidence, bordering on absolute certainty, indicate that conditions will not change, then air-purifying respirators can have some utility in protection against hazardous material incidents. If, however, as is most ordinarily the case, the substance or substances are unknown <u>or</u> their interactions are unknown, <u>or</u> the use conditions differ from those of the sorbent testing, <u>or</u> conditions are anticipated to change suddenly and without warning, <u>or</u> situations involving inadequate oxygen may occur, <u>then</u> the use of the air-purifying respirators based upon extrapolations from the test data is totally unwarranted [31].

b. Supplied air respirators

The second class of respirators commonly used in hazardous material incidents, the supplied air respirators, derived their name from the fact that air, never oxygen [35], is supplied to the wearer from some source, usually a compressor or bank of compressed air cylinders at some distance from the wearer's workstation. Current NIOSH approval requirements limit the length of supplied air hose to 300 feet [36]. This does not preclude, however, the location of the compressor or cylinder bank more than 300 feet from the workstation with the use of auxiliary piping or hose. The use of air compressors drawing from the ambient air at hazardous materials incidents is severely limited by the same constraints of air purification as are imposed upon air-purifying respirators. Concentrations of hazardous materials, which must be removed from the ambient air before it can be delivered to the wearer of a supplied air respirator, may be found 300 feet, 300 yards, or even 3 miles from the worksite. For this reason on-site air compression for respiration or suit cooling is recommended only in those situations in which the contaminant can be either readily removed by sorbents in the air purification system of the compressor, or, can otherwise be prevented from reaching the air intake of the compression system [37]. Therefore, air compressor based supplied air respirators have little utility in most hazardous materials incidents.

Supplied air respirators suitable for use with compressed air from cylinders are classified as Type C supplied air respirators [38]. They are further divided into three subtypes depending upon mode of operation [39]. The first subtype, the continuous flow respirator, is as the name implies, one that continuously flows breathing air into the facepiece, helmet, or hood worn by the wearer. Since the supply of compressed breathing air in the cylinder is limited and relatively expensive, the use of Type C continuous flow respirators cannot be recommended. The other two classes, demand and pressure demand respirators, are basically demand respirators; that is, the flow of air only occurs on the inhalation demand of the wearer.

They differ, however, in that the first type, the demand respirator, creates a negative pressure in the facepiece during inhalation [40], and in the event of a facepiece or face seal leakage, may draw contaminated atmosphere into the wearer's breathing zone [41]. A pressure demand respirator, on the other hand, should maintain a slight positive pressure in the facepiece during both inhalation and exhalation at moderate workrates [42], and the amount of leakage through the faceseal or facepiece is negligible [41]. For these reasons, of the 3 types of supplied air respirators, only the Type C, pressure demand type, is considered suitable for use in hazardous materials incidents.

Selection of pressure demand supplied air respirators is contingent upon several environmental and work factors, one of the most important of which is the required mobility of the worker. Since the cylinders employed weigh up to 165 pounds, they tend to be regarded as fixed objects around which the 300 foot scope of the maximum permissible air hose may be deployed. The air hose itself creates a difficulty in mobility, not only from the weight and friction of dragging it along the ground but due to the fact that it requires the worker to retrace his steps to leave the work area. When working around multiple drums or tanks, climbing ladders, or moving in and out of doorways, this becomes a sufficiently serious problem to practically preclude the use of these respirators.

The respirator air line or hose is not tested for permeation against any substance other than gasoline [36] and may, while standing in puddles of spilled material, be permeated by the material thus contaminating the wearer's air supply.

The one feature which most mitigates against their use in hazardous material incidents is the fact that they are totally dependent upon the remote air supply. In the event of air supply depletion, failure of the air hose, or failure of the respirator, there are no provisions for respiratory protection during escape [34]. For this reason NIOSH does not approve the use of these devices for entry into or escape from an atmosphere which may be immediately dangerous to life or health [43]. This classification would include most, if not all, hazardous material incident locations during emergency operations [44].

When the pressure demand supplied air respirator is combined with a small escape cylinder of air to become a combination self-contained breathing apparatus/supplied air respirator, the disadvantage of relying upon the fixed air supply can be largely relieved [45]. This combination offers several advantages, the first of course being the escape capability [45]. Secondly, under some circumstances, the wearer may use some of the air supply which is self-contained to enter into and depart from his work station to reach his air supply point [45]. This is particularly advantageous when a contaminated zone must be traversed in order to reach the site where the air supply hookup for the supplied air respirator will be used.

c. Self-contained breathing apparatus

The third class of respirator which is commonly used in hazardous material incidents is a self-contained breathing apparatus. This device, as the name implies, utilizes a source of respirable air or oxygen carried by the wearer [46]. While this greatly enchances the mobility of the wearer, it does dramatically limit the duration of respiratory protection. The devices commonly worn in hazardous material incidents range from a 30 minute to a 60 minute rated duration at a moderate workrate of approximately 40 liter minute volume [33]. Self-contained breathing apparatus may be approved by NIOSH/MSHA either for entry into and escape from a hazardous atmosphere or for escape only [46].

The escape only apparatus are designed to be light weight, easily carried, and of limited duration [47]. They may not contain all of the necessary safety features required for devices approved as entry and escape units [47]. The rationalization of these deficiencies is a trade-off between light weight and high mobility and a high degree of dependability. Therefore, in the design of these units, desirable safety features such as redundant regulators [48], gas pressure or liquid volume/measuring devices [49, 50], and low pressure or volume warning devices, are ommitted as a trade-off for light weight and low bulk. Escape only apparatus have little application in hazardous materials incidents except as a backup device for use by rescue teams to replace the breathing apparatus of a victim in the event that the victim's apparatus fails or runs out of air. Some people have recommended a combined used of escape self-contained breathing apparatus and air-purifying respirators, the thought being that the air-purifying respirator could be used for routine operations and the escape self-contained breathing apparatus could be donned in the event that an emergency situation arose [51]. As we have seen previously, the air-purifying respirators are not suitable for the overwhelming majority of hazardous materials incidents and the selection of this combination, which may in fact exceed the weight of a properly designed self-contained breathing apparatus, is hence usually irrational.

Self-contained breathing apparatus for entry into and escape from a hazardous material incident are available in two basic design types [46]. The first, an open circuit self-contained breathing apparatus, is so named because the exhaled air containing a relatively high concentration of carbon dioxide and a lowered concentration of oxygen is exhaled directly to the outside atmosphere [52].

In contrast, in closed circuit breathing apparatus, this exhaled air is recycled by removing the carbon dioxide with some form of alkaline scrubber and by replenishing the oxygen with either liquid oxygen, gaseous oxygen, or by some oxygen-generating chemical [53].

The common open circuit self-contained breathing apparatus operated in pressure demand mode is useful in hazardous material incidents, providing duration of from 30 minutes to 1 hour at the moderate workrate of 40 liter minute volume [33]. Although these 30 minute to 1 hour rated units weigh up to 35 pounds [54], they provide the ultimate protection currently available [41].

Closed circuit breathing apparatus may have durations ranging from 15 minutes to 4 hours but only 30 minutes to 2 hours in units which maintain a positive facepiece pressure at moderate workrates [33].

Closed circuit apparatus are generally much lighter than an equally rated duration open circuit apparatus, since the exhaled oxygen and nitrogen are combined with a small amount of makeup oxygen and are recycled back to the user [53]. There are two major disadvantages of closed circuit breathing apparatus:

1) They are oxygen based and in the event of relief valve operation or faceseal leakage may fill the suit with several liters or more of oxygen. In the event of flame impingement, this could prove disasterous to the wearer of the suit [55].

2) The second and most important disadvantage is that by its very nature the closed circuit apparatus in conserving oxygen also conserves the heat normally exchanged in exhalation [56]. In addition the scrubber material to remove carbon dioxide from the exhaled breath also generates a significant amount of heat [56]. In total, approximately two to three kilocalories per minute are generated (or retained) by the breathing apparatus [56]. When this device is worn under the suit in the Type A configuration without adequate additional cooling, the heat dissipation is virtually nil and the wearer must retain not only the metabolic heat output normally exchanged in respiration but an additional one to two kilocalories per minute generated by the scrubber. It's for this reason that closed circuit self-contained apparatus are not recommended for use in Type A configurations without an auxiliary cooling device capable of removing not only the metabolic but the breathing apparatus generated heat. Type B configurations in which the closed circuit apparatus is worn outside the suit usually allow for adequate heat dissipation from the respirator itself. Due to the possibility of having a rated duration longer than 30 minutes, however, additional cooling may be required to remove the metabolic heat produced.

The closed circuit breathing apparatus worn in an outside-the-suit configuration offers one additional disadvantage which is not common with the open circuit breathing apparatus, that of possible permeation through the breathing bag [57]. This bag, with a minimum capacity of 5-6 liters, is only tested for permeation to gasoline and may provide a mechanism for contamination of the breathing apparatus and the breathing air if permeation of the exposed bag takes place [57].

## 2. Chemical Protective Clothing

### a. Fully encapsulating suits

Fully encapsulating suits are one-piece garments which provide chemical protection for the entire body [58]. Boots and gloves may be integral, attached and replaceable, or separate [58].

These suits may utilize a separate, supplied air respirator or self-contained breathing apparatus, a combination supplied air respirator/self-contained breathing apparatus, or be supplied air directly as an air supplied suit. In any case, they are intended to provide an integrated, sealed microenvironment which cannot be entered by a contaminant in any form or state.

Fully encapsulating suits (not fully encapsulated) are also called "moon suits," "level A suits," or "acid suits" depending upon the particular jargon of the group using them.

b. Non encapsulating suits

Non encapsulating suits, which commonly consist of a jacket and hood in combination with a pair of pants or bib overalls made from paper thin unwoven fabric to full butyl, are frequently used when gas tight body protection is not required [59]. Many workers feel that these two-piece suits are more comfortable than fully encapsulating suits. Studies have indicated that the degree of cooling allowed by the two-piece suit is not significantly greater than that of a fully encapsulating suit and, therefore, much of the increased wearer comfort may be attributible solely to psychological factors or decreased encumbrance [60].

Non encapsulating suits can provide excellent protection against splashes, dust, and other materials which cannot migrate between the overlaps of the various layers. Usually when these suits are worn in the field, connection between the pant cuff and the boot and between the glove and the sleeve will be tape sealed [59].

c. Aprons

Since many operations such as sampling, labeling, or analysis may focus the primary exposure of the worker on the chest and forearms, fully sleeved and gloved aprons are commonly used over light weight non encapsulating clothing to provide additional splash protection [51]. When compared with a fully encapsulating suit of similar material and thickness, the sleeved apron can provide for considerably less heat stress and, hence, more comfort since the back of the apron or more than 50% of the body area is exposed. Of course if the non fully encapsulating suit worn underneath is also impermeable to body moisture then this cooling advantage is lost. Sleeved aprons, when worn with disposable gloves or worn with overgloves, can be quite useful when quantities which may be splashed are small, localized, and the possibility of total body contact is minimal.

d. Specialized protective equipment

Specialized protective equipment is equipment which, while not normally designed for protection against hazardous materials, is commonly used in hazardous materials incidents. Such equipment may be used either in the absence of chemical protective clothing or to supplement chemical protective clothing.

(1) Fire fighter's protective clothing

The most common specialized protective equipment used on a hazardous material incident is the structural firefighter's protective clothing. This clothing normally consists of a helmet, (NFPA standard 1972-1979) [61], a running or bunker coat and running or bunker pants, (NFPA standard 1971-1981) [62], boots, gloves, and a self-contained breathing apparatus. The NFPA standard 1971-1981 for firefighters protective clothing [62] specifies a three-piece garment consisting of an outer shell, an inner liner, and an intermediate vapor barrier. Only the vapor barrier offers any barrier to the transmission of gases, vapors, or liquids. The standard requires that it have a minimum water penetration of 25 psi which is adequate to prevent the passage of hot water or steam. Common vapor barrier materials are neoprene, coated duck, or GOR-TEX (TM), a semi-permeable membrane impervious to liquids but permeable to vapor. Firefighters protective clothing is not designed to nor does it provide adequate protection against chemical permeation or degradation [63]. It may offer limited protection against solid materials and liquids but no protection against gases or vapors [63]. Due to the construction and porosity of the outer shell, decontamination of the garments would be quite difficult. Therefore, firefighters protective clothing alone should not be worn in areas where protection against chemical splashes or permeation is required. In most situations, it does offer adequate protection against conductive and convective heat, steam, hot water, particles, and the ordinary hazards of fire fighting [62].

(2) Proximity or approach garments

Another type of specialized gear is that providing protection against radiant heat exposures. These garments variously labeled proximity suits or approach suits consist of a one or two piece over-garment with hood, gloves, and occasionally boot covers of an aluminized nylon or cotton fabric [64]. They are normally worn over other protective clothing such as firefighter's bunker gear, flame retardant coveralls, or, in one case, chemical protective clothing of a Type A configuration. This particular ensemble would normally be employed in a hazardous materials incident for short term radiant heat exposure, such as would occur while closing a valve, stopping a leak, or firefighting in the presence of a flammable or combustible liquid fire. In most instances these will be worn without auxiliary cooling garments and may for some firefighting operations be worn without protective breathing apparatus [64]. However, if exposure to a toxic atmosphere or prolonged use for more than 2 or 3 minutes is envisioned, then both the cooling garment and appropriate self-contained breathing apparatus are required [65]. These garments would offer little if any protection against chemical permeation or degradation but may provide some protection against minor splashes. When used in conjunction with chemical protective clothing, particularly a Type A suit, both a self-contained breathing apparatus and auxiliary cooling are required for any use [65].

(3) Flotation gear

Work over or around water can create the problem of providing additional flotation in the event that the worker wearing chemical protective clothing should fall into the water. Several ad hoc studies have been conducted of the flotation properties of fully encapsulating and non fully encapsulating suits [66, 67]. In neither instance are the results sufficiently conclusive to allow one to disregard the provision of additional flotation. The bibs and taped-on boots of a non encapsulating suit can be inflated with air to form water wings to allow limited flotation [66]. Depending upon the location and configuration of vents in Type A suits these may also provide flotation. Most Type A suits have the exhaust vents in the back at about shoulder level [68]. As long as these vents are immersed under sufficient hydrostatic pressure to prevent air leakage, air entrained in the suit with open circuit self-contained breathing apparatus exhalations can provide significant flotation. If, however, the wearer is floating with the vents upward, hydrostatic pressure will squeeze the suit virtually air free encapsulating the wearer and providing little buoyancy. Life jackets or work vests can add from between 15 1/2 to 25 pounds of buoyancy which is not subject to compromise by attitude [69]. They do, however, provide additional bulk and restrictions of mobility. If used they should be worn underneath the chemical protective clothing to provide them some protection from degradation. Self-contained breathing apparatus do not provide adequate buoyancy to compensate for their increased weight to the wearer. Neither closed circuit nor open circuit breathing apparatus can be expected to perform adequately under water [70]. Certain open circuit breathing apparatus with mask-mounted regulators may provide some protection in shallow depths [70]. The manufacturer of each apparatus should be contacted for the recommendations in the event that the wearer of their self-contained breathing apparatus is submerged.

(4) Blast and fragmentation suits

Hazardous material incidents involving potentially explosive materials pose a unique problem in the selection and use of personal protective equipment. There is no available ensemble which provides adequate protection against blast and fragmentation for more than a minute quantity of explosive material at distances less than about 20 feet [71]. At normal working distances of 3 to 6 feet wearers of currently available blast or fragmentation vests and clothing will receive some protection against both blast and/or fragmentation; however, they should expect injury in the event of detonation of more than a couple of ounces TNT equivalent material [71]. Bomb blankets which reduce fragmentation and help to direct blast may provide some additional protection [71]. Bomb carriers or baskets which redirect the blast afford even greater protection. However, with materials of more than about 1/4 of a pound TNT equivalent, the wearer cannot expect to remain uninjured at distances of less than 10 feet [72]. In confined spaces or when the wearer is interposed between a reflecting surface and the blast, safe distances may have to be doubled [72].

(5) Anti-radiation suits

Personal protection equipment for protection against ionizing radiation, such as anti-contamination (or anti-C) suits offer little in the way of protection against radiation [73]. Rather, the equipment is designed to prevent the ingestion or inhalation of radioactive materials contained on particulates or to prevent skin contamination with these particulates [73]. Actual attenuation of radiation is seldom attempted with protective clothing. Lead-containing rubber garments such as gloves, aprons, boots, and pants are available commercially, but their selection should be based upon a full evaluation by a competent health physicist for each and every application [73].

(6) Cooling garments

Because of the heat stress and reduced tolerance incurred during the wearing of personal protective equipment, various types of personal cooling devices have been designed in an attempt to improve worker performance. These devices provide either total or partial body cooling through the use of a circulating gas or liquid.

Many applications of protective clothing may benefit from the use of an additional auxiliary cooling system depending on the relative capabilities of the system. The cooling provided has the potential to not only remove heat generated by metabolism but also environmental heat and heat generated by other portions of the protective equipment (such as a closed circuit self-contained breathing apparatus).

Basically there are three types of cooling garments commonly in use. The first relies upon evaporative cooling by circulating cool dry air throughout the suit or portions of the suit [74]. Cooling may be enhanced by the use of a vortex cooler or by refrigeration coils and a heat exchanger. Commonly these devices require between

10 and 25 cubic feet per minute of respirable air and are therefore uneconomical for use in most hazardous material incidents [74]. If, however, tremendous quantities of clean respirable air can be economically made available, then they do serve a purpose in economically, if noisily, cooling exposed workers.

Air supplies for cooling or for respiration should meet the air quality standards of the Compressed Gas Association's Commodity Specification for Air, CGA 7.1 (ANSI Z86) for at least Type I Grade D air. This limits the amount of carbon monoxide, hydrocarbons, carbon dioxide, oxygen, and odor that the air may contain.

These contaminants may enter the air supply if a compressor is used to compress the air. Oil lubrication and its subsequent breakdown by heat of compression can introduce all of these contaminants, among others. For this reason, it is imperative that the compressor installation meet the applicable requirements of 29 CFR 1910.134 (d)(2)(ii). Contamination of breathing air may also occur from contaminated ambient air used by the compressor. On-site filtration and purification of the large quantities of contaminated air required by air cooling is seldom feasible.

Control of water vapor is important since cooling will be mostly evaporative. If the incoming air is highly humid, it may condense in the vortex cooler adding condensed water to the system and raising the relative humidity of the "cooling air" to 100%, effectively reducing evaporative cooling. Breathing air which is quite dry, if used with a facepiece for prolonged periods, can be irritating by drying the nose and mouth.

The use of compressed air (never oxygen) from cylinders may be the only feasible source of cooling air. If two or more large (240-300 SCF) cylinders are manifolded together with "one-way" check valves, then a 2-man team could be supplied for at least 8 minutes at maximum flows. The air supply duration might be longer if more cylinders are provided, or if lower flow vortex coolers or cooling without vortex coolers is used.

The second type of cooling device consists of a jacket or vest which contains multiple pockets for the insertion of packets of water ice [75]. This conductive cooling device can be quite effective. However, it does pose problems of storing and recharging the device in the field. The third device consists of a water ice reservoir and circulating tubes with a small battery powered pump which circulates chilled water throughout the tubing [76]. The tubing may cover any part of the body, most usually, the upper torso. This device, while requiring battery power and the weight of a pump, does have the distinct advantage of allowing recharging in the field simply by adding additional ice and draining off the melted water, or by replacing cold blocks in an external heat exchanger.

Opinions differ as to the relative efficacy of these three cooling devices. Recent studies conducted for the military which are yet unpublished indicate that water ice cooling devices may be only about 10-20% efficient in reducing core temperature. That is, 5 to 10 times as much water ice will have to be melted to sorb heat from the body as calculations would indicate.

If adequately sized and operated under the conditions for which they are suited, each of these devices can provide significant cooling and enhance comfort of the exposed worker. The choice of cooling capacity and type is dependent upon a host of factors including the metabolic rate of the wearer, ambient temperatures, radiation, imposed heat load by closed circuit breathing apparatus, and the availability of an adequate compressed air supply, or the availability of refreezing devices for the vest or of cubed or chipped ice for the recirculating water devices.

Early prototypes were air ventilated, vortex, or pressurized suits. Although these suits were useful in providing cooling, there were several major disadvantages associated with their use. Liquid-cooled garments and ice vests, allowing increased mobility and greater potential for heat removal, were subsequently developed to overcome some of the deficiencies of the air ventilated garments [77, 78].

The effectiveness of personal cooling devices will depend somewhat upon the particular model and style selected, as well as the actual conditions under which it is used [22, 79, 80]. During extended use or severe exposure, such garments have been shown to be effective in reducing signs of heat stress both at rest and during work [22, 75, 80-89]. Significant reductions are generally observed in rectal temperature, sweat rate, heart rate, and skin temperature [89]. Improved psychological benefits, subjective perceptions, and enhanced performance on mental tasks have also been shown to occur [86].

Therefore, cooling systems appear to be useful in reducing heat strain to the individual during prolonged work or severe thermal exposure. For short exposures with light thermal loads, cooling systems may not be essential.

e. Other protective components

(1) Helmets

Most of the fully encapsulating and non fully encapsulating suits allow for the use of protective helmets but some of the supplied air respirators may be incompatible with the use of such helmets [33]. Determination of the need for head protection from low velocity impact on the top of the head from a falling object should be determined before use of a suit or configuration which precludes the use of a helmet is adopted. Where operations may include fire fighting, rescue or other emergency situations, the use of head protection is mandatory.

(2) Gloves

Many manufacturers of chemical protective gloves offer selection guides for their products which are primarily based upon the degradation of the product by various hazardous materials [90]. Few go into other selection criteria which may be of equal importance, such as glove permeation, flexibility, resistance to mechanical damage from abrasion, puncture, laceration, or from physical agents such as ultraviolet radiation, cold, excessive heat, or flame impingements [90]. Since the hands and the feet usually come into the most prolonged and intimate contact with the hazardous material, flexibility in the selection and use of gloves should be maintained where practical. That is, if a fully encapsulating suit or gloved and sleeved apron is worn, provisions may also be made for the use of overgloves which can provide supplemental protection or, at the very least, provide some measure of protection of the more expensive undergarment from abrasions, tears, and similar physical insults.

(3) Boots

The prime chemical protection for the foot is a chemical resistant boot when used as part of a non-encapsulating suit. The usual foot extension of a fully encapsulating suit worn under a boot serves this purpose when such a suit is worn. For ease of decontamination and for limited chemical protection, light weight latex or plastic overbooties may be worn over the regular boot.

Additional protection may be offered by boots with toe caps, for protection against crushing, and puncture resistant inner soles. Chemically resistant boots can be obtained with these features or, less desirably, the toe protection can be provided by laced on toe caps and the puncture resistance provided by slip-in inner soles. Many boots are sold with labels indicating that they meet the relevant ANSI standard ANSI Z41.1 [91]. This standard classified the impact and compression resistance of shoes into several classifications, with the highest number providing the most protection.

f. Accessories

Several pieces of accessory equipment are required to complete the ensemble and provide that additional safety and convenience which the wearer has every right to expect.

The first of these is a knife, which is commonly carried by wearers of fully encapsulated suits to be used in the event they must hack their way out of the suit due to equipment failure [92]. Commonly carried is a skin diver's double edged knife or similar sheath or hunting knife with a 4 to 6-inch blade. This is probably excessive and offers quite an opportunity for the wearer or his coworkers to be inadvertently stabbed. More practical and certainly less expensive is a small, replaceable blade knife similar to those used for opening cardboard cartons. As long as this can be either opened with one gloved hand or otherwise provided with some type of safety covering it offers an ideal combination since it is inexpensive, sharp, has a replaceable blade and can be discarded if contaminated.

A second accessory device which is not frequently carried but should become an integral part of any ensemble is a personal locator beacon [93]. These may either operate by radio, by light, or by sound and should be capable of being actuated either by the wearer in the event of an emergency or by the emergency itself in the event the wearer is incapacitated. One such alarm, for example, sounds with an intermittent or varying tone between 1000 and 4000 hertz at a sound pressure level of 95 dBA at 3 meters if the wearer is immobile for more than 30 seconds. The device is also intrinsically safe.

A third piece of essential equipment is a personal flashlight or lantern. Many lightweight and inexpensive permissible or explosion-proof flashlights or lanterns are available for carrying by all employees who may be engaged in emergency operations or who may be forced to work after dark or in confined spaces. To minimize decontamination problems the flashlight can be sealed in a transparent plastic bag.

The last item of essential personal equipment is a personal dosimeter. These must be selected with care and are totally dependent upon the nature and extent of the anticipated exposure [94]. Direct reading instrumentation is available for evaluating most forms of ionizing radiation, oxygen deficiency, the lower flammable limit, and certain toxic components of a hazardous material atmosphere. Appropriate dosimeters should be selected and at least one issued to each team. Individual passive dosimeters should be provided to each employee in order that a record may be kept of the employee's exposure. In the use of fully encapsulating suits, consideration should be given to placing a passive dosimeter within the suit in order to estimate actual body exposure. Electrical equipment should be appropriately approved either as intrinsinctly safe or for the class and group of hazard as defined in Article 500 of the National Electrical Code [95]. Division 1 locations must be assumed.

## B. ENSEMBLE FACTORS

### 1. Suit/Respirator Configurations

Fully encapsulating suits usually come in four different configurations based upon the type of respiratory protective device used with the suit.

- One, sometimes called Type A (or Type I), is comprised of either a supplied air respirator, a combination supplied air respirator/self-contained breathing apparatus, or a self-contained breathing apparatus (SCBA) which is worn under the suit [68].

- The second, a variation of the Type A suit, also called Type III, is an air supplied suit in which the suit forms a respiratory inlet covering (there is no facepiece) and air is supplied to the suit for respiration, pressurization, and possibly cooling [74].

- The third, a Type B (or Type II) suit, uses the same respirators as the Type A suit; however, they are mounted externally to the suit and their face pieces become an integral exposed part of the suit itself. There are no supplied air suits of this configuration [96].

- The fourth, a Type A (or Type I) suit (with respirator worn inside the suit) also has a facepiece which is an integral exposed part of the suit itself.

SUIT CONFIGURATION MATRIX

| RESPIRATOR LOCATION | FACEPIECE ARRANGEMENT<br>INSIDE SUIT | OUTSIDE SUIT |
|---|---|---|
| INSIDE SUIT | "A" CONFIGURATION<br>CASE 1 SCBA (Type I)<br>CASE 2 SAR (Type III) | "A" CONFIGURATION<br>CASE 4 (Type I) |
| OUTSIDE SUIT | NONE | "B" CONFIGURATION<br>CASE 3 (Type II) |

NIOSH has determined that the self-contained breathing apparatus of the latter two ensembles are presently not approved since the addition of the suit to the facepiece voids the approval of the respirator unless done as part of an extension of approval [97]. Currently there have been no such extensions of approval. Therefore, there are no such approved ensembles [33]. They are occasionally used.

The self-contained breathing apparatus used with the Type B suit may be either of an open circuit or a closed circuit design. Due to the heat generated by current closed circuit self-contained breathing apparatus and by the heat retention of exhalation, the use of a closed circuit SCBA with Type A suits is not recommended unless adequate cooling for the suit is provided. The additional weight of the cooling unit, about 12 pounds [75, 76], may offset the lighter weight of the closed circuit self-contained breathing apparatus, and thus negate the weight advantage of the closed

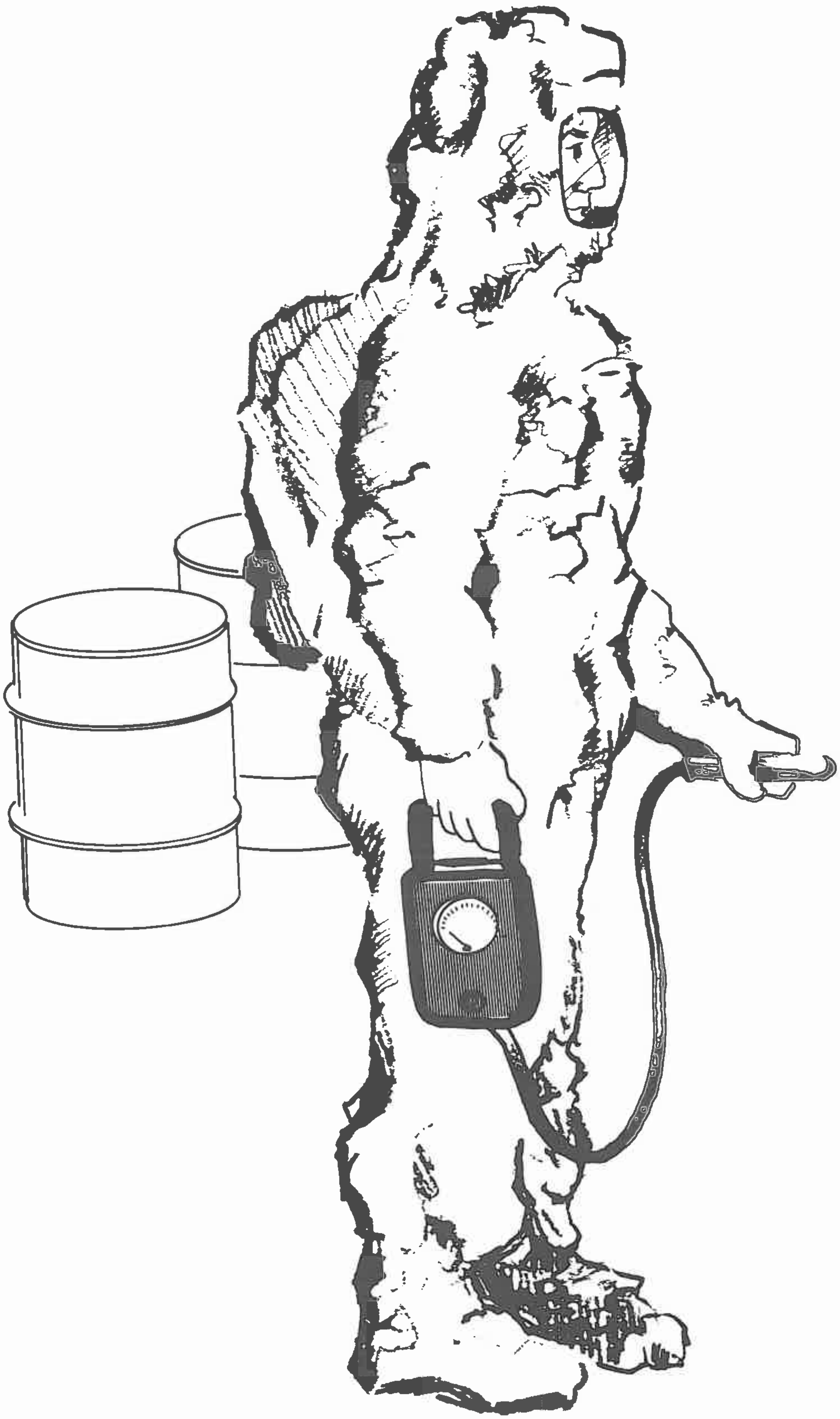

Figure I-1. "A" Configuration Suit - Case 1

Figure I-2. "B" Configuration Suit - Case 3 circuit SCBA over the open circuit without any offsetting increase in duration [98]. Duration for either positive pressure unit can be either 30 minutes or an hour.

Relief valve venting of a closed circuit SCBA can fill a Type A suit with several liters or more of oxygen which could create a decided hazard in the event of flame impingement upon the suit. Faceseal leakage could likewise provide oxygen enrichment inside the suit in either Type A or Type B suits.

2. Factors influencing duration of protection

There are a host of ensemble factors which influence the ability of the ensemble to provide protection over a finite period of time. These include coolant supply, CO2 sorbent supply, the oxygen or air supply, the heat transfer characteristics of the clothing, facepiece exhalation valve leakages of the respirator, valve and fastener leakages of the suit, the penetration of the air supply by contaminant, suit penetration through permeation or degradation, and the relationship of the breakthrough time to the permeation rate of the suit.

a. Coolant Supply - The amount of coolant carried by the wearer significantly influences mission duration. One kilogram of water ice can sorb approximately 80 kilocalories (kcals) in melting [99]. Therefore, if anticipated workrate (in kcals) and ambient heat loading (in kcals) can be estimated and the efficiency of the devices are known, then mission duration from the standpoint of coolant supply can be easily estimated based upon the weight of the ice carried. Remote coolant supply such as supplied air suits or two-stage refrigeration systems can extend duration at the expense of a trailing umbilical cord and increased complexity of the ensemble. The primary intent of auxiliary cooling is to reduce the influence of heat stress upon mission duration.

b. $CO_2$ Sorbent Supply - The $CO_2$ sorbent supply is an integral part of the design of a closed circuit self-contained breathing apparatus. Generally the apparatus are designed so that the oxygen supply is depleted prior to the depletion of the $CO_2$ sorbent. This is to prevent a bolus of $CO_2$ from breaking through the scrubber rendering the wearer unconscious without warning. At cold temperatures the efficiency of the scrubber is markedly reduced and $CO_2$ breakthrough is a possibility [100].

c. Oxygen/Air Supply - The amount of oxygen or air supplied for self-contained breathing apparatus has traditionally determined the estimated duration of the unit. For self-contained breathing apparatus, current devices are available for up to 4 hours duration at a moderate workrate of 40 liter minute volume [33]. As the workrate increases the duration of the unit decreases proportionately [101]. Supplied air apparatus or supplied air suits can overcome this limitation at the expense of the trailing umbilical cord. However, prolonged use of supplied air suits, particularly when coupled with supplied air coolant at high workrates or heat stress, can result in dehydration of the wearer [77, 102].

d. Heat Transfer Characteristics - The moisture permeability and insulating value of the protective ensemble are important in determining the heat transfer capabilities of clothing. For most commonly available chemical protective clothing it can be assumed that the moisture permeability is near zero and therefore evaporative body cooling is minimal [20, 22]. This greatly limits worker performance because evaporation is the primary means of dissipating heat during work. For impermeable clothing, mission duration is limited by the increase in heat storage of the wearer [20, 21, 27, 103]. With the use of semi-permeable clothing, splashes and liquids (but not gases and vapors) are prevented from entering the suit and some of the wearer's perspiration can evaporate, providing cooling. Present uses of this semi-permeable membrane are in the vapor barrier of structural firefighters protective clothing and in some splash protective suits. Another characteristic of clothing, the insulation or Clo value, influences the heat lost through means other than evaporation. The larger the Clo value, the larger the insulating capabilities of the garment and the lower the heat transfer capabilities [103, 104]. Therefore in hot environments, or at high workrates, avoid use of excessively insulated clothing where possible.

e. Facepiece leakage - Inboard facepiece leakage of contaminated atmosphere can seriously compromise mission duration [41]. The sorbed dose is a function of both the concentration and the minute volume [105]. Inboard leakage at moderate workrates is minimal with the use of positive pressure self-contained or supplied air respirators [41]. However, if workrates exceed approximately 67 liter minute volume, many of the common supplied air and self-contained breathing apparatus may no longer maintain a positive pressure during peak inhalation [106]. The amount of inboard leakage or the reduction of the protection factor is difficult to estimate and would vary from unit to unit. Units working at greater than 67 liter minute volume should be considered to offer no greater protection than a similarly equipped negative pressure respirator. That is, a protection factor of 10,000, which is usually given for a pressure demand self-contained breathing apparatus when tested at a 40 liter minute volume, should be considered to be a protection factor of only 50 at a 67 liter minute volume [41]. This is obviously a degradation of 2 orders of magnitude due to workrate. A similar reduction in protection factor from 10,000 to 50 is also occasioned by temperatures below about 60 degrees F or above about 90 degrees F [55]. High ambient temperatures, as may be occasioned by the wearing of a pressure demand SCBA inside a Type A fully encapsulating suit, could seriously degrade the respiratory protection provided by the SCBA. This mechanism is not clearly understood but it seems to involve the softening and increased flexibility of the regulator diaphragm [55].

f. Exhalation Valve Leakage - Exhalation valve leakage in a positive pressure respirator which is actually operating in positive pressure during the entire breathing cycle is minimal. However, the exhalation valve itself may be subject to the same softening as the regulator diaphragm and increased leakages at high temperatures or as the valve becomes cold or ice clogged could be considered possible. At higher workrates the contribution of exhalation value leakage may become increasingly important.

g. Suit Valve Leakage - Similar to the exhalation or exhaust valve, the suit relief valves are subject to the same types of malfunctions as those of the respirator. At excessively hot or cold temperatures these valves may leak more than the rates assumed under more normal work conditions.

h. Suit Fastener Leakage - Zippers, snaps, or other components of the suit fastener system may also significantly leak particularly if they are not adequately maintained or become cold and brittle from low temperature operation.

i. Air Supply Penetration - Air supply penetration by a hazardous material, either through permeation of air supply hose, attempts to use on-site air compressors with an inadequate air purification system, or from breakdown of lubricants in compressor systems of either supplied air or self-contained apparatus, can seriously contaminate the air supply, increase the sorbed dose, and hence, decrease mission duration.

j. Suit Penetration - Suit penetration or permeation is a function of a host of factors which include material type, thickness, method of manufacture, ambient concentrations, temperature, and pressure. Suit penetration usually occurs in two stages as the suit material is assaulted by a hazardous material [107]. Initially, no detectable quantity of the material permeates the suit [108]. After some period of attack, the hazardous material is detectable on the inside of the suit material in minute quantities [108]. The time from the initial attack until the detection of material on the inside of the suit is considered the breakthrough time [108]. Obviously, for mission durations less than the breakthrough time the suit is providing optimal protection. After the breakthrough time, the concentration on the unexposed side or wearer's side of the suit will slowly increase until a steady rate of permeation (or the steady state permeation rate) is reached [109]. The sorbed dose from suit permeation is therefore a function both of the breakthrough time and the steady state permeation rate. If the mission duration is less than the breakthrough time, then the sorbed dose will be nil since by definition no detectable hazardous material will permeate the suit. If, however, the mission duration is longer than the breakthrough time, then hazardous material will slowly build within the suit until it reaches the steady state permeation rate. At the steady state permeation rate, material will continue to break through the suit until equilibrium is reached. If exposure is prolonged, eventually the concentrations on both sides of the suit, in the ambient atmosphere and within the suit, will be approximately equal [109]. At this time, obviously, the suit is no longer providing any protection. Therefore, the determination of mission duration depends upon the breakthrough time, the permeation rate, and the allowable concentration within the suit. If the mission can be completed before the breakthrough time, then the suit will provide optimum protection. If, however, the suit is re-exposed to the material for a second wearing, or worn without adequate decontamination, even in the absence of the hazardous material, permeation may continue through the breakthrough time to the steady state permeation rate and to an actual sorbed dose [109].

## C. ENVIRONMENTAL FACTORS

The environmental factors which most significantly influence mission duration and equipment selection are temperature, humidity, characteristics of the exposing hazardous material (especially its concentration), the maximum allowable or acceptable dose of that material, and the presence of adequate oxygen in the atmosphere.

### 1. Temperature

For a detailed discussion of heat stress, readers are encouraged to refer to the NIOSH document "Criteria for a Recommended Standard . . . Occupational Exposure to Hot Environments" [110]. This document presents information on work practices, measurement techniques, biological effects of exposure, as well as a recommended standard. It should be pointed out, however, that this standard is not applicable to employees required to wear impermeable protective clothing.

Temperature may not only adversely effect the user [29, 111, 112] of personal protective equipment and the equipment itself [55], but it may also exacerbate the exposure from the hazardous material [105]. Virtually all testing of personal protective equipment is carried out at normal room temperatures (i.e., 70 to 75 degrees F) and usually in the absence of any radiant heat loading [113, 114].

Limited tests on self-contained breathing apparatus indicate that many open circuit apparatus cannot be counted on to give adequate protection at temperatures above about 90 degrees F at moderate to high workrates [55]. Similarly, tests of low temperature operation of self-contained breathing apparatus have been concerned in the past with the function of the unit, but not whether or not it provided adequate protection [114]. Based on very limited data, one must assume that use of self-contained breathing apparatus at temperatures below room temperature also occasions a risk of inadequate protection [100]. For that reason, we have adjusted the protection factor of the breathing apparatus dependent upon temperature variations.

The temperature also influences the heat loading of wearers of chemical protective clothing [27, 29, 116]. Temperatures different from skin temperature are important since the heat transfer from the skin is dependent upon the temperature gradient between the skin and the surrounding encapsulating suit.

2. Material

Probably no single environmental factor so influences the selection of protective equipment as the material against which protection is desired [107]. But unfortunately in many hazardous material incidents the identification and quantification of this material may be delayed beyond the selection stage or may not occur [9]. With full knowledge of the material, its concentration, temperature, relative humidity, and other environmental conditions, laboratory evaluation of candidate suit materials can usually allow selection of one which optimizes protection while minimizing weight, cost, and encumbrance to the wearer [90]. Emergency use situations, however, rarely allow for such rational selection of suit material. Therefore, several suits (or possibly only a single suit type) are usually preselected from those offering the widest range of protection against chemical substances which may be encountered. This selection is made easier by classifying substances into one of several broad categories such as liquids, gases, vapors, dusts or solids. Selection of general types of ensembles can then be made even without knowledge of the chemical resistance and permeation of the possible suit materials by specific substances. Substances which are known to chemically attack or permeate the selected suit materials must then be ruled out if any confidence is to be placed in the wearing of the protective ensemble.

Say, for example, that the suit selected is of a butyl rubber compound which the manufacturer recommends not be exposed to nitric acid for more than 20 minutes or the suit will be rapidly degraded. Use of a gas detector tube, specific for nitric acid, can rule out nitric acid if the specific reaction is not observed [17]. One detector tube available changes from a blue indicating color to yellow in the presence of nitric acid [17]. As long as the tube remains blue, significant nitric acid exposure is unlikely. While this "rule-out" procedure is useful in preventing the inadvertent overexposure to a material which rapidly degrades the suit, the absence of degradation does not imply the absence of permeation [117]. As more permeation data is added to our store of knowledge, it will be possible to extend the "rule-out" rule to substances having significant permeation. If the mission duration can be limited to times before significant degradation or permeation takes effect (i.e., before the degradation or breakthrough time) then, although the suit may subsequently be destroyed, the wearer can use it in relative safety. Therefore, the use of a butyl rubber suit to effect a 10-minute rescue in the presence of liquid nitric acid should not pose an undue risk to the wearer. All should realize, however, that the suit, having been attacked and degraded, must not be reused.

Of almost equal importance to the type of material involved in a hazardous material incident is its concentration [117]. Concentration and duration of exposure are, of course, the two factors which determine the potentially sorbed dose. Hence, for a given allowable dose, concentration and duration of exposure should be considered reciprocal [105]. This relationship, known as Haber's Law, simply states that the dose is equal to the product of the concentration and the time of exposure [105]. For some substances there is a limiting dose which over a short term exposure can be considered harmful. For these substances, threshold limit values (TLV®) or short term exposure limits (STEL) are recommended in the absence of mandated permissible exposure limits or when the TLV® or STEL's are more restrictive.

The TLV®-STEL is the maximal concentration to which workers can be exposed for a period of up to 15 minutes continuously without suffering: 1) irritation, 2) chronic or irreversible tissue change, or 3) narcosis of sufficient degree to increase accident proneness, impair self-rescue, or materially reduce work efficiency. No more than 4 excursions per day are permitted with at least 60 minutes between exposure periods, provided that the daily TLV® time-weighted average also is not exceeded. The STEL should be considered a maximally allowable concentration or ceiling, not to be exceeded at any time during the 15-minute excursion period. Other substances have an instantaneous ceiling called a threshold limit value ceiling. This means that the concentration of the particular substance should not be exceeded even instantaneously. These values, which are obtainable for many common industrial substances, are available in the "Threshold Limit Values for Chemical Substances and Physical Agents" publication of the American Conference of Governmental Industrial Hygienists [3]. This publication is produced annually, and the latest version should always be consulted, since increased knowledge and experience with some chemicals may cause a dramatic re-evaluation of their toxic potential [3]. The permissible exposure limits (PEL) of some substances are regulated by OSHA. NIOSH additionally may recommend new or different levels for the same substances or for unregulated substances. The most current information must be used to ensure safety. Listed substances are sometimes accompanied by a skin notation which identifies the potential contribution to the overall exposure by the cutaneous route including mucous membrane and eye either by airborne or more particularly by direct contact with the substance. It should be noted that the vehicles can alter the skin absorption [3]. It's recommended that skin contact either through gas, vapor, liquid or solid contact be prevented by the most protective means. Adequate respiratory protection will be provided in almost all instances by the positive pressure self-contained breathing apparatus if it is operated within the temperature ranges and work rates suggested.

3. Oxygen Deficiency

Normal room air at sea level pressure (760 mm Hg) contains about 20.9% oxygen by volume. The remainder is made up mostly of nitrogen with minor quantities of carbon dioxide and water vapor. Since gases in mixtures such as air exert a pressure proportional to their percentage of composition by volume, 20.9% of the normal atmospheric pressure at sea level (760 mm Hg) or some 159 mm Hg of this pressure is exerted by the oxygen in the air. This 159 mm Hg of pressure is called the "partial pressure of oxygen" (abbreviated as $pO_2$). As the total atmospheric pressure or barometric pressure changes, so does the $pO_2$ even though the percentage of oxygen in the air (20.9%) does not change. Conversely, as the percentage of oxygen in the air changes, so does the $pO_2$ even if the total atmospheric or barometric pressure remains the same.

The human body at sea level inhales air with a $pO_2$ of 159 mm Hg but due to gas exchange and the high moisture content of the air in the lungs, the $pO_2$ in the small air sacks (alveoli) is reduced to 104 mm Hg. This the body considers "normal". Changes in this alveolar $pO_2$ (or $pAO_2$) may affect the body adversely. Minor deviations over a short period can be tolerated but at a $pAO_2$ of 85 mm Hg, symptoms of oxygen deficiency or hypoxia develop. Note, these symptoms can occur <u>either</u> through changes in oxygen percentage <u>or</u> by changes in total pressure.

Therefore, to answer the question of what is an oxygen deficient atmosphere from a physiological viewpoint, one must either measure the $pAO_2$, which requires blood sampling, or measure both the percent oxygen and the total pressure (barometric pressure) and calculate the resulting $pAO_2$.

Figure I-3 reduces this calculation to a simple graph and is based on a "normal" $pAO_2$ of 104 mm Hg. Someone breathing air at the percentage oxygen and pressure noted on the upper line of the graph will react as if they were at sea level. High oxygen percentages can be obtained from oxygen based open circuit SCBA or closed circuit SCBA. At oxygen percentages above "normal", increases in flammability of materials can be noted and some materials considered nonflammable or noncombustible (such as Nomex (TM)) can readily burn. Prolonged inhalation of oxygen (more than 6 hours at a time) can also have adverse affects since the body is also sensitive to too high a $pAO_2$. This time may be reduced drastically in some abnormal lung conditions.

The lower line of the graph is calculated on the basis of a $pAO_2$ of 85 mm Hg. Combinations of pressure and percent of oxygen below this line will result in symptoms of hypoxia almost immediately. At extremely low $pAO_2$ (<30 mm Hg) useful consciousness may last only 12 seconds. Death ensues if escape or rescue is not possible.

Respirator users should maintain the $pAO_2$ at nearly normal levels of 104 mm Hg by selection of air or oxygen supplying respirators at combinations of oxygen depletion or pressure indicated below the average. For example, using Figure I-3, at a barometric pressure of 760 mm Hg, any atmosphere supplying respirator can be used since all will supply at least a nominal 21% oxygen. But at a barometric pressure significantly below 760 mm Hg, only an oxygen based SCBA can maintain the $pAO_2$ at levels to prevent some symptoms of hypoxia in the unacclimated.

Air-purifying respirators can not be used where the $pAO_2$ is below 85 mm Hg.

## D. HUMAN FACTORS

When examining human factors that influence mission duration, one must discuss the influence of the equipment and the environment upon the man, as

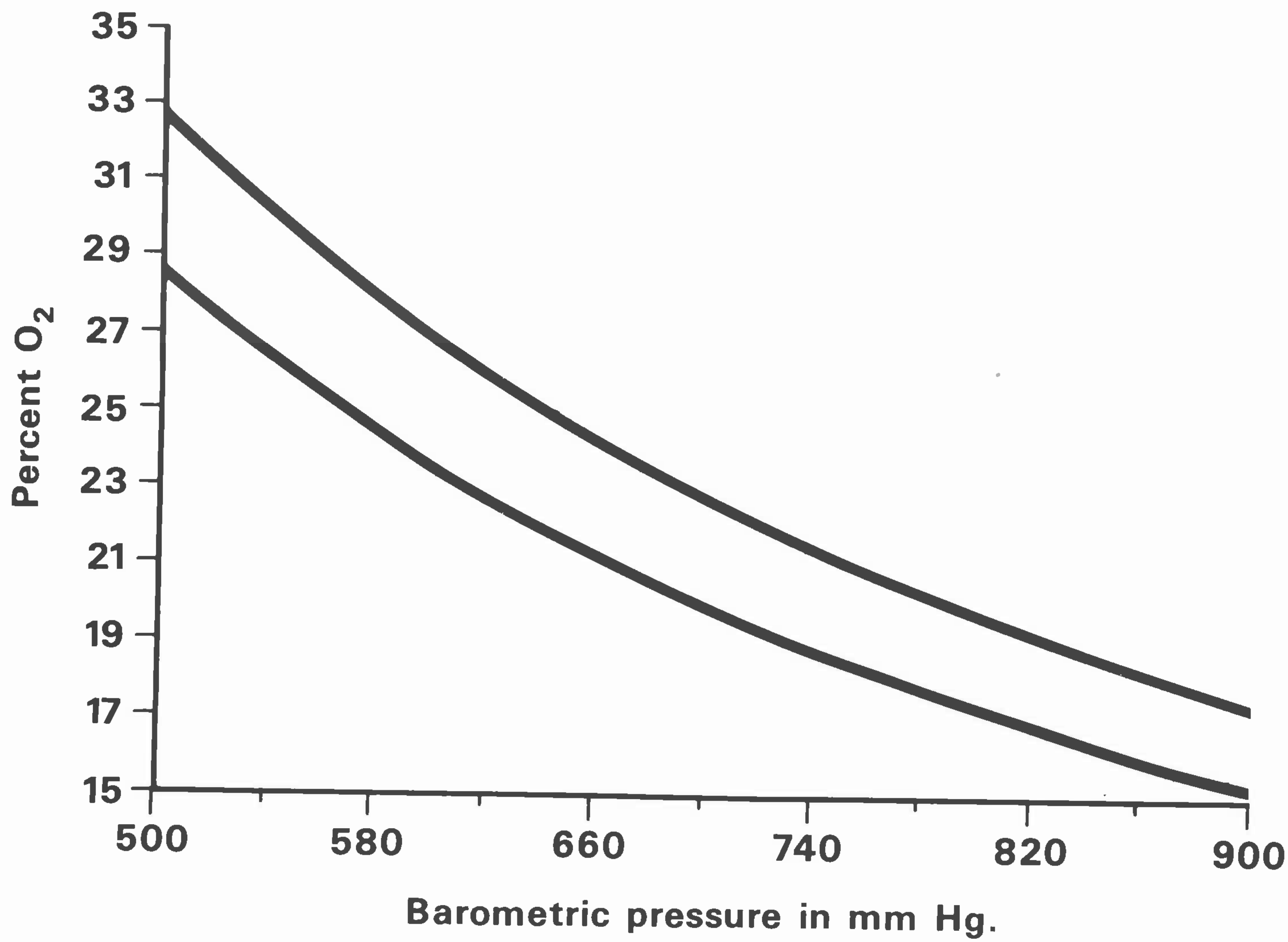


Figure I-3. PERCENT OXYGEN IN AIR TO MAINTAIN A CONSTANT ALVEOLAR OXYGEN PARTIAL PRESSURE AS A FUNCTION OF BAROMETRIC PRESSURE well as the characteristics of the man himself. The influence of the mission upon the man will be discussed separately.

1. Physiological Response

Equipment obviously has an influence on physiological response of the individual. Weight of the equipment, for example, increases the energy requirement for a given task [118-122]. Generally, the energy expenditure increases by 1.2% for every kilogram of added weight [120]. Any selection of equipment, therefore, should carefully evaluate the cost-benefit of all items to be worn or carried.

The water vapor permeability of the clothing also influences human response and endurance. The more impermeable the clothing is to water vapor, the more deleterious the effect will be. Research has shown that during work wearing impermeable clothing, the body temperature and heart rate rise at a faster rate than without impermeable clothing [111, 123-127]. Deaths have even been reported during exhaustive exercise in impermeable plastic suits at ambient temperatures as low as 80 degrees Farenheit [128]. The problem is one of heat dissipation.

Normally, in hot environments or during work, the body relies a great deal on heat lost through the evaporation of sweat [24, 129-131]. With impermeable clothing, the heat loss by the evaporation of water is not possible. The wearer continues to sweat profusely, but the sweat is not effective in cooling the body as the normal channels of dissipating heat are blocked. Additionally, the weight and burden of the protective equipment, which may exceed 50 pounds, adds to the metabolic cost of the work, increasing the amount of heat produced. The net effect is that heat must be stored within the body.

There is a limit to how much heat storage one can safely tolerate. Estimates vary, but Goldman suggests that man's voluntary tolerance limit for heat storage is approximately 80 kcals [132, 133]. As heat storage increases above this value the risk of heat collapse increases tremendously [132]. It is vitally important that workers be aware of this potential danger, the signs and symptoms of heat problems, and the personal factors which may influence heat tolerance.

Some of the predisposing factors for heat injury include:

1) lack of physical fitness

2) lack of acclimatization

3) age

4) dehydration

5) obesity [112].

Other predisposing factors are alcohol and drug usage, infection, sunburn, diarrhea, and chronic disease [134-136]. Administrative modifications (such as adjusting work/rest regimens, job slowdown or job rotation) may do a great deal to alleviate the problem. In the meantime, however, individual workers should do everything possible to protect themselves from illness: exercise regularly; acclimatize themselves to the heat, the clothing, and the workload; remain adequately hydrated; and strive to maintain their optimal weight. Once individuals suffer from heat stroke or heat exhaustion, they are predisposed to additional heat injuries [137]. Thus, prevention of heat illness is of utmost importance. Additionally, becoming aware of the symptoms and treatment of each disorder may prevent a serious situation from developing into a fatality. A proper education program is a necessity.

Protective clothing and equipment result in a general decrease in worker performance compared to that which the individual would normally be able to accomplish. The magnitude of the effect will vary considerably between individuals and will be dependent upon the type of clothing and respirator worn as well as the temperature and workrate.

In general, simply wearing a self-contained breathing apparatus (SCBA) reduces the maximal amount of work that can be performed by 20% [138]. On the other side of the coin, at workloads less than maximum, wearing the SCBA will increase the amount of energy expended by 20%. This, of course, means that more heat will be produced (about 13% more) [139] and more of that precious air supply will be used. In fact, there is increasing evidence that the duration of a SCBA in actual use may be reduced to 1/3 to 1/2 of the rated capacity depending upon the workrate [101]. Increases in blood pressure and heart rate as well as a decrease in endurance time may also be seen with the use of a respirator [140-142]. Additionally there is some evidence there is an increase in errors, rating of perceived exertion, and breathing discomfort associated with the use of a SCBA [143].

The addition of clothing also effects the performance of the worker. Simply donning a shirt and trousers may lead to a 40% reduction in heat loss [144]. The addition of a protective suit can result in significant increases in energy expenditure and reductions in worker performance. The increase in metabolic cost is dependent on the specific suit selected. For example, a pressurized suit, with its weight and bulkiness, may increase the necessary energy expenditure by as much as 2 - 4 times [77, 145]. The results are not as dramatic with less cumbersome suits, nevertheless the energy expenditure (and heat production) may be elevated by 13 - 47% [121, 122, 146, 147]. Generally, the energy expenditure increases by 1.2% for every kilogram of added weight [120].

The physiological effects of impermeable clothing are evident both at rest and with exercise [123, 127, 148, 149]. Even in cool environments heart rate, ventilation and body temperature are all elevated [112]. However, the magnitude of the effect of impermeable clothing is influenced by the environmental temperature. The higher the temperature, the more noticeable the effect and the shorter the work duration must be.

Because tolerance times while wearing personal protective equipment are dependent on many factors (the workrate, temperature, clothing, ensemble, and the worker) specific statements regarding actual tolerance times are difficult to make. The following general conclusions, however, may be drawn:

- Personal protective equipment creates a microenvironment, resulting in an increase in physiological strain at both rest and work.

- Tolerance times may be reduced to less than the duration of the breathing apparatus. This should be considered in the selection of a breathing apparatus, so that this does not occur.

- The greater the workrate, the greater the heat production, the greater the consumption of air, and the shorter the tolerance time.

- The higher the environmental temperature, the greater the performance decrement.

2. Human Characteristics

In attempting to provide protection for the wearer, one should consider not only environmental and equipment controls, but also human factors which may be used to reduce the strain of any given stress. Among these are:

a. physical condition

b. level of acclimatization

c. level of hydration

d. age

e. sex

f. weight

a. Physical Condition

This factor is without a doubt a most important factor in a person's ability to endure work. The more fit you are the higher workload you can safely tolerate [129, 136]. It follows, then, that at a given level of work the more fit individual will be able to perform with much less physiological strain on the body. This is indeed true. At a given workload, a well-conditioned person will have a lower heart rate, a lower rectal temperature, and a more efficient sweating mechanism than a less fit individual [129]. Generally, they may also breathe slightly less air and produce slightly less $CO_2$ for a given task [129, 150].

Graphs, such as the one in Figure I-4, have been developed which illustrate this principle. Note that at every workload, the fit individual is able to work for a longer period of time. Notice also that as the relative workload increases, endurance time decreases for both fit and sedentary individuals. This suggests that for any given anticipated mission duration, some minimum fitness level is required so that the worker may successfully complete the mission. For example, if the anticipated mission duration is one hour, then the worker should have a minimum fitness capacity so that the workload for the mission is less than 50% of his capacity. If the required workload is greater than 50% of the worker's capacity, then the duration of the mission may be compromised.

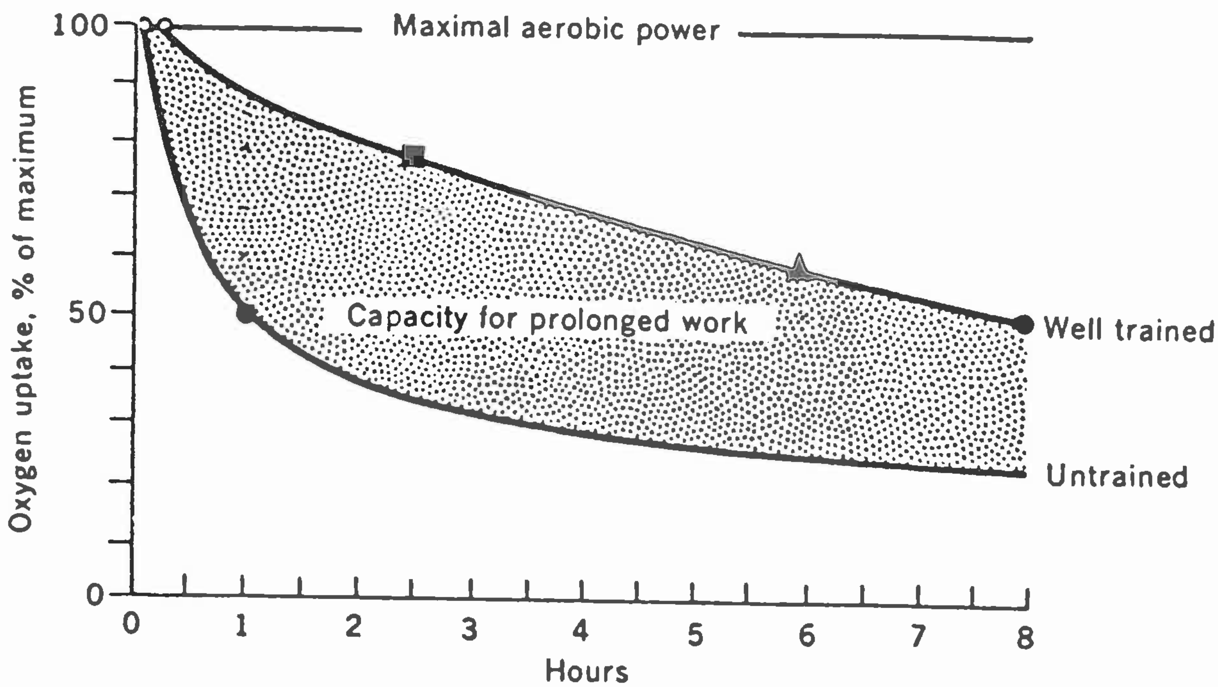


Figure I-4. The Effect of Training on Capacity for Prolonged Work

Because of this, it is suggested that a minimum fitness criterion be established for individuals working in personal protective equipment: definitely at least in "fair" physical condition as shown in Table I-1. A simple means of estimating one's fitness level would be to administer a field test, such as Cooper's 12-minute test [151]. This test is "surprisingly accurate, easy to administer, and requires no equipment" [151]. This test involves running and walking as far as is comfortably possible in 12 minutes. The distance is then recorded and compared to those specified in Table I-1. Please keep in mind that this test is designed to be a maximal test, and as such, medical clearance may be needed for some individuals (especially sedentary individuals or those over the age of 35). All workers should be encouraged to reach the good or excellent rating. The result will be reduced physiological strain and improved endurance levels. Properly implemented aerobic training programs should therefore be encouraged for all employees.

Table I-1

| Fitness Category | | Distance Covered | Oxygen Consumption ml/kg/min |
|---|---|---|---|
| I | Very Poor | less than 1.0 mile | 28.0 or less |
| II | Poor | 1.0 to 1.24 miles | 28.1 to 34 |
| III | Fair | 1.25 to 1.49 miles | 34.1 to 42 |
| IV | Good | 1.50 to 1.74 miles* | 42.1 to 52 |
| V | Excellent | 1.75 miles or more | 52.1 or more |

*For men over 35 years of age, 1.40 miles in 12 minutes is consistent with the good fitness category. For women, the good fitness category appears to be greater than 1.30 miles in 12 minutes.

b. Level of Acclimatization

Acclimatization refers to the physiological changes occurring within an individual which reduce the strain caused by the heat stress of the environment [110, 152]. Therefore an acclimatized person will generally have a lower heart rate and body temperature than an individual who is unaccustomed to working in the heat [129, 153-155]. Another adaptation that occurs with acclimatization is an increased sweat rate, so that the acclimatized individual begins sweating sooner, sweats more, and is able to maintain a lower skin and deep body temperature at a given heat stress [129, 154, 156, 157]. Sweat composition also becomes more dilute with acclimatization so that less salt is lost in the sweat [129, 154].

The acclimatization process occurs quite rapidly, with noticeable improvements occurring after just a few days of exposure to a hot environment [135, 136]. However the benefits of acclimatization are also lost quite rapidly with very little being retained after two weeks of nonexposure [136]. NIOSH recommends that the unacclimatized worker be progressively acclimatized over a period of 6 days before being allowed to do full work on a hot job [110, 136]. The acclimatization schedule would begin with 50% of the anticipated workload and exposure time progressing an additional 10% each day through day six [110, 136]. Because fit or trained individuals adjust better to the heat than do less fit individuals, the acclimatization period may often be shortened, perhaps by 2 or 3 days

[135]. However, it is important to note a high level of fitness does not replace heat acclimatization [135, 150, 158, 159].

c. Level of Hydration

Level of hydration, although often overlooked, is a most important factor in optimizing worker performance [155, 160]. Dehydration refers to excessive loss of body water. If the body is even slightly dehydrated, heat tolerance, performance capabilities and work time may be drastically reduced [129, 150, 160]. Therefore, it is very important that enough fluids are ingested to ensure that dehydration does not occur. Thirst is not an adequate indicator of hydration level [129, 134]. Five or six glasses of water per day are generally recommended, but requirements for workers in protective clothing may be even higher because of the nature of the job (high heat and workrate). If these requirements are not met, the workers will progressively become more dehydrated, dramatically reducing their performance capabilities and work tolerance [129].

It is strongly recommended that fluids, preferably water or dilute drinks, be drunk before beginning work, during interim rest periods, and then enough afterwards to replace that which was lost by sweating. Drinking about 2 glasses (16 ounces) of water before beginning work will help ensure adequate hydration. Workers should also be required to weigh themselves before and after work. In order to adequately replenish body fluids, 8 ounces of water should be ingested for every 1/2 pound of weight which was lost. So, if 2 1/2 pounds of weight are lost, 5 glasses of water are necessary to replace it. If the fluid loss is not replaced, dehydration will occur, affecting the ability to tolerate heat and endangering one's health [161]. Ingesting salt tablets or drinks with high electrolyte levels is normally not recommended and may indeed cause additional dehydration and may retard acclimatization [160, 162].

d. Age

Although there is a general decline in maximum work capacity with increasing age, this is not always the case. Active, well-conditioned seniors often have performance capabilities equal to or exceeding young sedentary individuals. However, there is some evidence that older individuals are less effective in compensating for a given heat stress (as indicated by a lower sweat rate and a higher core temperature) [163, 164]. Older individuals also appear to become dehydrated more frequently and are at a greater risk for heat stroke [129]. However, several studies have indicated that at moderate thermal loads physiological responses of "young" and "old" subjects are similar and performance is not affected [135, 164, 165]. Age, therefore, should not be used as an exclusive criterion in judging whether or not an individual should be exposed to a moderate heat stress. The more important criterion (and more socially acceptable) is fitness level. Periodic physical examinations should be used to evaluate work capacity, as well as screen for chronic diseases of the heart, lungs, kidney, liver, etc. Any significant disease should be considered as a possible reason for excluding any worker, regardless of age, from work involving high levels of heat stress.

e. Sex

The female's maximal capacity to do work is on the average about 10 - 30% below that of her male counterpart [129, 150]. The primary reasons for this are due to the greater oxygen-carrying capacity of the blood and the larger stroke volume of the heart in the male [129, 166, 167]. But again a similar situation exists as with aging: not all males have greater capacities than all females. Therefore, maximal performance capability, instead of gender, would be a much more appropriate and fair criterion in the selection of the workers. The literature indicates that females tolerate heat stress at least as well as their male counterparts [26, 168-173].

f. Weight

Heat loss is a function of the surface area (or size) available for heat transfer while heat production, on the other hand, is dependent on the weight or the mass of the object. Heat balance is determined by the ratio of heat loss to heat produced. Obese and stocky individuals carry around a lot of weight (so they produce a large amount of heat) but they do not have an equally large surface area to dissipate that heat. This imbalance leads to an increased thermal stress, both at work and at rest, making the overweight individual more susceptible to heat illness. Therefore, it has been suggested that anyone exceeding their standard weight by 15% or more be excluded from working in a hot job [135]. The use of height-weight tables are not recommended. Instead, a more valid procedure such as skinfold measurements, anthropometry, or hydrostatic weighing should be employed when feasible.

Body weight also influences the duration of the air supply. A larger individual must breathe more air to supply all his tissues with oxygen. For example, at extremely high workloads, the large man might need as much as 40 liters of air more than the smaller man each minute [174].

In conclusion, several human factors which influence physiological strain and worker tolerance have been identified. In order to optimize performance, one should become physically fit, acclimatized, well hydrated, and maintain their optimum weight. Performance decrements generally due to age or sex, factors which cannot be controlled, can be partially or completely offset by adherence to these principles.

E. MISSION FACTORS

The mission's influence upon the selection of personal protective equipment stems from two sources: the anticipated duration of the mission, and the workrate required of those assigned to carry out that mission. There is, however, no necessary direct relationship between these two values since the amount of time spent on a given level of exertion and a degree of exertion expended are both mediated by physical, physiological, social, economic, and equipment limitations. Our task is to minimize the influence exerted by the equipment limitations through rational selection. Anticipated mission duration must be based upon experience in supervising, performing similar missions, or upon some temporal increment of that mission. That is, the assignment of a half hour mission or the assignment of a half hour segment of a longer mission. Only a few equipment parameters are independent from workrate. These few would include: battery life or duration for instruments, lighting, circulation pumps or blowers, and similar equipment.

In the selection of chemical protective clothing for hazardous material incidents one of the fundamental factors to be considered is the anticipated duration of the mission. Once this is firmly established then a rational selection of appropriate clothing can then begin. While this may seem a strange precondition for selection, virtually all the factors which influence the selection of protective equipment are based upon the time for which the equipment must be effective. That is, there are few threat-protective countermeasure sets which do not include the element of time. Protective clothing may prevent the permeation of a given hazardous material for a specific period of time, but certainly not indefinitely. Likewise the heat buildup in a chemical protective suit under given work and environmental conditions may preclude the use of the suit for longer than a period of a few minutes.

The most important mission factor which influences mission duration is the workrate. The workrate in turn influences the consumption rate of coolant, the production rate of carbon dioxide, and the consumption rate of oxygen or of the air supply.

<u>Workrate</u> - It's intuitive that the workrate is inversely proportional to work duration [129, 175]. The harder you work the less time you can spend doing that work. This simple factor is often overlooked in the determination of anticipated mission duration and the selection of protective equipment.

<u>Cooling Consumption Rate</u> - Given a finite amount of coolant, obviously mission duration is limited by the consumption rate of that coolant. The faster the coolant is used, (i.e., absorbs heat) the shorter the duration at which it is effective. As an example, melting water ice sorbs approximately 80 kcals per kilogram [99]. At a heat production rate of 80 kcals an hour it will take roughly an hour to melt one kilogram of ice. At the production rate of 400 kcals an hour, however, one kilogram of ice can be melted in approximately 12 minutes. Therefore the relationship between heat production and coolant capacity is an important factor to consider in selection of cooling garments and the determination of mission duration.

<u>CO2 Production Rate</u> - With a finite amount of carbon dioxide scrubber in a closed circuit breathing apparatus the $CO_2$ production rate limits the duration of the breathing apparatus. These units are normally designed to have an excess scrubber capacity so that this does not limit duration in normal use. With open circuit breathing apparatus $CO_2$ production rate does not directly limit the duration of the unit since the $CO_2$ produced by metabolism is dumped outboard of the system with each exhalation.

<u>Oxygen/Air Supply Consumption Rate</u> - The relationship between workrate and oxygen consumption is also a direct one [129, 134, 174]. That is, as workrate

increases more oxygen must be supplied to the tissues. Therefore, oxygen consumption and ventilation must increase to meet the demands. For example, desk work or very slow walking only utilizes approximately 400 ml of oxygen per minute, while machine assembly or faster walking utilizes approximately 800 ml of oxygen per minute. Jogging, on the other hand, may require 2 to 3 liters of oxygen per minute [129, 174]. Ventilation follows a similar pattern, varying from 6 liters a minute during sleep to greater than 100 liters per minute during strenous work [129, 176]. The consumption of oxygen is dependent upon body weight, with the heavier individual requiring more oxygen to supply all his/her tissues with oxygen [129, 174]. With a finite air supply or oxygen supply as is commonly used in a self-contained breathing apparatus, mission duration can be severely limited by air or oxygen supply. Therefore anticipated mission duration should be based on estimated workrate. For example, if, perhaps, an open circuit SCBA is rated as a 30 minute unit, the air supply in the cylinder is 1200 liters (30 minutes multiplied by 40 liters per minute). This means that at an average ventilation of 40 lpm the unit should provide sufficient air for 30 minutes use. If, however, the ventilation rate is 80 lpm (as is common with heavy work), the unit would only supply sufficient air for 15 minutes use. On the other hand, if light work is performed (20 lpm) the unit may last 60 minutes. Therefore, prior to estimating mission duration, one should have a rough idea of anticipated workrate.

Fitness level of the wearer may also influence the duration of the unit. Well-conditioned individuals have a very efficient oxygen utilization system. They, therefore, can extract more oxygen out of a given volume of air, resulting in an increased unit duration [129, 150]. Other factors may also influence the duration of the unit. Heat, anxiety, and lack of acclimization may all induce hyperventilation, increasing the ventilation rate and decreasing the duration of the breathing apparatus. It is important, then, for respirator users to be fit, well-trained, and heat acclimatized [150].

## Part II: PPE SELECTION GUIDE

INTRODUCTION: How to Use the Selection Guide

This part presents step-by-step guides to the selection of respirators, chemical protective clothing, and ancillary equipment which comprise the PPE ensemble necessary to workers who encounter hazardous materials. The decision logic employed permits the person responsible for planning a hazardous materials incident mission to make the most appropriate selection of PPE components, configurations and ensembles.

The Respirator section (R) and the Chemical Protective Clothing section (C), which includes ancillary equipment, are presented in the same manner. Each page represents a critical factor that requires a decision; i.e., a step in the logic process, and is given the letter designation for the component being selected and a number designation representing sequence (e.g., R1). The decision process is not a straight-line sequence. Rather, each specific decision affects the sequence of subsequent factors to be considered.

Each page contains the letter/number designation for the step, a title which reflects the factor under consideration, a brief discussion of that factor, the reference(s) supporting the information contained in the discussion, and "yes" or "no" statements which allow the user to choose the applicable statement. The choice determines the next step in the sequence, which is indicated by the number to the right of the statement.

The final step in all decision processes will be a full description of the appropriate respirator, protective clothing, or ancillary equipment necessary for the mission.

RESPIRATORS (R)

R 1

## FIRE FIGHTING & RESCUE

The operations of fire fighting and rescue are always considered to involve atmospheres immediately dangerous to life and health and thus require the most dependable and effective respiratory protection possible [177].

---

IF THE OPERATION INVOLVES RESCUE OR FIRE FIGHTING

GO TO R 27

IF THE OPERATION INVOLVES NO RESCUE OR FIRE FIGHTING

GO TO R 2

R 2

## SUBSTANCE IDENTIFICATION

The positive identification of a substance may allow the use of effective air-purifying respirators. In the event that the substance cannot be positively identified, then only the most dependable and effective respiratory protection should be used [92].

---

IF THE SUBSTANCE IS IDENTIFIED

GO TO R 3

IF THE SUBSTANCE IS UNIDENTIFIED

GO TO R 25

R 3

PERMISSIBLE EXPOSURE LIMIT/THRESHOLD LIMIT VALUE®

The determination of the efficiency of the respirator is dependent upon knowledge of the permissible exposure limit or threshold limit value for the airborne contaminant [34].

---

IF THE PERMISSIBLE EXPOSURE LIMIT OR THRESHOLD LIMIT VALUE IS KNOWN
GO TO R 4

IF THE PERMISSIBLE EXPOSURE LIMIT OR THRESHOLD LIMIT VALUE IS UNKNOWN
GO TO R 25

® ACGIH

## R 4

## CONCENTRATION

Once the hazardous material is identified, the airborne concentration which has been, or which could be, generated is an important determinant of the required efficiency of required respiratory protection. If the concentration cannot be measured or estimated, then only the most dependable and effective respiratory protection should be used [178].

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IF THE CONCENTRATION OF HAZARDOUS MATERIAL IS KNOWN

GO TO R 5

IF THE CONCENTRATION OF HAZARDOUS MATERIAL IS UNKNOWN

GO TO R 25

R 5

LOWER FLAMMABLE LIMIT/MINIMUM EXPLOSIVE CONCENTRATION

Contaminant concentrations above the lower flammable limit or the minimum explosive concentration can be ignited causing an explosion. Only the most dependable and effective respiratory protection should be used [34].

---

IF THE CONCENTRATION IS AT OR ABOVE THE LOWER FLAMMABLE LIMIT OR THE MINIMUM EXPLOSIVE CONCENTRATION

GO TO R 25

IF THE CONCENTRATION IS BELOW THE LOWER FLAMMABLE LIMIT OR THE MINIMUM EXPLOSIVE CONCENTRATION

GO TO R 6

R 6

## IMMEDIATELY DANGEROUS TO LIFE OR HEALTH (IDLH)

"Immediately dangerous to life or health" means conditions that pose an immediate threat to life or health or conditions that pose an immediate threat of severe exposure to contaminants, such as radioactive materials or carcinogens, mutagens or teratogens, which are likely to have adverse cumulative or delayed effects on health. Only the most dependable and effective respiratory protection can be used [44].

---

IF THE CONCENTRATION OR CONDITION IS IMMEDIATELY DANGEROUS TO LIFE OR HEALTH OR THE IDLH OR CONCENTRATION ARE UNKNOWN

GO TO R 25

IF THE CONCENTRATION OR CONDITION IS NOT IMMEDIATELY DANGEROUS TO LIFE OR HEALTH

GO TO R 7

R 7

## OXYGEN DEFICIENT ATMOSPHERES

Man needs a minimum amount of oxygen to sustain life and somewhat more for effective work. Both barometric pressure and percentage of oxygen present are factors in determining if the atmosphere is oxygen deficient. Self-contained breathing apparatus are required in oxygen deficient atmospheres (See Figure I-3, page 33) [178].

---

IF THE ATMOSPHERE IS NOT OXYGEN DEFICIENT

GO TO R 8

IF THE ATMOSPHERE IS OXYGEN DEFICIENT OR THIS IS UNKNOWN

GO TO R 25

## R 8

## REQUIRED PROTECTION FACTOR (PF)

The protection factor (PF) is the ratio of the contaminant concentration outside and inside the respirator. Since the concentration inside the respirator must be less than the PEL or TLV®, the PF then determines the maximum concentration in which the respirator can be used [34].

$$RPF = \frac{\text{AMBIENT CONCENTRATION}}{\text{PEL or TLV®}}$$

---

IF THE REQUIRED PROTECTION FACTOR IS GREATER THAN 50 OR IS UNKNOWN
GO TO R 25

IF THE REQUIRED PROTECTION FACTOR IS EQUAL TO OR LESS THAN 50
GO TO R 9

## R 9

## AEROSOLS

Airborne materials of greater than molecular size are considered aerosols. Dusts, fumes, mists, fogs and smokes are the most commonly encountered hazardous aerosols. Aerosols can usually be readily filtered from otherwise respirable air with simple respirators having a high efficiency filter [179].

---

IF THE CONTAMINANT IS SOLELY AN AEROSOL

GO TO R 10

IF THE CONTAMINANT IS NOT AN AEROSOL OR IF IT IS AN AEROSOL MIXED WITH A GAS OR VAPOR

GO TO R 11

R 10

## SUBLIMATION OR DECOMPOSITION OF AEROSOLS

Aerosol material trapped on a respirator filter may be inhaled if the material decomposes or sublimes into a gas or vapor since filters are ineffective against gases or vapors.

Materials having a vapor pressure in mm Hg greater than the $\frac{TLV^{®}}{2000}$ in ppm should be considered to have a significant vapor pressure [178].

---

IF THE AEROSOL HAS A SIGNIFICANT VAPOR PRESSURE, SUBLIMES, DECOMPOSES OR IF THESE PROPERTIES ARE UNKNOWN

GO TO R 11

IF THE AEROSOL DOES NOT HAVE A SIGNIFICANT VAPOR PRESSURE, AND NEITHER SUBLIMES NOR DECOMPOSES

SELECT RESPIRATOR A

R 11

RADIOACTIVE GASES & VAPORS

Air-purifying respirators cannot be used for protection against any radioactive gas or vapor [180].

---

IF THE CONTAINANT IS A RADIOACTIVE GAS OR VAPOR

GO TO R 23

IF THE CONTAMINANT IS NOT A RADIOACTIVE GAS OR VAPOR

GO TO R 12

## R 12

## WARNING PROPERTIES

Gas masks cannot be used for protection from materials which have inadequate warning of sorbent breakthrough. Materials which have an odor, irritation or taste at or below the PEL or TLV® can usually be considered to have adequate warning properties. Exceptions are materials which cause olfactory fatigue or whose odors are so pronounced at very low concentrations that they may be perceived even with a properly functioning respirator [34, 181].

---

IF THE MATERIAL HAS ADEQUATE WARNING PROPERTIES

GO TO R 13

IF THE MATERIAL HAS INADEQUATE WARNING PROPERTIES OR THEY ARE UNKNOWN

GO TO R 23

## R 13

## SORBENT EFFICIENCY

The sorbents for gases and vapors are influenced by many factors which can affect their efficiency. NIOSH has established sorbent efficiences for only a few substances (see Table II-1 below). Other reputable sources of sorbent efficiency information can be used to determine the adequacy of respiratory protection provided by the canister. Use of gas and vapor sorbent respirators for chemicals whose sorption properties are unknown is unwarranted.[31, 182].

Table II-1

GASES/VAPORS TESTED BY NIOSH

| | |
|---|---|
| AMMONIA | CARBON TETRACHLORIDE* |
| MONOMETHYLAMINE | SULFUR DIOXIDE |
| HYDROGEN CHLORIDE | CARBON MONOXIDE |
| CHLORINE | VINYL CHLORIDE |
| FORMALDEHYDE | |

* Use of sorbent respirators not recommended

---

IF SORBENT EFFICIENCY IS KNOWN AND APPROPRIATE

GO TO R 14

IF SORBENT EFFICIENCY IS UNKNOWN OR INAPPROPRIATE

GO TO R 23

## R 14

## USE RELATIVE HUMIDITY

The relative humidity during use shows little effect below 65%. Above 65%, the canister service life may be drastically altered. This problem has not been adequately studied and therefore use of sorbent respirators at relative humidities above 65% is not recommended [31, 183].

---

IF USE RH IS EQUAL TO OR LESS THAN 65%

GO TO R 15

IF USE RH IS GREATER THAN 65% OR IS UNKNOWN

GO TO R 23

R 15

USE TEMPERATURE

Gas mask canisters, other than for carbon monoxide, are tested by NIOSH at a use temperature of 25 + $2.5^{\circ}$ C (72.5 - $81.5^{\circ}$ F). The effects of varying use temperatures on sorbent efficiency have not been adequately studied. Lower temperatures may prevent adequate sorbent efficiency. Higher temperatures may cause excessive desorption and rapid breakthrough. Extrapolation of sorbent efficiency to unknown conditions is unwarranted [31, 183].

---

IF THE USE TEMPERATURE IS CONSIDERED TO ADVERSELY AFFECT USE

GO TO R 23

IF THE USE TEMPERATURE IS NOT CONSIDERED TO ADVERSELY AFFECT USE

GO TO R 16

R 16

## HEAT OF REACTION

Sorption or catalytic reactions may produce heat which may increase the heat load of the user or, in extreme cases, cause the respirator canister to ignite. Substances listed in Table II-1, with the exception of carbon monoxide, do not produce excessive heat when tested at the concentrations and flowrates specified.

Carbon monoxide (CO) may generate excessive temperatures of more than 100 $C^{o}$ (212 $F^{o}$) at challenges of 1% (10,000 ppm). Since these concentrations of CO are far above the IDLH (0.15% - 1500 ppm) they are of little practical importance for hazardous materials incidents. Phosphine, however, can ignite the canister at challenge concentrations below 1% (10,000 ppm) [32].

---

IF THE CHEMICAL PRODUCES A HIGH HEAT OF REACTION AT THE AMBIENT CONCENTRATION OR IT IS UNKNOWN
GO TO R 23

IF THE CHEMICAL DOES NOT PRODUCE A HIGH HEAT OF REACTION AT THE AMBIENT CONCENTRATION
GO TO R 17

## R 17

## SHOCK IGNITION SENSITIVITY

Some substances such as nitroglycerin, PETN, or nitromethane may be concentrated by a sorbent canister and make the canister into a low level explosive device. For this reason, sorbent respirators are not recommended for use with potentially explosive substances [184].

---

IF THE SUBSTANCE IS A POTENTIAL EXPLOSIVE OR IT IS UNKNOWN

GO TO R 23

IF THE SUBSTANCE IS NOT A POTENTIAL EXPLOSIVE

GO TO R 18

R 18

CHIN STYLE GAS MASKS

The maximum test concentration of chin style gas masks is 0.5% (5000 ppm). Use at concentrations above this value may dramatically reduce service life and is therefore not recommended [185].

---

IF THE USE CONCENTRATION IS MORE THAN 5000 ppm

GO TO R 19

IF THE USE CONCENTRATION IS 5000 ppm OR LESS

SELECT RESPIRATOR b

R 19

## MAXIMUM TEST CONCENTRATION

Gas mask canisters are tested to a maximum concentration of 2% (20,000 ppm) (ammonia 3% (30,000 ppm)) and are expected to give service times of from 6-12 minutes. Since these service times are so short, use of canisters at higher concentrations may reduce service times to unreasonably short periods and is, therefore, not recommended [182].

---

IF THE CONCENTRATION IS OR IS LESS THAN 2%

GO TO R 22

IF THE CONCENTRATION EXCEEDS 2%

GO TO R 20

R 20

MOBILITY

The prime distinguishing characteristic between a supplied air respirator (SAR) and the self-contained breathing apparatus (SCBA) is the restriction to mobility produced by the trailing air line of the SAR [38].

---

IF MOBILITY IS REQUIRED

GO TO R 27

IF MOBILITY IS NOT REQUIRED

GO TO R 21

## R 21

## REQUIRED AIRFLOW

Supplied air respirators of Type C pressure demand mode are tested to maintain a facepiece pressure which is not negative at flowrates up to 115 lpm. This corresponds to a minute volume ($V_e$) of about 40 liters. A $V_e$ in excess of 40 liters can result in a degradation of the protection factor by X200 (from 10,000 to 50) [42].

---

IF ANTICIPATED $V_e$ IS EQUAL TO OR MORE THAN 40 LITERS OR IS UNKNOWN
GO TO R 27

IF ANTICIPATED $V_e$ IS LESS THAN 40 LITERS

SELECT RESPIRATOR E

R 22

FRONT EXPOSURE

Full size canister gas masks are made to be front mounted (canister worn on the chest) or back mounted (canister worn on the back). Some repetitive uses of a gas mask, such as drum sampling, barrel crushing, or lab benchwork, may enable the placement of the canister in the position of lower exposure to extend its service life [186].

---

IF THE EXPOSURE IS PRIMARILY IN THE FRONT

SELECT RESPIRATOR D

IF THE EXPOSURE IS PRIMARILY IN THE BACK OR IF NO DIFFERENCE IN EXPOSURE IS NOTED

SELECT RESPIRATOR C

R 23

MOBILITY

The prime distinguishing characteristic between a supplied air respirator (SAR) and the self-contained breathing apparatus (SCBA) is the restriction to mobility produced by the trailing air line of the SAR [38].

---

IF MOBILITY IS REQUIRED

GO TO R 27

IF MOBILITY IS NOT REQUIRED

GO TO R 24

## R 24

## REQUIRED AIRFLOW

Supplied air respirators of Type C pressure demand mode are tested to maintain a facepiece pressure which is not negative at flowrates up to 115 lpm. This corresponds to a minute volume ($V_e$) of about 40 liters. A $V_e$ in excess of 40 liters can result in a degradation of the protection factor by X200 (from 10,000 to 50) [42].

---

IF ANTICIPATED $V_e$ IS EQUAL TO OR MORE THAN 40 LITERS OR IS UNKNOWN
GO TO R 27

IF ANTICIPATED $V_e$ IS LESS THAN 40 LITERS
SELECT RESPIRATOR E

R 25

MOBILITY

The prime distinguishing characteristic between a supplied air respirator (SAR) and the self-contained breathing apparatus (SCBA) is the restriction to mobility produced by the trailing air line of the SAR [38].

---

IF MOBILITY IS REQUIRED

GO TO R 27

IF MOBILITY IS NOT REQUIRED

GO TO R 26

## R 26

## REQUIRED AIRFLOW

Supplied air respirators of Type C pressure demand mode are tested to maintain a facepiece pressure which is not negative at flowrates up to 115 lpm. This corresponds to a minute volume ($V_e$) of about 40 liters. A $V_e$ in excess of 40 liters can result in a degradation of the protection factor by X200 (from 10,000 to 50) [42].

---

IF ANTICIPATED $V_e$ IS EQUAL TO OR MORE THAN 40 LITERS OR IS UNKNOWN GO TO R 27

IF ANTICIPATED $V_e$ IS LESS THAN 40 LITERS

SELECT RESPIRATOR G

R 27

REQUIRED AIRFLOW

Self-contained breathing apparatus of the open circuit pressure demand mode are tested to maintain a facepiece pressure which is not negative at flowrates up to 200 lpm. This corresponds to a minute volume ($V_e$) of about 67 liters. A $V_e$ in excess of 67 liters can result in a degradation of the protection factor by X200 (from 10,000 to 50) [106].

---

IF ANTICIPATED $V_e$ IS EQUAL TO OR MORE THAN 67 LITERS OR IS UNKNOWN
SEE NOTE F

IF ANTICIPATED $V_e$ IS LESS THAN 67 LITERS

GO TO R 28

R 28

SERVICE LIFE (POSITIVE PRESSURE SCBA)

The maximum rated service life for a current positive pressure self-contained breathing apparatus (SCBA) at a $V_e$ of 40 liters is 2 hours [33].

---

IF THE REQUIRED SERVICE LIFE AT A $V_e$ OF 40 LITERS IS EQUAL TO OR GREATER THAN 2 HOURS

SEE NOTE F

IF THE REQUIRED SERVICE LIFE AT A $V_e$ OF 40 LITERS IS LESS THAN 2 HOURS

GO TO R 29

R 29

SERVICE LIFE (POSITIVE PRESSURE SCBA)

The maximum rated service life for a current open circuit positive pressure self-contained breathing apparatus (SCBA) at a $V_e$ of 40 liters is 1 hour [33].

---

IF THE REQUIRED SERVICE LIFE AT A $V_e$ OF 40 LITERS IS EQUAL TO OR GREATER THAN 1 HOUR

SELECT RESPIRATOR H

IF THE REQUIRED SERVICE LIFE AT A $V_e$ OF 40 LITERS IS LESS THAN 1 HOUR

SELECT RESPIRATOR I

HiEPF
or
PAPHiE*

A

TITLE: HIGH EFFICIENCY DUST, FUME & MIST RESPIRATOR WITH FULL FACEPIECE.

DESCRIPTION: A POWERED OR NON POWERED AEROSOL FILTERING RESPIRATOR WITH REPLACEABLE FILTERS.

ATTRIBUTES:
- o NOT FOR EMERGENCY USE
- o FILTER 99.97% EFFICIENT AGAINST 0.3 μm DOP
- o PF = 50
- o PROVIDES EYE PROTECTION

STANDARDS: NIOSH 30 CFR Part 11 Subpart K
(TC 21 C XXX)
See 30 CFR 11.130 (d) [187]

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

GMScHiE*

B

TITLE: CHIN STYLE GAS MASK WITH GAS/VAPOR CANISTER EQUIPPED WITH A HIGH EFFICIENCY DUST, FUME & MIST FILTER.

DESCRIPTION: A NON POWERED FULL FACEPIECE GAS MASK WITH THE CANISTER DIRECTLY ATTACHED TO THE FACEPIECE.

CANISTER IS SELECTED BASED ON THE GAS OR VAPOR PRESENT.

ATTRIBUTES:

- NOT FOR EMERGENCY USE
- PF = 50
- MAXIMUM TEST CONCENTRATION = 5000 ppm (0.5% v/v)
- FILTER 99.97% EFFICIENT AGAINST 0.3 μm DOP
- PROVIDES EYE PROTECTION

STANDARDS: NIOSH 30 CFR PART 11 SUBPART I
(TC 14G XXX)
SEE 30 CFR 11.90 (a)(3) [188]

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

GMScHiE*

C

TITLE: FRONT MOUNTED GAS MASK WITH GAS/VAPOR CANISTER EQUIPPED WITH A HIGH EFFICIENCY DUST, FUME & MIST FILTER.

DESCRIPTION: A NON POWERED FULL FACEPIECE GAS MASK WITH THE CANISTER MOUNTED ON THE WEARER'S CHEST AND ATTACHED TO THE FACEPIECE BY A BREATHING TUBE.

CANISTER IS SELECTED BASED ON THE GAS OR VAPOR PRESENT.

ATTRIBUTES:

- o NOT FOR EMERGENCY USE
- o PF = 50
- o MAXIMUM TEST CONCENTRATION = 20,000 ppm (2% v/v)(AMMONIA 3% v/v)
- o FILTER 99.97% EFFICIENT AGAINST 0.3 μm DOP
- o PROVIDES EYE PROTECTION

STANDARDS: NIOSH 30 CFR PART 11 SUBPART I
(TC 14G XXX)
SEE 30 CFR 11.90 (a)(1) OR (2) [189]

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

GMScHiE*

D

TITLE: BACK MOUNTED GAS MASK WITH GAS/VAPOR CANISTER EQUIPPED WITH A HIGH EFFICIENCY DUST, FUME & MIST FILTER.

DESCRIPTION: A NON POWERED FULL FACEPIECE GAS MASK WITH THE CANISTER MOUNTED ON THE WEARER'S BACK AND ATTACHED TO THE FACEPIECE BY A BREATHING TUBE.

CANISTER IS SELECTED BASED ON THE SINGLE GAS OR VAPOR PRESENT.

ATTRIBUTES:

- o NOT FOR EMERGENCY USE
- o PF = 50
- o MAXIMUM TEST CONCENTRATION = 20,000 ppm (2% v/v)(AMMONIA 3% v/v)
- o FILTER 99.97% EFFICIENT AGAINST 0.3 µm DOP
- o PROVIDES EYE PROTECTION

STANDARDS: NIOSH 30 CFR PART 11 SUBPART I
(TC 14G XXX)
SEE 30 CFR 11.90 (a)(1) OR (2) [189]

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

E

TITLE: TYPE "C" SUPPLIED AIR RESPIRATOR WITH FULL FACEPIECE OPERATED IN THE PRESSURE DEMAND MODE.

DESCRIPTION: A POSITIVE PRESSURE RESPIRATOR SUPPLIED WITH BREATHING AIR FROM CYLINDER(S) CONNECTED TO THE RESPIRATOR BY NOT MORE THAN 300 FEET OF HOSE.

ATTRIBUTES:
- o NOT FOR EMERGENCY USE
- o PF = 10,000 ($V_e$ < 40 Liters)
- o 300 FOOT MAXIMUM HOSE LENGTH
- o NO ESCAPE CAPABILITY

STANDARDS: NIOSH 30 CFR PART 11 SUBPART J
(TC 19C XXX)
SEE 30 CFR 11.110(a)(5) [38]

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

F

TITLE: NONE AVAILABLE

DESCRIPTION: NIOSH HAS NOT EVALUATED THESE CHARACTERISTICS IN AVAILABLE RESPIRATORS SINCE THEY EXCEED THE MINIMUM PERFORMANCE LEVELS SET BY 30 CFR PART 11. [190]

PERFORMANCE SHOULD BE VERIFIED BEFORE USE.

ATTRIBUTES:

STANDARDS:

G

TITLE: COMBINATION COMPRESSED AIR OPEN CIRCUIT SELF-CONTAINED BREATHING APPARATUS AND SUPPLIED AIR RESPIRATOR WITH FULL FACEPIECE OPERATING IN THE PRESSURE DEMAND MODE.

DESCRIPTION: SUPPLIED AIR RESPIRATOR WITH AUXILIARY SELF-CONTAINED AIR SUPPLY WHICH CAN BE USED FOR ESCAPE OR EGRESS.

UNITS WITH AN AUXILIARY AIR SUPPLY RATED FOR 15 MINUTES OR LONGER DURATION MAY BE USED FOR EMERGENCY ENTRY IF NOT MORE THAN 20% OF THE RATED CAPACITY IS USED FOR ENTRY.

ATTRIBUTES:
- o FOR LIMITED EMERGENCY USE
- o AUTOMATIC CHANGEOVER REQUIRED
- o PF = 10,000 (Ve < 40 liters SAR; $V_e$ < 67 liters SCBA MODE)
- o UP TO 60' RATED DURATION SCBA

STANDARDS: NIOSH 30 CFR PART 11 SUBPARTS H & J
(TC 13F XXX)
SEE 30 CFR 11.70 (b) [45]

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

H

TITLE: COMPRESSED OXYGEN CLOSED CIRCUIT SELF-CONTAINED BREATHING APPARATUS WITH FULL FACEPIECE OPERATED IN A POSITIVE PRESSURE MODE

DESCRIPTION: CLOSED OR PARTIALLY CLOSED CIRCUIT APPARATUS WITH CARBON DIOXIDE SCRUBBER AND OXYGEN SOURCE.

ALARM WARNS OF 20-25% REMAINING OXYGEN SUPPLY.

ATTRIBUTES:
- o FOR EMERGENCY USE
- o PF = 10,000 ($V_e$ < 40 liters)
- o 30', 60' & 2 HOUR RATED DURATION UNITS

STANDARDS: NIOSH 30 CFR PART 11 SUBPART H
(TC 13F XXX)
SEE 30 CFR 11.70 (a) (1) [53]

NIOSH HAS NO SPECIFIC TEST REQUIREMENTS FOR THIS SCBA

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

SCBAF;PD*

I

TITLE: COMPRESSED AIR OPEN CIRCUIT SELF-CONTAINED BREATHING APPARATUS WITH FULL FACEPIECE OPERATED IN THE PRESSURE DEMAND MODE

DESCRIPTION: CYLINDER OF COMPRESSED AIR USUALLY CARRIED ON THE WEARERS BACK. FLOW REGULATED ON DEMAND (INHALATION) OF THE WEARER WITH THE FACEPIECE PRESSURE REMAINING ABOVE AMBIENT AT LOW TO MODERATE FLOWS.

ALARM WARNS OF 20-25% REMAINING AIR SUPPLY

ATTRIBUTES:
- o FOR EMERGENCY USE
- o PF = 10,000 ($V_e$ < 67 liters)
- o 30' & 60' RATED DURATION UNITS
- o 2216 psig & 4500 psig RATED CYLINDERS
- o 45 $ft^3$ to 90 $ft^3$ CAPACITY

STANDARDS NIOSH 30 CFR PART 11 SUBPART H
(TC 13F XXX)
SEE 30 CFR 11.70 (a) (2) (ii) [191]

* Classification in NIOSH/OSHA Pocket Guide to Chemical Hazards

Chemical Protective Clothing (C)

## C 1

## SPECIAL PROBLEMS

There are several special problem areas which may require ancillary equipment to supplement or replace the normal chemical protective clothing. These would include fire, whether structural fire fighting or flammable or combustible liquid fire fighting; the potential blast and fragmentation effects of explosives; and work over water.

---

IF THE POTENTIAL FOR FIRE OR BLAST OR FRAGMENTATION EXISTS, OR WORK OVER WATER WILL BE CONDUCTED

GO TO C 2

IF THE POTENTIAL FOR FIRE OR BLAST OR FRAGMENTATION DOES NOT EXIST, OR IF WORK OVER WATER IS NOT INVOLVED

GO TO C 12

## C 2

## FIRE

Operations which potentially involve fire or exposure to flame or radiant heat are special cases since chemical protective clothing offers little, if any, resistance to flame or heat.

Consideration should be given to the possible effects of contamination of clothing with flammable or combustible materials. If either condition exists then additional protective clothing may be required.

---

IF SUBSTANCE IS FLAMMABLE OR INVOLVED IN FIRE

GO TO C 9

IF SUBSTANCE IS NOT FLAMMABLE OR NOT INVOLVED IN FIRE

GO TO C 3

C 3

## FLOATATION

No chemical protective garment offers adequate and dependable floatation in the event the wearer falls into water. Work over water usually will require a U.S. Coast Guard approved floatation device such as a work vest or life jacket. If such a device is worn, it must be protected from contamination but it normally can only be worn under a fully encapsulating suit. Other users should consider enclosing the device in a plastic bag [69].

---

IF WORK OVER WATER IS ANTICIPATED

SELECT SPECIAL PROTECTION J
GO TO 12

IF NO WORK OVER WATER IS ANTICIPATED

GO TO C 4

## C 4

## RADIATION

Ionizing radiation may require specialized protective ensembles.

---

IF THE EXPOSURE INVOLVES IONIZING RADIATION

GO TO C 8

IF THE EXPOSURE DOES NOT INVOLVE IONIZING RADIATION

GO TO C 5

## C 5

## BLAST AND FRAGMENTATION

Protection against blast and fragmentation is not particularly effective. If only very small quantities of a substance are involved (a couple of ounces) or distances are great (more than 10') then protection can be effective. With larger quantities, closer distances or inside or with a nearby reflective surface, the user of the protective equipment will be injured but his injuries _may_ be lessened by the ensemble [71].

---

IF THE SUBSTANCE MAY DETONATE OR PRODUCE FRAGMENTATION

GO TO C 6

IF THE SUBSTANCE MAY NOT DETONATE OR PRODUCE FRAGMENTATION

GO TO C 12

## C 6

## EXPLOSIVE EFFECTS

Protective equipment for blast and fragmentation effects of explosives is suitable only for quite limited quantities of substance. More than a couple of ounces of explosive may be sufficient to cause severe or even lethal injuries despite the use of protective equipment. As a rule of thumb, any quantity of explosives greater than 1/4# TNT equivalent should require reevaluation of the mission which makes PPE a necessity (i.e. Don't do it!) [71].

---

IF EXPLOSIVE IS LESS THAT 4 oz. $TNT_e$

| | |
|---|---|
| SELECT SPECIAL PROTECTION | I |
| GO TO | C 12 |

IF EXPLOSIVE IS 4 oz. OR MORE $TNT_e$

| | |
|---|---|
| GO TO | C 7 |

## C 7

## DISTANCE TO EXPLOSIVES

With the limitations on quantity of explosive to 1/4#, consideration should then be given to the distance of the explosive to the wearer of the PPE. Distances greater than 10 feet are recommended, or 20 feet if the wearer and explosive are indoors or the wearer is interposed between the explosive and a reflective surface such as a wall [71].

---

IF THE DISTANCE TO THE EXPLOSIVE IS EQUAL TO OR GREATER THAN 10 FEET UNREFLECTED OR EQUAL TO OR GREATER THAN 20 FEET REFLECTED

SELECT SPECIAL PROTECTION I
GO TO C 12

IF THE DISTANCE TO THE EXPLOSIVE IS LESS THAN 10 FEET UNREFLECTED OR LESS THAN 20 FEET REFLECTED

SEE NOTE K
GO TO C 12

C 8

IONIZING RADIATION AND CONTAMINATION PROTECTION ONLY

If the substance involved is radioactive then two different problems exist. One, protection against the direct effects of the ionizing radiation (shielding) cannot usually be provided by protective clothing. Secondly, protection against contamination can usually be provided by the appropriate selection of a material for protection against the non radioactive form of the substance.

If protection from a radioactive substance is directed solely to avoiding body contamination then use of appropriate chemical protective clothing will suffice.

If protection is required against the direct effects of ionizing radiation (shielding) or against tritium ($^3H$) then consultation with a knowledgeable health physicist is recommended before selection [73].

---

IF ONLY CONTAMINATION PROTECTION IS REQUIRED

GO TO C 12

IF PROTECTION AGAINST IONIZING RADIATION OR AGAINST TRITIUM ($^3H$) IS REQUIRED

SEE NOTE L
GO TO C 12

## C 9

## STRUCTURAL FIRE FIGHTING

Chemical protective clothing is not suitable for operations involving structural type fire fighting. Conversely, fire fighters turnout gear offers little chemical protection. Limited exposures of one hazard to the inappropriate equipment can be tolerated for short periods but any operation which envisions both heavy chemical exposure and significant fire fighting exposure must be redefined [62].

---

IF INVOLVED IN STRUCTURAL FIRE FIGHTING

| | |
|---|---|
| SELECT CLOTHING | F |
| GO TO | C 12 |

IF NOT INVOLVED IN STRUCTURAL FIRE FIGHTING

| | |
|---|---|
| GO TO | C 10 |

## C 10

## RADIANT HEAT

Chemical protective clothing (CPC) offers little protection from radiant heating. Such protection, in the form of proximity (fire) suits are available to wear over the CPC and can provide good protection, up to 90% reflectance, for a limited time period. They do not offer protection for fire or flame entry. In many instances, use of protective water sprays may be necessary to allow approach to a fire [64].

---

IF EXPOSED TO RADIANT HEAT

| | | |
|---|---|---|
| | SELECT CLOTHING | G |
| | GO TO | C 12 |

IF NOT EXPOSED TO RADIANT HEAT

| | | |
|---|---|---|
| | GO TO | C 11 |

C 11

FLASH FIRE

Users of chemical protective clothing (CPC) who may be exposed to a flash fire may be required to wear flame or fire retardant coveralls (such as Nomex (TM)) under the CPC. If the CPC is combustible or becomes contaminated with a flammable or combustible material, then exposure to a flash fire situation should be avoided [64].

---

IF POTENTIAL FOR EXPOSURE TO FLASH FIRE EXISTS

SELECT CLOTHING H
GO TO C 12

IF NO POTENTIAL FOR FLASH FIRE EXISTS

GO TO C 12

## C 12

## SUBSTANCE IDENTIFICATION

Substance identification is one of the most important factors in selection of personal protection equipment. Chemical resistance (permeation and degradation), fastener and material leakage and the necessity for precautions against fire and explosion are all substance dependent. If a positive identification can be made then specific protective materials may usually be selected. In the absence of positive identification, classification by chemical properties may be attempted. If classification is impractical, then an arbitrary selection is made and the presence of specific substances or classes of substances for which this choice is inappropriate must be ruled out.

---

IF THE SUBSTANCE CAN BE IDENTIFIED

GO TO C 13

IF THE SUBSTANCE CANNOT BE IDENTIFIED

GO TO C 22

## C 13

## KNOWN PERMEATION CHARACTERISTICS

The permeation of a substance through a suit material is a major factor in the protection the suit will provide from the substance. If this information is known, then it may be applied to the field situation. If the permeation data is not known, then recourse to classification or to preselection must be made. Permeation may occur even in the absence of degradation so both factors must be considered [192].

---

IF THE PERMEATION RATE AND BREAKTHROUGH TIME ARE KNOWN

GO TO C 14

IF THE PERMEATION RATE AND BREAKTHROUGH TIME ARE UNKNOWN

GO TO C 22

C 14

PERMEATION DATA

The permeation data should be specific as to test conditions and results. General guidelines such as good, fair or poor are not that helpful but they may be used if nothing else is available. The dose permeating the suit is proportional to the time duration of exposure (MD - BT), the permeation rate (PR), and the exposed surface area (BSA) [90].

Permeation Dose = (MD - BT) (PR) (BSA)

where: MD = mission duration; PR = permeation rate
BT = breakthrough time; BSA = suit surface area.

---

IF THE PERMEATION DOSE IS LESS THAN THE TOXIC DOSE

GO TO C 15

IF THE PERMEATION DOSE IS EITHER EQUAL TO OR GREATER THAN THE TOXIC DOSE OR IS UNKNOWN

GO TO C 13

## C 15

## KNOWN DEGRADATION CHARACTERISTICS

If degradation is known to occur with a specific substance or group of substances, then it's a relative contra-indication to the use of the suit material.

Swelling, weight gain, change in physical properties or cracking are all indications of unacceptable degradation [193].

---

IF DEGRADATION DATA IS KNOWN

GO TO C 16

IF DEGRADATION DATA IS UNKNOWN

GO TO C 13

C 16

## DEGRADATION DATA

If degradation does not occur during the anticipated mission duration then the suit material is acceptable. If degradation does occur then mission duration or exposure should be modified to prevent degradation. Reuse of a suit suggests that no degradation or weight gain is acceptable. Single use suits may have to be evaluated in terms of acceptable degradation without unacceptable employee exposure.

Relative rankings of good, fair, poor, etc. are of limited use [193].

---

| | | |
|---|---|---|
| IF DEGRADED BY SUBSTANCE | GO TO | C 13 |
| IF NOT DEGRADED BY SUBSTANCE | GO TO | C 17 |

## C 17

## AIRBORNE

Airborne substances include those generated by operations which due to particle size have very rapid settling times. This is to allow for protection against large particles which may penetrate suit openings from sprays, splashes, or "dust" clouds.

---

IF THE SUBSTANCE IS AIRBORNE GO TO C 18

IF THE SUBSTANCE IS NOT AIRBORNE GO TO C 20

C 18

SKIN EFFECTS

Skin effects include not only acute irritation but chronic effects and the hazards associated with skin contamination and subsequent ingestion or inhalation. Permissible skin exposure data are not available so that prevention of any exposure may be the goal of skin protection [194].

---

IF THE SUBSTANCE HAS SKIN EFFECTS OR IS UNKNOWN

SELECT CLOTHING M

IF THE SUBSTANCE HAS NO SKIN EFFECTS

GO TO C 19

C 19

## PHYSICAL STATE

The physical state of the substance is of importance in determining the infiltration rate or ease of infiltration through fasteners or interfaces of personal protective equipment. Additionally, the need for and extent of decontamination must be considered.

---

IF THE SUBSTANCE IS A GAS OR VAPOR

SELECT CLOTHING D

IF THE SUBSTANCE IS AN AEROSOL

SELECT CLOTHING C

C 20

PHYSICAL STATE

The physical state of the substance is of importance in determining the infiltration rate or ease of infiltration through fasteners or interfaces of personal protective equipment. Additionally the need for and extent of decontamination must be considered.

---

| | | |
|---|---|---|
| IF THE SUBSTANCE IS A LIQUID | | |
| | GO TO | C 21 |
| IF THE SUBSTANCE IS A SOLID | | |
| | SELECT CLOTHING | C |

## C 21

## SKIN

Skin effects include not only acute irritation but chronic effects and the hazards associated with skin contamination, skin absorption and subsequent ingestion or inhalation. Permissible skin exposure data are not usually available so that prevention of any exposure may be the goal of skin protection [194].

---

IF THE SUBSTANCE HAS SKIN EFFECTS OR IF IT IS UNKNOWN

SELECT CLOTHING E

IF THE SUBSTANCE HAS NO SKIN EFFECTS

SELECT CLOTHING C

C 22

SUBSTANCE CLASSIFICATION

If the substance cannot be identified but chemical classification is possible, then use of a look- up table based upon the recommendations of manufacturers can be used for a tentative material selection [90].

---

IF SUBSTANCE CAN BE CLASSIFIED

GO TO C 23

IF SUBSTANCE CANNOT BE CLASSIFIED

GO TO C 25

## C 23

## PERMEATION

Permeation data listed by a class of substances may be used to determine the acceptability of protection afforded by a suit material. Ranking (1 of 6) or relative rankings (excellent) may imply maximal protection. Your judgement must be used to determine if the consequences of exposure due to suit permeation are acceptable in light of the mission goals to be obtained.

---

IF THE PERMEATION ACCEPTABLE

GO TO C 24

IF THE PERMEATION IS NOT ACCEPTABLE

GO TO C 22

C 24

DEGRADATION

Degradation data listed by a class of substances may be used to determine the acceptability of protection afforded by a suit material. Ranking (1 of 6) or relative rankings (excellent) may imply maximal protection. Your judgement must be used to determine if the consequences of exposure due to suit degradation are acceptable in light of the mission goals to be obtained.

---

IF THE DEGRADATION IS ACCEPTABLE

GO TO C 17

IF THE DEGRADATION IS NOT ACCEPTABLE

GO TO C 22

C 25

## DETECTOR TUBE "RULE-OUT" GUIDE

If classification cannot be made, detector tubes (or other similar methods) may be used to "rule-out" the use of certain materials used in chemical protective clothing [195].

---

IF YOU USE DETECTOR TUBES OR A SIMILAR METHOD

GO TO C 26

IF YOU DO NOT USE "RULE-OUT"

SELECT CLOTHING A

C 26

Detector tubes may be used to rule out the use of certain materials used in chemical protective clothing. The following suggestion uses a Drager detector tube. Use of other manufacturer's tubes has not been evaluated [17].

| TUBE | PART NO. | REACTION | RESULTS CODE |
|---|---|---|---|
| NITROUS FUMES | 64-24001 | REDDISH-BROWN | 2 |
| | | NONE | 4 |

GO TO C 27

C 27

Detector tubes may be used to rule out the use of certain materials used in chemical protective clothing. The following suggestion uses a Drager detector tube. Use of other manufacturer's tubes has not been evaluated [17].

| TUBE | PART NO. | REACTION | RESULTS CODE |
|---|---|---|---|
| EPICHLORHDORIN | 67-28111 | PALE YELLOWISH-ORANGE | 2 |
| | | NONE | 4 |

GO TO C 28

C 28

Detector tubes may be used to rule out the use of certain materials used in chemical protective clothing. The following suggestion uses a Drager detector tube. Use of other manufacturer's tubes has not been evaluated [17].

| TUBE | PART NO. | REACTION | RESULTS CODE |
|---|---|---|---|
| FORMIC ACID | 67-22701 | YELLOW | 1 |
| | | NONE | 4 |

GO TO C 29

Detector tubes may be used to rule out the use of certain materials used in chemical protective clothing. the following suggestion uses a Drager detector tube. Use of other manufacturer's tubes has not been evaluated [17].

| TUBE | PART NO. | REACTION | RESULTS CODE |
|---|---|---|---|
| METHYL BROMIDE | 67-28211 | BROWN | 1 |
| | | NONE | 4 |

GO TO C 30

C 30

Detector tubes may be used to rule out the use of certain materials used in chemical protective clothing. The following suggestion uses a Drager detector tube. Use of other manufacturer's tubes has not been evaluated [17].

| TUBE | PART NO. | REACTION | RESULTS CODE |
| --- | --- | --- | --- |
| ETHYL ACETATE | CH 20201 | PALE GREEN<br>BROWNISH-GREEN | GO TO 32<br>GO TO 31 |
| | | NONE | 4 GO TO C 33 |

C 31

Detector tubes may be used to rule out the use of certain materials used in chemical protective clothing. The following suggestion uses a Drager detector tube. Use of other manufacturer's tubes has not been evaluated [17].

| TUBE | PART NO. | REACTION | RESULTS CODE |
|---|---|---|---|
| HYDROCARBON | CH 25401 | YELLOW | 4 |
| | | BROWN-REDDISH BROWN | 1 |
| | | NONE | 4 |

GO TO C 33

C 32

Detector tubes may be used to rule out the use of certain materials used in chemical protective clothing. The following suggestion uses a Drager detector tube. Use of other manufacturer's tubes has not been evaluated [17].

| TUBE | PART NO. | REACTION | RESULTS CODE |
|---|---|---|---|
| ACETONE | CH 22901 | YELLOW | 2 |
| | | NONE | 4 |

C 33

RESULTS CODE

Circle every number which is a result of testing. Select clothing indicated by intersection of rows and columns. Where more than one letter is indicated, select clothing N.

| | 1 | 2 | 4 |
|---|---|---|---|
| 1 | B | N | B |
| 2 | N | A | A |
| 4 | B | A | A, or B or M |

A

TITLE: FULLY ENCAPSULATING SUIT OF BUTYL RUBBER IN "A" CONFIGURATION

DESCRIPTION: ONE PIECE GARMENT FULLY COVERING HEAD, TORSO, AND EXTREMITIES. USED WITH SCBA WHICH IS WORN UNDERNEATH THE SUIT ("A" CONFIGURATION). MAY HAVE INTEGRAL BOOTS AND/OR GLOVES. HELMET, IF REQUIRED, IS ADDITIONAL IN MOST SUITS. BOOT COVERS USUALLY USED.

ATTRIBUTES:
- o FULLY ENCAPSULATING
- o "GAS TIGHT"

STANDARDS:
PERMEATION: ASTM F739-81 [196]
SWELLING AND SOLUBILITY: ASTM D471-79 [197]
STRENGTH DEGRADATION: ASTM D543-67(1978) [198]
BOOT TOE CAP: ANSI Z41-1981 [91]
HELMET: ANSI Z89.1-1981 [114]

B

TITLE: FULLY ENCAPSULATING SUIT OF VITON IN "A" CONFIGURATION

DESCRIPTION: ONE PIECE GARMENT FULLY COVERING HEAD, TORSO, AND EXTREMITIES. USED WITH SCBA WHICH IS WORN UNDERNEATH THE SUIT ("A" CONFIGURATION). MAY HAVE INTEGRAL BOOTS AND/OR GLOVES. HELMET, IF REQUIRED, IS ADDITIONAL IN MOST SUITS. BOOT COVERS USUALLY USED.

ATTRIBUTES:
- o FULLY ENCAPSULATING
- o "GAS TIGHT"

STANDARDS:
PERMEATION: ASTM F739-81 [196]
SWELLING AND SOLUBILITY: ASTM D471-79 [197]
STRENGTH DEGRADATION: ASTM D543-67(1978) [198]
BOOT TOE CAP: ANSI Z41-1981 [91]
HELMET: ANSI Z89.1-1981 [114]

C

TITLE: "DISPOSABLE" COVERALLS OF NONWOVEN FABRIC. MAY BE COATED WITH PLASTIC

DESCRIPTION: ONE PIECE GARMENT FULLY COVERING TORSO AND EXTREMITIES. USED WITH ANY APPROPRIATE RESPIRATOR, BOOTS, BOOT COVERS, AND GLOVES. HELMET AND/OR HOOD MAY BE REQUIRED AS ADDITIONAL ITEMS.

ATTRIBUTES:
- o DISPOSABLE
- o LIMITED DUST AND/OR LIQUID TIGHTNESS

STANDARDS:
PERMEATION: ASTM F739-81 [196]
SWELLING AND SOLUBILITY: ASTM D471-79 [197]
STRENGTH DEGRADATION: ASTM D543-67(1978) [198]
BOOT TOE CAP: ANSI Z41-1981 [91]
HELMET: ANSI Z89.1-1981 [114]

D

TITLE: NONENCAPSULATING SUIT. USUALLY OF PLASTIC IMPREGNATED CLOTH, RUBBER, OR SOLID PLASTIC SHEET

DESCRIPTION: USUALLY TWO PIECE GARMENT FULLY COVERING HEAD, TORSO, AND EXTREMITIES. CONSISTS OF JACKET WITH HOOD AND BIB PANTS. USED WITH ANY APPROPRIATE RESPIRATOR, BOOTS, BOOT COVERS, AND GLOVES. HELMET MAY BE REQUIRED AS ADDITIONAL ITEM. GLOVES AND BOOTS TAPED.

ATTRIBUTES: o DUST AND LIQUID TIGHT

STANDARDS: NONE

E

TITLE: SPLASH SUIT. USUALLY OF PLASTIC IMPREGNATED CLOTH OR PLASTIC.

DESCRIPTION: USUALLY TWO PIECE GARMENT COVERING TORSO AND EXTREMITIES. CONSISTS OF JACKET AND PANTS. USED WITH ANY APPROPRIATE RESPIRATOR, BOOTS, BOOT COVERS AND GLOVES. HELMET, HOOD APRON, GLOVED APRON, OR GLOVED SLEEVES MAY BE USED.

ATTRIBUTES: o LIQUID RESISTANT

STANDARDS: NONE

F

TITLE: FIRE FIGHTER'S TURNOUT GEAR, USUALLY OF HIGH TEMPERATURE RESISTANT NYLON

DESCRIPTION: TWO PIECE GARMENT CONSISTING OF PANTS AND COAT, USED WITH HOOD, HELMET, GLOVES, BOOTS, AND SCBA

ATTRIBUTES:

- LIMITED HEAT RESISTANCE
- VERY LIMITED CHEMICAL RESISTANCE
- USED PRIMARILY FOR STRUCTURAL TYPE FIRE FIGHTING

STANDARDS:

COAT AND PANTS: NFPA 1971-1981 [62]
HELMET: NFPA 1972-1979 [61]
GLOVES: NFPA (proposed) [199]
BOOT TOE CAP: ANSI Z41-1981 [91]

G

TITLE: PROXIMITY SUIT (FIRE). ALUMINIZED HIGH TEMPERATURE RESISTANT NYLON OR RAYON.

DESCRIPTION: ONE, TWO, OR THREE PIECE GARMENT CONSISTING OF COAT, PANTS, AND HOOD OF ALUMINIZED (REFLECTIVE) MATERIAL. ALUMINIZED GLOVES AND BOOT COVERS MAY BE PROVIDED. USED WITH SCBA.

ATTRIBUTES:
- o VERY LIMITED CHEMICAL RESISTANCE
- o LIMITED HEAT RESISTANCE
- o UP TO 90% REFLECTIVITY
- o ASBESTOS UNACCEPTABLE

STANDARDS: NONE COMMERCIAL
COAT: MIL-C-29145A [200]
PANTS: MIL-T-29146A [201]
GLOVES MIL-G-87077 [202]
HOOD MIL-H-29144A [203]

H

TITLE: FLAME/FIRE RETARDANT COVERALLS

DESCRIPTION: COVERALLS WORN AS AN UNDERGARMENT WHERE FLASH FIRES MAY OCCUR.

ATTRIBUTES: o FLAME/FIRE RETARDANT

STANDARDS: NONE COMMERCIAL

DISCUSSION: NOMEX WILL BURN WITH SLIGHT OXYGEN ENRICHMENT SUCH AS MIGHT OCCUR WITH A CLOSED CIRCUIT SCBA AND AN "A" CONFIGURATION FULLY ENCAPSULATING SUIT.

I

TITLE: BLAST/FRAGMENTATION SUIT

DESCRIPTION: HEAD AND TORSO PROTECTION WORN WITH OTHER PROTECTIVE CLOTHING. HEARING PROTECTION (PREFERABLY MUFF TYPE) MUST BE WORN.

ATTRIBUTES:

- o LIMITED BLAST AND FRAGMENTATION ATTENUATION AND MITIGATION
- o PERSONAL INJURY WILL PROBABLY OCCUR IN THE EVENT OF AN EXPLOSION.

STANDARDS: NONE COMMERCIAL

J

TITLE: FLOATATION GEAR

DESCRIPTION: LIFE JACKETS OR WORK VESTS OF UNICELLULAR PLASTIC FOAM, FIBERGLASS, KAPOK, OR SIMILAR APPROVED MATERIAL.

ATTRIBUTES: o PROVIDE w17 1/2 TO 25# FLOATATION.

STANDARDS: WORK VEST, LIFE JACKET: USCG 46 CFR Part 160 [69]
(VARIOUS TYPES ARE AVAILABLE)

K

TITLE: NONE AVAILABLE

DESCRIPTION: NO PROTECTIVE EQUIPMENT MEETING THESE PERFORMANCE CRITERIA ARE KNOWN.

L

TITLE: REQUIRE HEALTH PHYSICS CONSULTATION

DESCRIPTION: RUBBER PROTECTIVE APRON AND GLOVES ARE AVAILABLE WITH DIFFERING ATTENUATIONS FOR IONIZING RADIATION. THIS ATTENUATION IS USUALLY GIVEN AS A LEAD EQUIVALENT IN mm. AND WOULD PROVIDE THE SAME PROTECTION AS THE STATED THICKNESS OF LEAD. THEIR SELECTION AND USE REQUIRES SPECIALIZED CALCULATION WHICH CAN BEST BE PERFORMED BY A HEALTH PHYSICIST.

M

TITLE: FULLY ENCAPSULATING SUIT IN "A" CONFIGURATION

DESCRIPTION: ONE PIECE GARMENT FULLY COVERING HEAD, TORSO, AND EXTREMITIES. USED WITH SCBA WHICH IS WORN UNDERNEATH THE SUIT ("A" CONFIGURATION). MAY HAVE INTEGRAL BOOTS AND/OR GLOVES. HELMET, IF REQUIRED, IS ADDITIONAL IN MOST SUITS. BOOT COVERS USUALLY USED. MATERIAL SHOULD BE SELECTED BASED UPON THE PERMEATION AND DEGRADATION DATA OBTAINED FOR THIS MATERIAL/CHEMICAL COMBINATION. YOU CAN USE EITHER VITON OR BUTYL.

ATTRIBUTES:
- o FULLY ENCAPSULATING
- o "GAS TIGHT"

STANDARDS:
PERMEATION: ASTM F739-81 [196]
SWELLING AND SOLUBILITY: ASTM D471-79 [197]
STRENGTH DEGRADATION: ASTM D543-67(1978) [198]
BOOT TOE CAP: ANSI Z41-1981 [91]
HELMET: ANSI Z89.1-1981 [114]

N

TITLE: FULLY ENCAPSULATING SUIT IN "A" CONFIGURATION

DESCRIPTION: ONE PIECE GARMENT FULLY COVERING HEAD, TORSO, AND EXTREMITIES. USED WITH SCBA WHICH IS WORN UNDERNEATH THE SUIT ("A" CONFIGURATION). MAY HAVE INTEGRAL BOOTS AND/OR GLOVES. HELMET, IF REQUIRED, IS ADDITIONAL IN MOST SUITS. BOOT COVERS USUALLY USED. MATERIAL SHOULD BE SELECTED BASED UPON THE PERMEATION AND DEGRADATION DATA OBTAINED FOR THIS MATERIAL/CHEMICAL COMBINATION.

SINCE SUBSTANCES TO WHICH THE SUIT IS EXPOSED PERMEATE BOTH VITON AND BUTYL COMPOSITE, BUTYL OVER VITON SUITS WITH AN OVERGARMENT MAY BE REQUIRED. EXPOSURE MUST BE MAINTAINED AT A MINIMUM!

ATTRIBUTES:
- o FULLY ENCAPSULATING
- o "GAS TIGHT"

STANDARDS:
PERMEATION: ASTM F739-81 [196]
SWELLING AND SOLUBILITY: ASTM D471-79 [197]
STRENGTH DEGRADATION: ASTM D543-67(1978) [198]
BOOT TOE CAP: ANSI Z41-1981 [91]
HELMET: ANSI Z89.1-1981 [114]

## Part III: Calculating the Required Cooling Capacity and Air/Oxygen Supply

### INTRODUCTION: The Mission and the Man

Once a suitable ensemble of PPE - respirator, chemical protective clothing, and ancillary equipment - has been selected, factors which affect mission duration must be carefully considered. Of great concern is the interaction of human and environmental factors which influence the buildup of heat within the PPE/wearer microenvironment, and which affect the rate of air/oxygen consumption as well.

Several important factors must be considered in calculating: 1) the cooling capacity required to maintain suit temperature at a level which will reduce the risk of heat injury to the worker, and 2) the amount of air/oxygen supply necessary for completion of the projected task. These calculations are essential in the determination of whether:

- a cooling device is necessary
- the available cooling capacity is sufficient to accomplish the intended mission
- the available air/oxygen supply is sufficient to accomplish the intended mission
- the mission duration/work regimen must be adjusted to maintain the safety of the worker.

A procedure for the step-by-step calculation of necessary cooling capacity and air/oxygen supply follows. The procedure utilizes worksheets and look-up tables to guide the mission planner in selecting the proper components and in modifying the mission should cooling requirements and air/oxygen requirements exceed that available. The look-up tables follow the worksheets provided in this section.

### HOW TO USE THE CALCULATION WORKSHEETS

We can use calculations based on laboratory investigation and field experience to estimate the amount of time a wearer can use the various protective ensembles.

Five basic limitations to suit use time are:

1) suit permeation
2) suit degradation
3) air/oxygen consumption
4) coolant consumption
5) amount of body heat that can safely be stored.

The following pages discuss the use of the tables and calculations to estimate these factors. Mission duration is limited to the shortest time estimated.

Metabolic Heat

The amount of metabolic heat produced by a worker is dependent upon the workrate of the individual, the duration of the work, and modifications to his workrate and heat retention due to the protective ensemble.

Using Table III-1 you can look up the approximate rate of metabolic heat produced for various tasks.

Modifications to the workrates given in Table III-1, which are for a 154-pound person in light street clothes, can be made for:

- o slope (Table III-2)
- o terrain (Table III-2)
- o body weight (Table III-3)
- o ensemble weight (Table III-4)
- o ensemble encumbrance (Table III-5)
- o heat efficiency (Table III-9) and,
- o heat loading (Table III-10).

The product of these factors and the workrate is the metabolic heat stress rate. The amount of heat produced in kcals is simply the rate x task duration or

$$\frac{\text{kcal}}{\text{min}} \times \text{min} = \text{kcal}$$

where the times (in minutes) cancel out.

When more than a single task is required and the workrates differ, you can calculate the amount of heat generated by each task and add these amounts up.

$$\underset{\text{(first task)}}{(\text{kcal/min} \times \text{min})} + \underset{\text{(next task)}}{(\text{kcal/min} \times \text{min})} + \underset{\text{(last task)}}{(\text{kcal/min} \times \text{min})} = \underset{\text{(total of all)}}{\text{kcal}}$$

Or, you can estimate the composite workrate. The most conservative approach would be to take the maximum workrate and use that for your calculations.

## Environmental Heat

The major environmental heat stressors are based on a single average calculation. This factor, which varies with the dry bulb temperature, is given for temperatures above that of the normal skin temperature.

When this environmental heat stress from Table III-11 is added to the metabolic heat stress the sum is the total heat stress on the worker.

## Required Coolant Supply

The amount of coolant water ice required for a mission can be estimated by dividing the amount of heat generated by 80 kcal/kg and multiplying by the efficiency of the cooling garment.

## Coolant Duration

The duration of cooling (until the ice is just melted) can be estimated by dividing the weight of coolant provided by the total heat stress rate and multiplying by the efficiency of the cooling garment.

## Mission Duration without Cooling

The body can store about 80 kcal without serious ill effect. The time required to store this amount of heat can be estimated by dividing the 80 kcal by the total heat stress rate.

## Air Consumption Rate and Open Circuit SCBA or SAR Duration

Based on the relationship between workrate and the minute volume, estimation of the duration of common open circuit SCBA or combination SCBA/SAR can be made from Table III-8.

## Required Air Supply

Using the values of the Table III-8 for air consumption rates, we can estimate the required air supply for a given mission by multiplying the air consumption rate by the anticipated mission duration.

## Mission Duration Limited by Air Supply

The time required to consume a given air supply in an open circuit SCBA or SAR can be estimated by dividing the available air supply by the air consumption rate.

## Oxygen Consumption Rate

A rough estimation of the oxygen consumption rate can be obtained from Table III-8.

Mission Duration Limited by Oxygen Supply

A rough estimation of mission duration when using closed circuit SCBA can be obtained from Table III-8.

Required Oxygen Supply

The required oxygen supply for a closed circuit SCBA can be roughly estimated by using Table III-8.

Employee Fitness - Maximum or Peak Workrate

An estimate of the peak workrate of an employee can be obtained from Table III-6 if a subjective evaluation of the employee's overall physical fitness can be made. (See Table I-1.)

Sustained Workrate or Duty Factor

An estimate of an employee's ability to sustain a given workrate for a given period of time can be obtained from Table III-7

It must be emphasized that the results of the calculations following will be estimations, designed to aid the user in making equipment selection and procedural decisions. The decisions finally adopted must be based ultimately upon the user's best professional judgement.

TITLE: METABOLIC HEAT STRESS RATE

TO FIND: METABOLIC HEAT STRESS RATE IN $\frac{kcal}{min}$

ENTER: AVERAGE ENERGY EXPENDITURE IN $\frac{kcal}{min}$ TABLE III-1

| | |
|---|---|
| SLOPE FACTOR | TABLE III-2 |
| TERRAIN FACTOR | |
| BODY WEIGHT FACTOR | TABLE III-3 |
| ENSEMBLE WEIGHT FACTOR | TABLE III-4 |
| ENCUMBRANCE FACTOR | TABLE III-5 |
| HEAT EFFICIENCY FACTOR | TABLE III-9 |
| HEAT LOAD FACTOR | TABLE III-10 |

= AVERAGE ENERGY EXPENDITURE $\left(\frac{kcal}{min}\right)$

CALCULATION: SLOPE FACTOR X TERRAIN FACTOR X
BODY WEIGHT FACTOR X EQUIPMENT WEIGHT FACTOR X
ENCUMBRANCE FACTOR X EQUIPMENT HEAT FACTOR

$$=\frac{kcal}{min} \times (f_1) \times (f_2) \times (f_3) \times (f_4) \times (f_5) \times (f_6) \times (f_7)$$

RESULT: $= \frac{kcal}{min}$

NOTES: On the following worksheets, the calculated results from each worksheet are designated by worksheet number (e.g., W1, W2, W3 . . . etc.).

TITLE: ENVIRONMENTAL HEAT STRESS RATE

TO FIND: ENVIRONMENTAL HEAT STRESS RATE IN $\frac{(kcal)}{(min)}$

ENTER: ENVIRONMENTAL TEMPERATURE (DRY BULB) in $^{o}C$

CALCULATION: LOOK UP ENVIRONMENTAL HEAT STRESS RATE IN TABLE III-11

$\frac{(kcal)}{(min)}$

RESULT: $= \frac{kcal}{min}$

NOTES:

TITLE: TOTAL HEAT STRESS RATE

TO FIND: TOTAL HEAT STRESS RATE IN $\frac{(kcal)}{(min)}$

ENTER: METABOLIC HEAT STRESS RATE IN $\frac{(kcal)}{(min)}$ W1

ENVIRONMENTAL HEAT STRESS RATE IN $\frac{(kcal)}{(min)}$ W2

METABOLIC HEAT STRESS RATE $\frac{(kcal)}{(min)}$ +

ENVIRONMENTAL HEAT STRESS RATE $\frac{(kcaL)}{(min)}$

CALCULATION: $= \frac{(kcal)}{(min)} + \frac{(kcal)}{(min)}$

RESULT: $= \frac{kcal}{min}$

NOTES: W1 + W2 = W3

TITLE: REQUIRED COOLANT SUPPLY

TO FIND: REQUIRED AMOUNT OF ICE FOR A GIVEN MISSION

ENTER: TOTAL HEAT STRESS RATE IN $\frac{\text{(kcal)}}{\text{(min)}}$ W3

MISSION DURATION

$$= \frac{\text{TOTAL HEAT STRESS RATE } \frac{\text{(kcal)}}{\text{(min)}} \times \text{MISSION DURATION (min)}}{80 \ \frac{\text{kcal}}{\text{kg}}} \times \text{cooling efficiency } .2$$

CALCULATION: $= \frac{\frac{\text{kcal}}{\text{min}} \times \text{min}}{\frac{80\ \text{C}}{\text{kg}}} \times .2$

COOLANT (ICE) WEIGHT IN KILOGRAMS*

RESULT: = kg

NOTES: * 1 KILOGRAM = 2.2 POUNDS
1 POUND = 0.45 KILOGRAMS

TITLE: COOLANT DURATION

TO FIND: COOLANT DURATION IN MINUTES AT A GIVEN HEAT STRESS RATE

ENTER: TOTAL HEAT STRESS RATE IN $\frac{(kcal)}{(min)}$ W3

COOLANT (ICE) WEIGHT IN KILOGRAMS*

$$= \frac{\text{COOLANT WEIGHT (kg)} \times \frac{80 \text{ kcal}}{\text{kg}}}{\text{TOTAL HEAT STRESS RATE } \frac{\text{kcal}}{\text{min}}} \quad \text{x cooling efficiency .2}$$

CALCULATION:= $\frac{\frac{\text{kg x 80 kcal}}{\text{kg}}}{\frac{\text{kcal}}{\text{min}}} \quad \text{X} \quad .2$

RESULT: = DURATION (min)

NOTES: * 1 KILOGRAM = 2.2 POUNDS
1 POUND = 0.45 KILOGRAMS

TITLE: MISSION DURATION WITHOUT COOLING

TO FIND: MISSION DURATION IN MINUTES IF COOLING IS NOT PROVIDED

ENTER: TOTAL HEAT STRESS RATE IN $\frac{(kcal)}{(min)}$ W3

$$= \frac{80 kcal}{\text{TOTAL HEAT STRESS RATE } \frac{(kcal)}{(min)}}$$

CALCULATION: $= \frac{80}{\frac{kcal}{min}}$

RESULT: = min

NOTES:

TITLE: AIR CONSUMPTION RATE & OPEN CIRCUIT SCBA/SAR DURATION

TO FIND: AIR CONSUMPTION RATE ($V_e$) & DURATION OF OPEN CIRCUIT SCBA/SAR

ENTER: METABOLIC RATE $\frac{(kcal)}{(min)}$ W1

CALCULATION: LOOK UP VALUES IN TABLE III-8

RESULT: AIR CONSUMPTION RATE ($V_e$)*

DURATION OF OPEN CIRCUIT SCBA

NOTES: * ALSO CALLED MINUTE VOLUME

TITLE: REQUIRED AIR SUPPLY

TO FIND: REQUIRED VOLUME OF AIR FOR A GIVEN MISSION USING OPEN CIRCUIT SCBA OR SAR

ENTER: METABOLIC RATE $\frac{(kcal)}{(min)}$ W1

ANTICIPATED MISSION DURATION

CALCULATION: LOOK UP AIR CONSUMPTION RATE IN TABLE III-8

= AIR CONSUMPTION RATE X ANTICIPATED MISSION DURATION

$= \frac{\text{liters}}{\text{min}} \times \text{min}$

RESULT: REQUIRED AIR SUPPLY IN LITERS*

NOTES: * 1 LITER = 0.035 CU. FEET
1 CU. FOOT = 28.32 LITERS
45 CU. FEET - 1200 LITERS
90 CU. FEET - 2400 LITERS

TITLE: MISSION DURATION - AIR SUPPLY

TO FIND: MISSION DURATION IN MINUTES AT A GIVEN WORKRATE & AIR SUPPLY

ENTER:

AVAILABLE AIR SUPPLY IN (LITERS)

AIR CONSUMPTION RATE IN $\frac{\text{(LITERS)}}{\text{(min)}}$ W7

$$= \frac{\text{AVAILABLE AIR SUPPLY (LITERS)*}}{\text{AIR CONSUMPTION RATE } \frac{\text{(LITERS)}}{\text{(min)}}}$$

CALCULATION: $= \frac{\text{liters}}{\frac{\text{liters}}{\text{min}}}$

RESULT: = min

NOTES: * 1 LITER = 0.035 CU. FEET
1 CU. FOOT = 28.32 LITERS

TITLE: OXYGEN CONSUMPTION RATE & CLOSED CIRCUIT SCBA DURATION

TO FIND: OXYGEN CONSUMPTION RATE ($Vo_2$) & DURATION OF CLOSED CIRCUIT SCBA

ENTER: METABOLIC RATE $\frac{(kcal)}{(min)}$ W1

CALCULATION: LOOK UP VALUES IN TABLE III-8

RESULT: OXYGEN CONSUMPTION RATE ($Vo_2$)*

DURATION OF CLOSED CIRCUIT SCBA

NOTES: * ALSO CALLED OXYGEN UPTAKE

TITLE: REQUIRED OXYGEN SUPPLY

TO FIND: RATED DURATION CLOSED CIRCUIT SCBA REQUIRED FOR A GIVEN MISSION

ENTER: METABOLIC RATE $\frac{(kcal)}{(min)}$ W1

ANTICIPATED MISSION DURATION

CALCULATION: LOOK UP RATED DURATION OF CLOSED CIRCUIT SCBA WHICH MEETS THE CALCULATED DURATION (Table III-8)

RESULT: REQUIRED RATED DURATION CLOSED CIRCUIT SCBA

NOTES:

TITLE: MISSION DURATION - $O_2$ SUPPLY

TO FIND: MISSION DURATION IN MINUTES AT A GIVEN WORKRATE & $O_2$ SUPPLY

ENTER: METABOLIC RATE $\frac{(kcal)}{(min)}$ W1

CALCULATION: LOOK UP DURATION OF CLOSED CIRCUIT SCBA USED AT THE GIVEN METABOLIC HEAT STRESS RATE (Table III-8)

RESULT: MISSION DURATION IN MINUTES AT A GIVEN WORKRATE AND $O_2$ SUPPLY

NOTES:

TITLE: EMPLOYEE FITNESS

TO FIND: FITNESS TO PRODUCE A GIVEN WORKRATE

ENTER: METABOLIC RATE IN $\frac{(kcal)}{(min)}$ W1

PHYSICAL FITNESS CATEGORY

CALCULATION: LOOK UP EXPECTED PEAK WORKRATE FOR A GIVEN PHYSICAL FITNESS CATEGORY (Table III-6)

RESULT: REQUIRED LEVEL OF FITNESS FOR PEAK WORKRATE

NOTES:

W 14

TITLE: EMPLOYEE DUTY FACTOR

TO FIND: ABILITY OF EMPLOYEE TO SUSTAIN A GIVEN WORKRATE

ENTER: METABOLIC RATE IN $\frac{(kcal)}{(min)}$ W1

MISSION DURATION

CALCULATION: LOOK UP EXPECTED DUTY FACTOR
(Table III-7)

RESULT: SUSTAINED PEAK WORKRATE

NOTES:

TITLE: WORK-REST REGIMEN

TO FIND: REQUIRED REST PERIOD IN MINUTES FOR A GIVEN TASK

ENTER: TOTAL HEAT STRESS RATE $\frac{(kcal)}{(min)}$* W3

MISSION DURATION (min)

RESTING FACTOR TABLE III - 12

CALCULATION: = MISSION DURATION (min) X RESTING FACTOR

$= min \times (f_1)$

RESULT: = REQUIRED REST PERIOD IN MINS.

NOTES: * USED TO FIND RESTING FACTOR

TABLE III - 1
ESTIMATE OF METABOLIC (WORK) RATES

| TASK | kcal/min |
| --- | --- |
| WALKING, LEVEL ON BLACKTOP | |
| 2 MPH | 2 1/2 - 4 |
| 3 MPH | 4 - 5 |
| 4 MPH | 6 - 7 |
| BENCH CHEMISTRY | 2 - 4 |
| LIGHT CARPENTRY | 5 - 6 |
| SHOVELING | |
| LIGHT EARTH | 6 - 7 |
| 10 PER MIN. 10 kg. | 7 - 8 |
| 10 PER MIN. 14 kg. | 10 - 11 |
| 10 PER MIN. 16 kg. | 11+ |
| ESCAPE (RUNNING 6 MPH) | 11+ |
| CLIMBING | |
| STAIRS | 15 |
| LADDER (40 FPM) | 9 |
| VERTICAL LADDER (40 FPM) | 12 |
| DESCENDING | |
| STAIRS | 5 |
| LADDER | 3 |
| VERTICAL LADDER | 4 |

[Adapted from 174, 204-207]

TABLE III-2
ESTIMATE OF CORRECTION FOR
VARIOUS SLOPES/TERRAINS

SLOPE FACTOR*

| SLOPE (% GRADE) | SPEED IN WALKING ASCENDING 2 mph | 3 mph | DESCENDING |
|---|---|---|---|
| 0 | 1 | 1 | 1 |
| 5 | 1.56 | 1.64 | 0.75 |
| 10 | 2.12 | 2.24 | 0.75 |
| 15 | 2.64 | 2.88 | 0.75 |
| 20 | 3.2 | 3.52 | 0.75 |
| 25 | 3.76 | 4.12 | 0.75 |

[adapted from 173]

TERRAIN FACTOR*

| | FACTOR |
|---|---|
| BLACKTOP SURFACE | 1.0 |
| DIRT ROAD/GRASS | 1.1 |
| LIGHT BRUSH/FURROWS/STUBBLE | 1.2 |
| PLOWED FIELD | 1.4 |
| HEAVY BRUSH | 1.5 |
| SWAMPY BOG | 1.8 |
| LOOSE SAND | 2.1 |

*Use only when actually moving.
[adapted from 174]

TABLE III - 3
CORRECTION FOR BODY WEIGHT

| WEIGHT (kg) | POUNDS | FACTOR |
|---|---|---|
| 50 | 110 | 0.76 |
| 60 | 132 | 0.88 |
| 70 | 154 | 1.00 |
| 80 | 176 | 1.12 |
| 90 | 198 | 1.24 |
| 100 | 220 | 1.36 |
| 110 | 242 | 1.48 |
| 120 | 264 | 1.60 |
| 130 | 286 | 1.72 |
| 140 | 308 | 1.84 |

[adapted from 174]

TABLE III - 4
ENSEMBLE WEIGHT

| | FACTOR |
|---|---|
| RESPIRATOR (CHOOSE ONE) | |
| 30' - 60' OPEN CIRCUIT SCBA | 1.19 |
| 30' - 60' CLOSED CIRCUIT SCBA | 1.15 |
| COMBINATION SAR/5' ESCBA | 1.1 |
| SUPPLIED AIR RESPIRATOR P/D | 1.02 |
| GAS MASK | |
| FRONT OR BACK MOUNTED | 1.03 |
| CHIN | 1.02 |
| CLOTHING (CHOOSE ONE) | |
| FULLY ENCAPSULATING SUIT | 1.03 |
| PROXIMITY SUIT | 1.03 |
| NON ENCAPSULATING SUIT | 1.02 |
| BOOTS | 1.03 |
| COOL VEST | 1.05 |
| FIRE FIGHTERS ENSEMBLE WITHOUT SCBA | 1.12 |
| LIFE JACKET | 1.02 |
| IONIZING RADIATION SUIT (LEAD EQUIVALENT) | * |
| BLAST & FRAGMENTATION SUIT | * |

[adapted from 138, 139]

$$* \ \frac{\text{WGT LBS}}{2.2} \times 1.012 = \text{FACTOR}$$

TABLE III-5
ENCUMBRANCE

| | FACTOR |
|---|---|
| FULLY ENCAPSULATING SUIT | 1.3 |
| PROXIMITY SUIT | 1.3 |
| NON ENCAPSULATING SUIT | 1.0 |

[adapted from 145]

TABLE III - 6
FITNESS FACTOR*

| RATING | | KCAL/MIN |
|---|---|---|
| I | VERY POOR | < 10 |
| II | POOR | 10-12 |
| III | FAIR | 12-14 |
| IV | GOOD | 14-18 |
| V | EXCELLENT | > 18 |

[adapted from 153]

TABLE III-7
DUTY FACTOR*

| | |
|---|---|
| MAXIMUM (ONE OR TWO MINUTES) | 1.0 |
| 15' | .8 |
| 4 hr. | .5 |
| 8 hr. | .3 |

[adapted from 208]

* 35 year old 70 kg male used as basis

TABLE III - 8
ESTIMATE OF RESPIRATORY PROTECTIVE
EQUIPMENT SERVICE LIFE

| WORKRATE kcal/min | $Vo_2$ lpm | Ve lpm | DURATION (in min.) 30' OPD* | 60' OPD* | 60' CCP** |
|---|---|---|---|---|---|
| 1 | 0.21 | 10 | 120.0' | 240.0' | 58.2 - 99.7 |
| 2 | 0.42 | 14 | 85.7' | 171.4' | |
| 3 | 0.63 | 18 | 66.7' | 133.4' | |
| 4 | 0.84 | 21 | 57.1' | 114.2' | |
| 5 | 1.04 | 24 | 50' | 100' | |
| 6 | 1.25 | 29 | 41.4' | 82.8' | |
| 7 | 1.46 | 34 | 35.3' | 70.6' | |
| 8 | 1.67 | 41 | 29.3' | 58.6' | 58.2 - 99.7 |
| 9 | 1.88 | 45 | 26.7' | 53.4' | 58.2 - 92.8 |
| 10 | 2.08 | 50 | 24.0' | 48.0' | 58.2 - 83.9 |
| 11 | 2.29 | 59 | 20.3' | 40.6' | 58.2 - 76.2 |
| 12 | 2.50 | 68 | 17.6' | 35.2' | 58.2 - 69.8 |
| 13 | 2.71 | 77 | 15.6' | 31.2' | 58.2 - 64.4 |
| 14 | 2.92 | 87 | 13.8' | 27.6' | 58.2 - 59.8 |
| 15 | 3.13 | 96 | 12.5' | 25.0' | 55.8 |
| 16 | 3.33 | 105 | 11.4' | 22.8' | unable to |
| 17 | 3.54 | 115 | 10.4' | 20.8' | determine |
| 18 | 3.75 | 125 | 9.6' | 19.2' | |
| 19 | 3.96 | 135 | 8.9' | 17.8' | |
| 20 | 4.17 | 145 | 8.3' | 16.6' | |
| 21 | 4.38 | 155 | 7.7' | 15.4' | |
| 22 | 4.58 | 165 | 7.3' | 14.6' | |

* OPD = Open circuit pressure demand

** CCP = Closed circuit positive pressure

TABLE III - 8
ESTIMATE OF RESPIRATORY PROTECTIVE
EQUIPMENT SERVICE LIFE (continued)

| WORKRATE kcal/min | $Vo_2$ lpm | Ve lpm | DURATION (in min.) 30' OPD* | 60' OPD* | 60' CCP** |
|---|---|---|---|---|---|
| 23 | 4.79 | 175 | 6.9' | 13.8' | unable to |
| 24 | 5.00 | 185 | 6.5' | 13.0' | determine |
| 25 | 5.21 | 195 | 6.2' | 12.4' | |

* OPD = Open circuit pressure demand

** CCP = Closed circuit positive pressure

[adapted from 129]

TABLE III - 9
ESTIMATE OF METABOLICALLY MEDIATED HEAT STRESS

| | FACTOR |
|---|---|
| HEAT EFFICIENCY | .8 - .9 |

[adapted from 24, 130]

TABLE III-10
HEAT LOAD - CLOSED CIRCUIT SCBA

| | FACTOR |
|---|---|
| + "B" SUIT CONFIGURATION | 1.10 |
| + "A" SUIT CONFIGURATION | 1.37 |

[adapted from 56]

TABLE III -11
ESTIMATE OF ENVIRONMENTALLY
MEDIATED HEAT STRESS

| DBT° C > 33° C (ABOVE Tsk) | kcal/min. | DBT (°C) |
|---|---|---|
| 1 °C | 0.07 | 34 |
| 2 | .14 | 35 |
| 3 | .21 | 36 |
| 4 | .28 | 37 |
| 5 | .35 | 38 |
| 6 | .42 | 39 |
| 7 | .49 | 40 |
| 8 | .56 | 41 |
| 9 | .63 | 42 |
| 10 | .70 | 43 |
| 11 | .77 | 44 |
| 12 | .84 | 45 |
| 13 | .91 | 46 |
| 14 | .98 | 47 |
| 15 | 1.05 | 48 |
| 16 | 1.12 | 49 |
| 17 | 1.19 | 50 |
| 18 | 1.26 | 51 |
| 19 | 1.33 | 52 |
| 20 | 1.40 | 53 |

Based on a suit having a body surface area (BSA):

$$BSA = 1.8\ m^2$$

and an insulation value of:

Clo - clo* = 2.5

[adapted from 209]

TABLE III - 12
WORK/REST

| kcal/min | RESTING FACTOR = $\frac{(kcal/min - 1)}{4}$ |
|---|---|
| 1 | |
| 2 | NOT |
| 3 | REQUIRED |
| 4 | |
| 5 | 0.25 |
| 6 | 0.50 |
| 7 | 0.75 |
| 8 | 1.0 |
| 9 | 1.25 |
| 10 | 1.50 |
| 11 | 1.75 |
| 12 | 2.0 |
| 13 | 2.25 |
| 14 | 2.5 |
| 15 | 2.75 |
| 16 | 3.00 |
| 17 | 3.25 |

RESTING TIME = $\frac{(kcal/min - 1)}{4}$ X WORKTIME

TABLE II - 12 (continued)
WORK/REST

| kcal/min | RESTING FACTOR |
|---|---|
| 18 | 3.50 |
| 19 | 3.75 |
| 20 | 4.00 |
| 21 | 4.25 |
| 22 | 4.50 |
| 23 | 4.75 |
| 24 | 5.0 |
| 25 | 5.25 |

$$\text{RESTING TIME} = \left(\frac{\text{kcal/min}}{4} - 1\right) \times \text{WORKTIME}$$

[adapted from 135, 206, 210, 211]

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# APPENDIX A: Developing a PPE Program

## APPENDIX A: Developing a PPE Program

Selection and provision of safety equipment does not totally discharge the responsibility we all share in protecting human health from hazardous materials emergencies. Equipment, per se, does not anymore make an effective protection program than instruments, a symphony or rifles, an army.

What makes an effective program has often been the subject of research. One such study in 1976 by Cohen indicated that there were at least seven factors which distinguished successful safety programs and safety performance in industry. These include:

1. Strong management commitment to safety as defined by various actions reflecting management's support and involvement in safety activities.

2. Close contact and interaction between workers, supervisors, and management enabling open communications on safety as well as other job-related matters.

3. A workforce subject to less turnover, including a large core of married, older workers with significant lengths of service in their jobs.

4. A high level of housekeeping, orderly workplace conditions, and effective environmental quality control.

5. Well developed selection, job placement, and advancement procedures plus other employee support services.

6. Training practices emphasizing early indoctrination and follow-up instruction in job safety procedures.

7. Evidence of added features or variations in conventional safety practices serving to enhance their effectiveness [212].

Management commitment to safety was believed a major, controlling influence in attaining success in industrial accident prevention efforts. Open communication between workers, supervisors, and management was also considered of great significance. Overall, the nature of these distinguishing factors suggested that maximally effective safety programs in industry will be dependent on practices that can successfully deal with "people" variables [212].

These seven factors are embodied in ten elements of a personal protective equipment program.

1) material identification
2) environmental surveillance
3) medical surveillance
4) selection of equipment
5) training in and fitting of equipment
6) decontamination and cleaning
7) inspection, maintenance and storage
8) written program
9) program review and evaluation
10) operational use

MATERIAL IDENTIFICATION

Material identification and hazard evaluation in hazardous material incidents can range over the whole gamut of problems from ready identification to defining procedures for handling a substance whose properties remain unknown despite intensive investigation. The composition of in-process spills or releases can usually be identified by process workers, but as the material moves further down the process chain toward ultimate disposal and as additional, perhaps uninitiated, workers become involved with its handling, the necessity for field identification and characterization increases. In a hazardous waste site, all identification may be lost and chemical and physical analysis may be required to determine the identity of the substance.

While diagnostic algorithms are being developed for medical practice, no similar identification algorithms have been offered for hazardous materials control [213]. Other federal agencies, notably the U.S. Coast Guard, have developed a classification scheme for certain hazardous materials incidents [14]. The Coast Guard system, Chemical Hazards Response Information System (CHRIS, for short) is largely designed for HM spills or releases on water and the classification scheme is based upon a "behavior response," in contact with water and an "amelioration response," which is classified by chemical and physical properties. The system may be used either manually or by computer. A second system, the EPA Oil and Hazardous Materials Technical Assistance Data System (OHM-TADS) is also computer based, "... which enables the user to solve problems involving unidentified pollutants by inputting color, odor or other physical/chemical characteristics as observed on-scene [214]. The system responds with a list of the materials meeting the input characteristics." Neither system is able to make specific recommendations for safety and health which are both comprehensive and interactive.

The material identification system chosen should be easy to use, accurate and cover the most common occurences. If, for instance, 10 materials are subject to release in significant quantities, then a selection guide based upon rapid identification of these materials is easily derived. Transportation, warehousing and waste operations may be faced with a truly unknown substance. In this event recourse to laboratory analysis or direct reading instruments, classification schemes or worst case scenarios must be considered.

In the event that identification cannot be made prior to exposure, then prudence dictates that only the most stringent ("worst case") protective measures can be considered suitable.

ENVIRONMENTAL SURVEILLANCE

Hazardous materials incidents may create situations requiring extensive personal and area monitoring to assist in material identification, determination of potential exposures and delineation of material release [9].

Environmental surveillance can either involve direct reading instruments or detector tubes with high specificity or nonspecific instruments such as combustible gas indicators, flame ionization detectors, organic vapor analyzers, or gas chromatographs [215]. Direct reading instruments are essential if knowledge of results is to have significance in initial response activities.

Quantification for the determination of potential exposures must also be carried out on the scene so that appropriate precautions can be started. The extent of spillage or release (into sewers, basements, etc.) must also be evaluated so that appropriate ventilation, evacuation or other control measures can begin [216].

MEDICAL SURVEILLANCE

A medical surveillance program can interact with the personal protective equipment program in several ways:

1) The medical program can provide the basis for placement of workers after consideration of the physical and psychological limitations to the wearing of PPE;

2) It may serve as an evaluative tool of the adequacy and effectiveness of the PPE program;

3) It may also influence both selection and use of PPE directly through medical staff recommendation to operating personnel; and,

4) It may provide medical care to injured or ill users of PPE.

In turn, the medical program must receive information from several other sources if it is to successfully fulfill its mission:

1) The material identification scheme must provide relevant information about materials which are, or may be, encountered;

2) The environmental surveillance program must provide quantitative information concerning both hazardous materials and environmental stressors;

3) The personal protective equipment program must provide information on the selection and use of PPE as well as the operating characteristics of the PPE used;

4) The operational program(s) must provide information on actual use conditions, tasks performed, workrates, rest periods and a host of other influential factors in order that the contribution of the PPE itself as a human stressor may be evaluated.

Recommendations for the organization and staffing of a medical surveillance program to accomplish these tasks is beyond the scope of this Appendix but any such organization must consider these factors of interaction.

## EQUIPMENT SELECTION

Selection of personal protective equipment should consider factors encompassing four major areas and recognize the interrelationships among these areas:

1) the environment;

2) the mission;

3) the man; and,

4) his protective ensemble.

Reliance cannot be made solely upon traditional personal protective equipment selection schemes.

Consider, for example, three elements of an hazardous materials control scheme, material identification, environmental surveillance, and the selection of personal protective equipment. The traditional industrial approach would be the identification (recognition) of a material followed by environmental surveillance (evaluation) and then, based upon the surveillance, recommendation of personal protective equipment (control).

This scenario is the basis for most current hazardous materials incident control systems such as:

1) NIOSH/OSHA "Occupational Health Guidelines for Chemical Hazards," (1981) [11];

2) DOT "Hazardous Materials, Emergency Response Guidebook," (1980) [12];

3) EPA "Hazardous Materials Spill Monitoring: Safety Handbook and Chemical Hazard Guide," (1979) [13];

4) USCG "Chemical Hazardous Response Information System," (1978) [14]; and,

5) NFPA "Fire Protection Guide on Hazardous Materials," (1978) [15].

Unfortunately, the weakest link of this chain, the identification of the HM, is the most critical for these systems since specific information is retrievable only by substance name, and there is no material identification scheme.

Labeling and placarding have not proven totally effective in practice. Fully 40% of trucks in one study were either not placarded when they should have been or incorrectly placarded. Nearly one in four failed to carry the required shipping papers [18].

Even if correctly marked by the new DOT system (effective in November, 1981), the DOT Emergency Response Guide is necessary to identify the substance and a second (or third) source is required for personal protective equipment selection and environmental surveillance recommendations [11-15]. If the substance is not marked, then the system fails.

If, however, the fire fighter or other emergency team member purchases his chemical protective clothing before his response to a hazardous materials emergency, then the effect of this decision cannot be used in these systems to modify either material identification requirements or environmental surveillance.

If the Blanksville Volunteer Fire Department purchases two chemical protective suits of, say, Saranex/Tyvek composite, no current system will tell them that identification and quantification of toluene is required [16] or that the detector tube set they carry may have difficulty distinguishing toluene from kerosene [17, 216] (toluene readily penetrates the suit, kerosene doesn't). Other choices of protective clothing may alter the identification required to prevent suit failure [217].

There has been no system for alerting users of protective clothing as to these problems and there is no material identification scheme if they were made aware. The selection guide of Part II attempts to integrate the more important factors into an interactive system which specifies what information is required for rational selection of protective equipment.

Any system adopted must be of sufficient detail and clarity that the final decision is traceable to its antecedents in a rational and logical manner.

TRAINING AND FITTING

Training and fitting of personal protective equipment serves several vital needs in an effective protective equipment program.

1) it allows the user the opportunity to become familiar with the equipment in a non-hazardous situation before actual use;

2) it helps instill confidence by the user in his equipment;

3) it increases efficiency of operations while wearing protective equipment;

4) it may increase the efficiency of the protective equipment in protecting the user;

5) it will reduce expenses of maintenance;

6) it is required by federal regulation (29 CFR 19.10.134 for respirators and 29 CFR 1910.132; 1910.133(a)(2)(ii) & (iii); 1910.133(a)(5)) [218].

An effective training and fitting program will contain all of these elements:

- Explanation of the nature of the hazards and what would happen without the personal protective equipment (PPE).
- Emergency procedures in the event of PPE failure and self rescue.
- Site emergency plan and the individual's responsibilities and duties in an emergency.
- The buddy system and buddy breathing and aid.
- The medical surveillance program.
- The selection of PPE, how this selection can be modified to fit changed circumstances, and who is authorized to modify the PPE selection.
- Human factors which may influence the user's performance.
- The elements of the PPE program and the user's responsibilities.
- The user's responsibility for decontamination, cleaning, maintenance and repair of PPE (if any).

- Explanation of the operation of the selected PPE including its capabilities and limitations.

- Instruction in inspecting, donning, checking, fitting and use of PPE.

- Individualized quantitative fitting of PPE to a particular user.

- Practice use of PPE in normal air for a long familiarity period and, finally, wearing PPE in a test atmosphere to evaluate its effectiveness.

Training shall be at least annually and must be completed prior to actual use of personal protective equipment in a hazardous material incident. (See the following suggested lesson outline. It's difficult to be dogmatic about personal protective equipment training but some suggested guidelines are contained in this sample lesson outline.)

## PPE Sample Lesson Outline

1 - Introduction to Personal Protective Equipment

1.1 - Job Orientation

1.2 - Chemical and Physical Hazards
- 1.2.1 Hazard Identification
- 1.2.2 Environmental Surveillance
- 1.2.3 Medical Surveillance Program
- 1.2.4 Emergency Care
  - 1.2.4.1 Signs and Symptoms
  - 1.2.4.2 Emergency Action
  - 1.2.4.3 Seeking Medical Attention

1.3 Environmental Hazards
- 1.3.1 Temperature Extremes
  - 1.3.1.1 Heat Stress
  - 1.3.1.2 Cold
- 1.3.2 Relative Humidity
- 1.3.3 Weather

1.4 Site Emergency Plan
- 1.4.1 Personnel Entry Control
- 1.4.2 Personnel Locator System
- 1.4.3 Site Communications
- 1.4.4 Standby Personnel
  - 1.4.4.1 Duties
  - 1.4.4.2 Equipment
  - 1.4.4.3 Procedures
- 1.4.5 Escape Routes
- 1.4.6 Notification of an Emergency
- 1.4.7 Personal Responsibilities in an Emergency

2 - Selection of Personal Protective Equipment

- 2.1 Selection Factors
  - 2.1.1 Chemical Factors
    - 2.1.1.1 Breakthrough Time
    - 2.1.1.2 Permeation Rate
    - 2.1.1.3 Degradation
    - 2.1.1.4 Concentration and State
  - 2.1.2 Physical Factors
    - 2.1.2.1 Mechanical Strength
    - 2.1.2.2 Abrasion
    - 2.1.2.3 Puncture
    - 2.1.2.4 Tear Resistance
    - 2.1.2.5 Tensile Strength
    - 2.1.2.6 Flexibility and Dexterity
    - 2.1.2.7 Flame Resistance
    - 2.1.2.8 Temperature
    - 2.1.2.9 Permeability
  - 2.1.3 Environmental Factors
    - 2.1.3.1 Temperature
    - 2.1.3.2 Relative Humidity
  - 2.1.4 Human Factors
    - 2.1.4.1 Workrate
    - 2.1.4.2 Age
    - 2.1.4.3 Sex
    - 2.1.4.4 Weight
    - 2.1.4.5 Fitness
    - 2.1.4.6 Acclimatization
    - 2.1.4.7 Fit of Protective Equipment

- 2.2 Selection Process
  - 2.2.1 Who selects
  - 2.2.2 How is selection made
  - 2.2.3 Who can modify the selection

- 2.3 Equipment Selected
  - 2.3.1 Respiratory Protection
  - 2.3.2 Body Protection
  - 2.3.3 Head Protection
  - 2.3.4 Foot Protection
  - 2.3.5 Hand Protection

- 2.4 Employee Owned Equipment

3 - Equipment Familiarization

- 3.1 Pre-use Inspection

- 3.2 Donning

3.3 Final Inspection

3.4 Use

3.5 Emergency Use

3.6 Decontamination
- 3.6.1 Self Decon
- 3.6.2 Decon Line
- 3.6.3 Disposal

3.7 Doffing

3.8 Cleaning
- 3.8.1 User Cleaning
- 3.8.2 Secondary Cleaning
- 3.8.3 Disposal

3.9 Maintenance and Repair
- 3.9.1 User Maintenance
- 3.9.2 Second Level Maintenance
- 3.9.3 "Factory" Maintenance

3.10 Storage

3.11 Qualitative Fit Testing

4 - Quantitative Fit Testing

5 - Practice Exercise

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DECONTAMINATION

Decontamination (decon) is defined as those tasks undertaken to rid something of contamination. Herein the term is used in a very limited sense to refer to the measures taken to remove, fix, or detoxify hazardous materials which contaminate personal protective equipment.

Personal protective equipment must be decontaminated for several reasons, including:

- o to allow for safe removal of the PPE without contaminating the wearer (or others);
- o to permit the safe reuse of previously contaminated PPE;

- o to provide for safe servicing of the wearer ( changing air cylinders, etc.); and

- o allow emergency removal of PPE in the event the wearer becomes a casualty.

Each of these reasons may require a somewhat different approach and modifications to any decontamination plan.

The interactions among the contaminant, the PPE ensemble, and the decontaminant determine the efficiency of decontamination and the methods which may be selected.

A contaminant which coats the exterior surface of a suit may be much easier to neutralize or remove since the decontaminant or cleaning agent can gain easy access. Once permeation or degradation begins, it may become very difficult or even impossible to decontaminate the suit effectively. Thus, permeation and degradation times; elapsed time from contamination to decon attempts; the degree of permeation or degradation; surface bonding of the contaminant; the form, concentration, and properties of the contaminant; suit materials; and mission all play important roles in deciding which, if any, is the preferred decon method or preferred decontaminant. Some Tables which show preferred decon agents for classes of contaminants are at best misleading since they do not take into account these numerous factors. Many of the decon agents recommended are themselves hazardous materials and in the concentrations recommended for use are degrading to many common suit materials.

As an example, calcium hypochlorite in 5% solution (half the strength of the recommended decon solution) degrades neoprene and polyurethane. It also is toxic but is recommended for decontamination of unknown substances as well as biological agents, cyanides, pesticides, heavy metals, and non-acidic inorganic compounds.

The concentrated hypochlorite (HTH (TM)) is extremely reactive and corrosive.

It reacts explosively or forms explosive compounds with many common chemicals and can pose a severe problem for decon crews attempting to store, transport, or use it.

Other common decon agents which degrade suit materials are sodium bicarbonate, hydrochloric acid, sodium hypochlorite, and sodium hydroxide. The latter three are also toxic and corrosive as well.

Whatever method or agent is chosen, employees should be cautioned to seek immediate decon for any splash on the PPE since early removal may be the only realistic decon method. With breakthrough times of less than a minute for some substances, a quick decon or wash is imperative. Protective coverings which can be stripped away can provide a margin of safety to reduce the amount of contaminant which reaches the PPE. Assuming that it can be removed easily in the field, any plastic bag can be effective if stripped away immediately.

The selection of decon is as complex as the original selection of PPE but less is known about the operating characteristics of decon agents and their interactions with PPE. Until a rational decon system can be developed, the only safe assumption is that adequate decon of PPE can only be effected in exceptional cases and in severe exposures, all PPE should be considered disposable.

INSPECTION, MAINTENANCE AND STORAGE

Inspection, maintenance and storage of personal protective equipment are essential elements of an effective PPE program.

Inspection

An effective inspection program will probably feature 5 different inspections.

1) Incoming inspection of equipment received from the factory or distributor which would include operational testing;

2) Inspection of equipment being issued to workers;

3) Periodic inspection of equipment stored for use or issue;

4) Inspection after use or training and prior to maintenance; and, finally,

5) Inspection when questions as to suitability or problems with similar equipment arise.

Each inspection will cover somewhat different areas and to varying degrees of depth. Each must answer the question, "Can I depend upon this item?" Detailed procedures, where appropriate, are usually available from the manufacturer.

Maintenance

Maintenance procedures also can be expected to vary as to area and depth.

A convenient classification scheme often used is to divide maintenance into three levels:

Level 1 - user or wearer maintenance which requires a few common tools or which can be performed without tools;

Level 2 - shop maintenance which can be carried out by the owner's maintenance shop; and, Level 3 - specialized maintenance which can only be performed by the factory or a specialized repair depot.

In the latter instance, manufacturers frequently restrict the sale of certain parts and only allow those specially trained, equipped and "authorized" to purchase them.

Explicit procedures must be adopted in an attempt to ensure that maintenance is performed only by those having this specialized training, equipment and replacement parts.

Storage

Storage of equipment must be specified for both pre-issuance warehousing and, more importantly, post-issuance (in-use) storage. Many equipment failures can be directly attributed to improper storage.

Records must be kept of all inspections and maintenance procedures. This can be facilitated by giving each major, reusable piece of equipment an individual identification number and maintaining all records by that number. A periodic review of these records can serve to indicate an item or type of item with excessive maintenance costs or a particularly high level of "down time."

WRITTEN PROGRAM

Each of the program elements should be rendered in writing in the form of policy statements, procedures, guidelines or an equally appropriate format. The written program should be made available to all employees affected and a copy should be available at each worksite for reference.

If the document is maintained as a looseleaf notebook, then technical data on equipment used, maintenance manuals, specific federal, state or local regulations, or other essential information can be included as appendices.

The body of the document should not contain any easily dated material such as personal names, phone numbers, etc. Rather, these should also be appendices to facilitate maintaining an updated manual.

The manual should be reviewed and revised at least annually, preferably after the program review and evaluation, to maintain its utility.

PROGRAM REVIEW AND EVALUATION

The personal protective equipment program, as part of an overall, comprehensive, safety and health program, must be subjected to a periodic review and evaluation of program effectiveness.

Elements which should be considered include:

1) the number of person-hours in various protective ensembles;

2) accident-illness experience;

3) levels of exposure;

4) appropriateness of equipment selection;

5) adequacy of the operational guidelines;

6) adequacy of decontamination, cleaning, inspection, maintenance and storage programs;

7) adequacy and effectiveness of training and fitting programs;

8) coordination with overall safety and health program elements;

9) costs of the program;

10) the degree of fulfillment of program objectives;

11) the adequacy of program records; and,

12) recommendations for program improvement and modification.

The results of the evaluation of the program should be made available to the affected employees and presented to top management so that program adaptations may be made as needed.

USE

No area of a personal protective equipment program is more critical to its effectiveness than the factors affecting whether or not such equipment is actually used. Yet little, if any, research has been done on factors which provide incentives or disincentives for wearing PPE.

These factors may take several forms and can, for our purposes, be categorized as physical, psychological, social and economic. It should be clear that no hard and fast distinctions are implied. They may all be better characterized as "human" factors.

Physical factors which may influence the wearing of PPE include respiratory or cardiovascular disorders which are magnified when using PPE. Individuals may be sensitive to changes in $pO_2$, $pCO_2$, inhalation/exhalation resistance, RH or temperature of inhaled air or oxygen, or weight of the PPE. Similar factors such as pre-existing skin disorders, hypohydrosis, previous heat disorders, etc., may also adversely affect the user's ability to wear protective clothing or equipment. Individuals with low work capacities may be particularly reluctant to use PPE because of the added metabolic workload required with the additional weight and burden of the equipment.

The factors should be evaluated in the preplacement and periodic physical examinations and resolved there. If they arise during use, then an immediate medical re-examination and re-evaluation is indicated.

Psychological factors, such as claustrophobia, may disqualify 10% or more of the general population from wearing PPE due to their inability to appropriately react to the increased stress involved. Screening paper and pencil tests have been reported to be capable of identifying 75% of those with subsequent psychological stress related disabilities.

Many factors may occur which have both a physical and psychological basis such as comfort, restricted vision, facial pressure points of respirators, and breathing resistance. These may be amenable to minimization through training. Several studies have shown PPE wearers to have increased endurance times and decreased air consumption after an intensive training period.

Social factors, or how the work group perceives the wearing of PPE, may also influence an individual decision as to personal use. Training and educational techniques can be used to enhance peer acceptance of PPE use. Direct incentives, such as premium pay or tokens redeemable for merchandise have been proven effective in increasing utilization of PPE.

Economic disincentives including piecework in which the worker perceives a decrease in his productivity, and hence pay, through the wearing of PPE, or in which the worker is required to pay all or part of the cost of purchases or maintenance of his PPE, inhibit PPE use.

Whatever mechanism is used to motivate workers to wear PPE must ensure a very high degree of utilization if it is to be successful. For example, given a hazardous atmosphere at 100X the permissible exposure limit (PEL) for an 8-hour workday, an employee using a protective ensemble having a protection factor of 10,000 will be overexposed if his utilization of the ensemble is less than 99%; i.e., he removes it for 5 minutes during the 8 hours of exposure. Figure A-1 illustrates how severely protection decreases with minimal periods of non wear.

Worker input into the personal protective equipment program is vital if it is to gain acceptance. One national union has stated 6 general concerns regarding respirator programs which offer goal guidance for any personal protection:

"1. Greater emphasis must be given to the proper selection of respirators [PPE] ....

2. The fitting of respirators [PPE] must be more controlled than hit or miss, positive and negative fit tests. This problem includes the availability of facepieces of different sizes and fit-testing procedures that are more quantitative than qualitative.

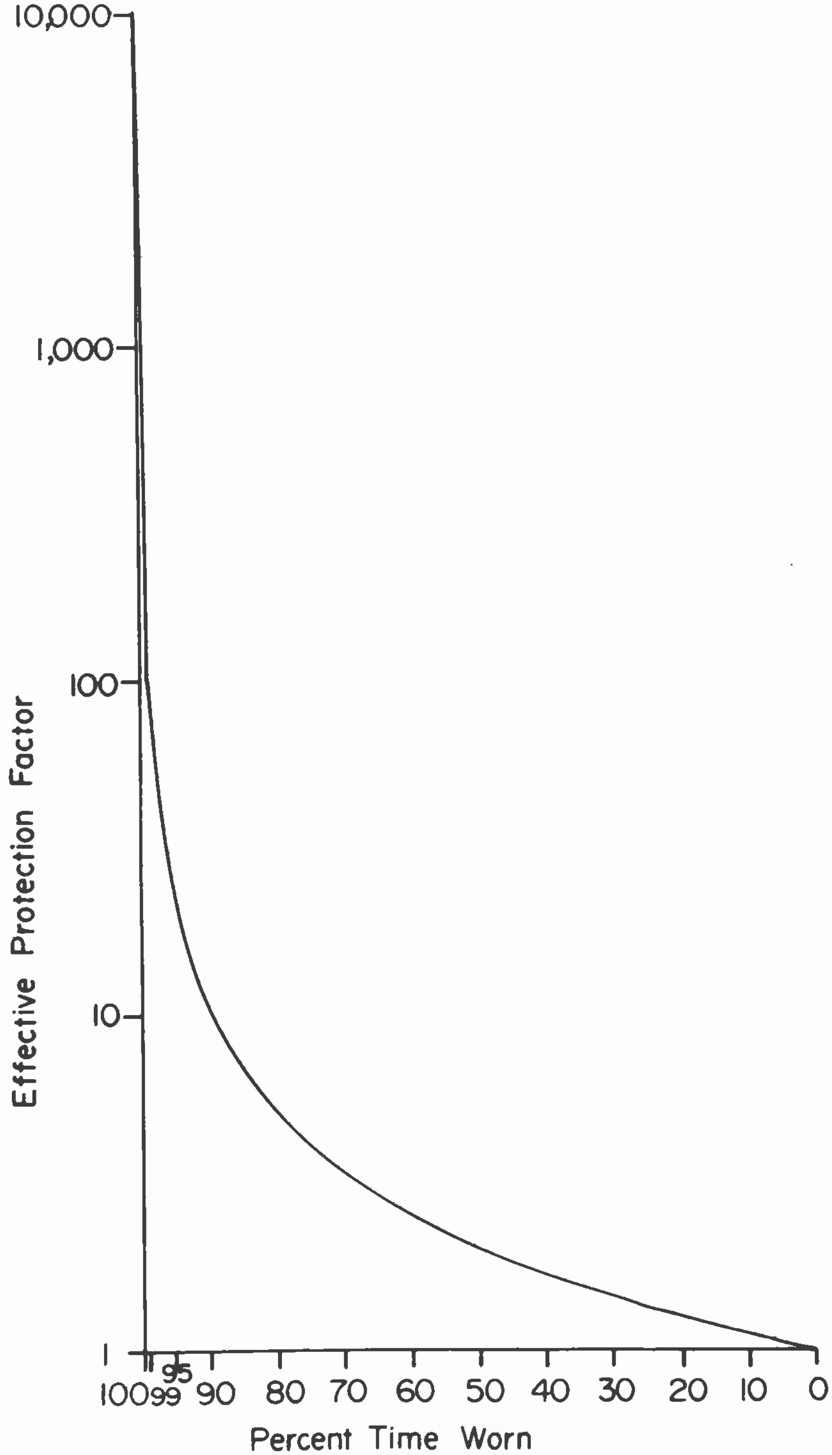


Figure A-1. Protection factor versus time worn

3. An element of employee choice in the selection of the type of respirator [PPE] ....

4. Provisions for limiting time for respirator [PPE] wear either by designating certain areas as break areas and providing time for using them or by averaging time of use based on the exposure level and protection factor of the respirator.

5. Determining whether an employee is able to wear respiratory [PPE] protection and economic protection for those workers whose health has already been damaged to such an extent that they cannot wear currently available respirators.

6. Concern for the actual development and enforcement of a respirator [PPE] program in the workplace where such questions as discipline and discharge for failure to wear a respirator or the unilateral imposition of a policy on facial hair can strain even the best of labor-management relations." [219]

The program, once adopted, must be considered a dynamic document which, hopefully, will both influence to change operating procedures and in turn be modified by operating experience. A static program will soon become obsolete.

APPENDIX B: Establishing an Emergency Rescue Program

# APPENDIX B: Establishing an Emergency Rescue Program

Effective response to any emergency situation begins with the understanding of, and preparation for, what can happen, what the probable consequences will be and what remedial action needs to be taken.

Rescue, particularly rescue during a hazardous materials incident, can be exceedingly dangerous. One study indicates that in 19 of 25 cases where rescue from a confined space was attempted, the rescuers were either killed or injured. These 19 cases resulted in 13 deaths and 30 injuries to rescuers. Only 5 of the original victims were saved [220].

Similar statistics are not available for hazardous materials incidents but where a hazardous material is responsible for the necessity of rescue, in all probability, the batting average is not much better.

Several factors probably influence this grim statistic:

1) failure to adequately plan;

2) failure to adequately train and equip personnel to carry out the plan; and

3) failure to properly execute the plan in an emergency.

Let's look at each of these factors in some detail and evolve the basic elements of an effective rescue program.

## PLANNING

Planning for a possible rescue or evacuation emergency should begin before the first contact with the HM site. The planner should be familiar with 1) the resources that will be committed to the site, 2) the nature of the anticipated hazard(s), 3) centers of population which may require rescue or evacuation, 4) available community resources which could be summoned in an emergency, and 5) the method(s) of alerting them.

Two recent publications of the Federal Emergency Management Agency (FEMA) are available to assist in this planning task:

"Planning Guide and Checklist for Hazardous Materials Contingency Plans," (FEMA-10/July 1981) [221]; and,

"Disaster Planning Guidelines for Fire Chiefs," (M&R-3, February, 1981) [222].

Every hazardous materials incident must have a rescue or emergency plan even if it entails only immediate evacuation. The plan must be understood by all and everyone must follow it to the degree possible. Whatever plan is developed must be reduced to writing even if it is only indicated on the entry control map.

Each plan must contain at least the following elements:

1) Personnel Entry Control - It is essential that the plan provide for control of entry into the scene of a hazardous materials incident and for the rapid estimation of casualties, both actual and potential. There are many cases, all perhaps preventable, where people have lost their lives because no one knew they were in a dangerous situation or area until they were missed, sometimes hours later. Or even more tragic, where rescuers have lost their lives in a rescue attempt in which the "victim" escaped unaided and never bothered to tell anyone. Some "victims" may even remain on the scene to watch their own "rescues."

On an unplanned hazardous materials incident site, such as a spill or release, the first responsible group on the scene should attempt to minimize the on-site entry and maximize the off-site egress, keeping careful count of each and their disposition.

Controlled entry on the scene may need to borrow a page from the bitter history of underground coal mining disasters. Each mine is now required by Federal law to establish a check-in and check-out procedure for everyone going underground [223]. Each miner is usually given 2 metal tags with a unique ID number at his time clock location. One he gives to a control point operator who posts it to indicate the miner is underground. The second tag is required to be securely fastened to the miner's lamp belt. Upon returning to the surface, the miner picks up the tag from the control point operator and turns it back into his time clock location.

A similar system is used in Britain to control entry and egress of fire fighters using SCBA [224].

No matter what system is used, it must include:

1) user identification

2) status (in or out of hot zone)

3) entry time

4) anticipated egress time

5) protective equipment used.

6) location of job on site

7) initiation of rescue plan if the user is "overdue"

2) Locator System - Personnel locator systems may be either passive or active. Passive locators include those systems which require no action or special equipment to provide surveillance and to initiate the rescue plan. Active locators are carried by personnel and require some personal actuation either by a flip of a switch, a change of attitude (falling down), or by a decrease in consumables such as an SCBA air supply.

Every HM site, no matter how small, must have a passive locator system. The simplest passive system is a rough map of the site with the location(s) and names of the crew assigned. This should be updated at least at each change of SCBA air supply or other consumable. Rest areas should also be included as well as assigned crew which are temporarily off-site. It may be kept in grease pencil on a truck window, on the entry board or in any other manner as long as it meets these criteria:

1) It must be written down;

2) It must be kept current;

3) It must be easy to locate;

4) It must remain outside the hot zone in the event of a massive release, fire, etc.; and,

5) It must be oriented with respect to a visible fixed point, relative to scale, with the scale given.

Several active locators are commericially available. One of the most common is the use of radio communications between the entry crew and the control point. Either voice actuated or manually actuated transmitters may be used, but a trade off must be made between ease of operation and unnecessary transmissions.

Other active systems use gas powered horns, battery powered sirens or battery powered personal/hand held public address systems.

COMMUNICATIONS

Most on-site communications are verbal. Unfortunately, most are impeded by on-site background noise and the use of the required personal protective equipment, particularly respirators. Selection of a respirator with good speech transmission properties is important. Some may have special speaking diaphrams and others simply rely upon the lens of the facepiece. Informal testing or experience can usually indicate those respirators which unnecessarily hinder speech. Continuous flow supplied air respirators or escape SCBA (ESCBA) are not approved by MSHA-NIOSH if they generate noise in excess of 80 dBA [225]. Unfortunately, even this amount of noise can block conversation. Additionally, the use of higher than recommended flow rates can easily increase this noise to levels beyond 100 dBA. Add this to background noise and communication is often impossible.

Hearing may also be impaired by personal protective equipment. For example, the continuous flow SAR with a helmet or hood, the hooded ESCBA, the chemical protective hood or suit, ear plugs or ear muffs may all interfere with hearing and communication.

Background noise may, by itself, make communication difficult or impossible. And lastly, the message length may also influence its understanding. Normal speech contains a high degree of redundancy. That is, most of the words we use in a sentence are not really necessary to convey the meaning. The percentage of redundant words increases as the length of the message increases so that paragraphs are more redundant than sentences and pages are more redundant than paragraphs. This redundancy is important, however, in helping to convey the meaning if one or more words are garbled. For example, "You dirty ____ ____ _____," conveys its meaning with 60% of the elements missing. Short, less redundant statements such as "watch out," "duck," or "fire" are more apt to be misunderstood than longer statements. Therefore in emergency situations, commands, since they have little redundancy, must be prearranged so that the context and additional visual or audible clues can convey the message.

One simple code, used in elevator controls, only has 4 possible messages:

1) stop;

2) up or forward or in;

3) down or backward or out; and,

4) emergency.

When preceeded by some attention getter, these signals can be given by tugs on a safety line, visually by hand signals, blasts on an airhorn or any other method agreed to in advance [226].

Effective communication requires some method of identification of individual workers so that verbal communications can be addressed to the right party. Color coding, numbers, and symbols are only three ways of long distance identification. At short ranges the name can be marked on the suit or coat. The latter method is probably desirable in any event.

STANDBY PERSONNEL

The most controversial aspects of a rescue plan are those requiring standby or rescue personnel for entry into a hazardous zone. Usually the plan will require one or more persons fully equipped with protective clothing and self-contained breathing apparatus ready to enter the site in the event of an on-site emergency.

When entry on-site requires the use of fully encapsulating (gas tight) or liquid splash chemical protective clothing, then some modifications in the interest of the safety of the standby personnel must also be considered.

Standby personnel wearing these outfits are subject to a high degree of stress from heat accumulation, $CO_2$ buildup and discomfort. All of these stressors can be relieved somewhat at the expense of using "consumables" such as ice, compressed air, oxygen or by providing an alternative external source of consumables, thus reserving the self-contained supply for the actual rescue mission.

This could be accomplished in several ways, for example through the use of an air supplied suit with a vortex tube (Ranque-Hilsch tube) cooling/heating system. Respiratory protection would be supplied by a 30' compressed air pressure demand SCBA in combination with a type "C" pressure demand SAR with automatic transfer capabilities.

Such an ensemble could be assembled from available components and could keep the standby personnel in good shape for about an hour. Response time would be on the order of 15 seconds or so and would only be limited by disconnection time from the air supply(s). Unfortunately, air consumption would be on the high side since the vortex tube requires some 10-20 SCFM of respirable air and the SCBA/SAR another 2-3 SCFM (resting).

Since this air capacity requirement exceeds the practical limits for cylinder supplies, this ensemble is only practical when a contamination-free area in which to locate the air compressor/purification system can be found within a few hundred feet of the standby personnel.

Entry and egress would be made on the SCBA without cooling or with the addition of a water circulation system which could be actuated in situ.

An alternative method is to completely suit the standby personnel and allow them to use self-contained consumables. This ensemble would require a 60' compressed air pressure demand SCBA with its possibly increased weight over the 30' SCBA/SAR and with the requirements for a 4500 psig respirable air source. In addition, the ensemble would require enough cooling capacity in a water cooled vest to minimize heat buildup during standby and to provide adequate cooling in the event that entry must be made. Standby time would be cut to about 30'. Therefore, using this strategy, standby personnel would be relieved with the work crews every 30'. Rotation between work crew and standby personnel could be accomplished.

A third alternative is to only partially dress the standby personnel and allow them several minutes to complete the donning of the personal protective equipment. If fully encapsulating suits are used, only undergarments such as coveralls would be worn and a complete dress-out in SCBA, cooling garment (if used) and suit would be required. If two piece liquid tight clothing is used, then the boots, covers, and bib overalls can be worn and the hooded jacket, gloves and SCBA rapidly added if entry is required. This method, although at a disadvantage in terms of response time, may be the most practical.

ESCAPE ROUTES AND REFUGES

Rescue plans must include planning escape routes and consideration of the use of refuges in the event of an emergency. This part of the rescue plan should be concerned only with the immediate removal of on-site personnel from a hazardous situation to a place of relative safety. It should not be confused with an off-site evacuation plan for the moving of the general population in areas surrounding the site. Of course these 2 plans should not conflict, but should be considered as separate items.

While each escape plan will vary, certain principles should be common throughout all plans:

1) The plan should provide for 2 or more escape routes which are separate and remote from each other and which lead to areas of relative safety. Multiple routes are necessary in the event that one is blocked by a fire, spill or vapor cloud. These routes must not overlap, since any common point could be involved in a fire or other emergency and block all routes. For the same reasons, the routes should be as remote from each other as practical.

2) All suitable escape routes should be marked unless their location is obvious (e.g., working in an open field). Marking for outdoor locations can utilize flagging, barricade tape, traffic cones or any other prearranged, easily recognized symbol. Plastic exit signs with directional arrows cost only a dollar or so, but can be lifesavers, especially in areas of drum storage or chemical process equipment.

Equally important is the marking of areas which do not offer safe escape or which could be used inadvertently in an emergency. Examples include low ground (which may fill with vapor or gases), or areas that may be blocked by natural barriers such as streams or cliffs. Areas above potential fire grounds may become involved in fire so rapidly that escape would be impossible. These should also be indicated, if necessary.

Indoors, escape routes should be marked by some method which can be located and followed in complete darkness. Fire fighters, for example, can follow their hose lines and determine direction by the hose couplings (the male, threaded, coupling usually points towards the fire). British fire fighters may also use a guide line secured off the floor between the safety of the control point and the scene of operations [101]. This line is marked with tell tale strings which indicate the direction to and from the scene. Each fire fighter carries a 20' line with snap hooks at each end. One hook is attached to the man. The other can be snapped to the guideline to allow the user to travel up to 20' from his guide line without losing contact with the escape route.

3) The escape plan must also consider access to areas both below and above ground, as well as the need to cross small streams, culverts, and banks. The wearers of chemical protective clothing and equipment will be greatly hampered in movement and exceptional efforts must be taken to provide adquate access. There are several points to consider in providing this access.

a) When emergency egress requires leaving a cut or excavation more than 3 feet deep, then ladders should be placed in the excavation so that someone escaping would not have to travel more than 25 feet to reach a ladder.

b) Egress from areas elevated more than 3 feet may also require the provision of a ladder or other means of rapid descent. If areas in structures less than 30' in height do not have 2 separate and remote exitways, then a ladder should be raised so as to provide a second means of egress. Structures of more than 3 stories or 30' in height in which the incident is on the first 2 stories or about 20' above grade may also benefit from laddering if vertical, upward travel is feasible for escape. Ladders in excess of 30-35 feet reach (40-44' painter's ladder or 30-35' fire department ladder) are not practical to provide or raise.

c) Portable ladders used for emergency egress should be rated for a working load of 250# and should be secured in place to prevent slipping.

d) Standard cleated ramps ("chickenboards") should be provided for crossing ditches and similar obstacles. A railing may also be required if the board is narrow or more than gently sloped.

e) If fixed ladders, particularly those with cages, must be used, then careful checking of toe and body clearance must be made prior to use, since chemical protective clothing and SCBA may not fit a standard installation.

f) Access ports such as manholes, crawlspaces, tunnels and hatches may all prevent escape while wearing the protective ensemble. Check them out. Be suspicious of any whose dimensions are less than 36".

4) The plan should consider remote refuges. Refuges within the distance which could be affected by a hazardous materials incident are not practical if any appreciable quantity (more than a few pounds) of materials are involved.

5) Escape routes must be made known to all who go on-site.

ENVIRONMENTAL CONDITIONS

Environmental conditions also play a major part in planning for escape and rescue. Wind speed and direction, temperature, the local topography, soil conditions and natural or man made features such as rivers, creeks, roads or buildings may all influence planning.

Continuous monitoring of wind speed and direction is essential over several points on site to allow some prediction of the spread of contamination if a release occurs. The simplest indicators will suffice for escape and rescue purposes. Plastic flagging tied to tomato stakes could be used. At least one location near an anticipated point or area of release should be chosen, as well as at least one at every area where personnel may congregate (e.g., command post, rest areas, showers and toilet facilities, assembly point(s) and decontamination line). While no such place would normally be sited downwind of a possible release, changes in wind direction and speed could endanger areas previously thought to be safe.

If special target hazards exist (hospitals, nursing homes or penal institutions) or a major escape route could be blocked by a release, then it may be desirable to postpone especially hazardous operations (righting a tank vehicle, or bulking materials) until the most favorable wind conditions.

EVACUATION DISTANCE

Consideration must also be given to evacuation distance. Estimations for evacuation or standoff distances for various substances and situations vary so greatly that a single recommendation is meaningless. For example, recommendations for a chlorine leak range from an isolation distance of 250 feet for a small leak, to the evacuation of an area 10,560 feet by 6,864 feet (2.6 square miles) for a large leak [227]. The questions, of course, are what is a small leak or a large leak and are these distances adequate or realistic?

Evacuation distances depend upon many factors, some of which may not be readily determinable on site. These include:

- the substance released;
- its state;
- the quantity released;
- the rate of release;
- the method of release;
- the vapor pressure of the substance;
- the toxicological properties of the substance;
- wind speed and direction;
- atmospheric stability;

- o air temperature and temperature differences at altitudes;
- o the altitude of release; and
- o local topography, to name a few.

Barriers may either enhance or retard the formation and subsequent travel of a cloud or plume. Likewise barriers may have similar effects on attenuation of blast and fragmentation.

Some general rules can be set based upon geometry and simple physics:

1) far is better than near;

2) for lighter than air or hot - low is better than high;

3) for heavier than air or cold - high is better than low;

4) upwind is better than downwind; and,

5) massive shielding is better than flimsy.

While these may seem trite, violation of these rules time and again has cost needless deaths and injuries.

REASSEMBLY AFTER ESCAPE

The first order of business after an evacuation is to count noses. Did everyone make it out? Does someone need assistance? Who will form a rescue party? Where do you search? These and numerous other questions after an evacuation can most easily be answered if all concerned can communicate in an interactive manner. No matter how or where it's done, it is an immediate, imperative need, a must and it must become a rote part of any plan.

EQUIPMENT

Little specialized equipment would be necessary for the majority of hazardous materials incident related rescues. Unless someone is trapped beneath heavy equipment or has fallen down a borehole or some other calamity has befallen them (in which case, call for outside help), only a couple of items of equipment may be desirable to provide over and above that normally found on the scene of a hazardous materials incident.

The first item is a simple escape self-contained breathing apparatus (ESCBA) or a second SCBA which can be brought to a victim to replace or supplement his SCBA.

The second is a wire basket litter (Stokes litter) which can be used to carry the victim under difficult circumstances of terrain and weather but is still easy to decontaminate and allows easy decontamination of the victim.

## TRAINING

Training for rescue and evacuation in hazardous materials emergencies is not standardized. Each group must develop the training program which best fits their needs. Both the Environmental Protection Agency [228] and the Federal Emergency Management Administration [229] offer courses including field exercises in hazardous materials incidents. Each state has a fire department fire school, many of which offer rescue or hazardous materials training. In addition, many chemical companies, railroads, trade associations and independent contractors also have specialized courses and materials of value [230].

Whatever rescue training is carried out, and at least some is a must, it should follow these general guidelines:

1) The training should be directly related to the anticipated situation.

2) It should be relatively short and repeated frequently, say 1 hour every month.

3) The skills should be practiced frequently.

4) Training should be as realistic as practical within obvious safety limits (no live bombs used!).

5) Everyone should participate.

Off-site training in emergency medical care (emergency medical technician (EMT)) is a definite plus but at least one, if not everyone, of the rescue team should have some recognized current first aid certificate which includes cardiopulmonary resuscitation (CPR).

## THE RESCUE OPERATION

Actual rescue operations usually follow a definite time sequence which starts with the notification of trouble and continues through to the preparation of equipment and personnel for the next emergency. The whole process can generally be divided into 10 steps:

1) Notification

2) Size-up

3) Request assistance

4) Response

5) Survey

6) Extrication

7) Stabilization

8) Decontamination

9) Transport

10) Recovery

No hard and fast, step-by-step, sequence should be inferred. Rather that each rescue operation usually contains all of these elements, but several may be out of sequence or carried on simultaneously.

1) Notification

Notification of an incident may be as simple as seeing it happen or as complex as requiring an elaborate communications system. By whatever means notification arrives, it should contain sufficient information to allow a reasonable response. Essential information includes:

1 - WHAT - what happened?

2 - WHERE - where did it happen?

3 - WHO - who did it happen to?

4 - WHEN - when did it happen?

5 - HOW - how did it happen?

6 - TO WHAT EXTENT - how bad is it?

7 - WHAT ASSISTANCE - what help is needed?

If you can answer these seven questions, you are well on the way to an effective rescue. Miss one or more and your success is in doubt.

The message does not have to be elaborate. For example: "We just [WHEN] had an accident! Jones and Smith [WHO] were sampling from the drums [HOW] in section 6 [WHERE] when one of the drums spewed junk [WHAT] all over both of them [TO WHAT EXTENT]. They are out cold! [WHAT ASSISTANCE]" This 32 word message begins the second element of your rescue effort, the size up.

2) Size-up

Size-up is nothing more than taking the information you get in the notification, adding the information you have about your capabilities and evaluating what has happened, what could happen and what can be done about it. Unlike many decisions you make on a daily basis, a size-up must be made immediately and continuously and it must be right!

Using the notification message we can begin extracting a lot of information for analysis. As soon as you hear that Jones and Smith went down in Section 6, you can look to the entry board or locator system to see where they are, how long they have been there, what they were doing and what protective equipment they are using.

Since both men are down we can assume an external cause, that is, chemical exposure, heat stress or something that could influence both men at the same time. Using up all the air in the SCBA could do it but we see from the entry board they have only been in 10 minutes with 30' SCBA and their task is drum sampling which is not <u>that</u> physically demanding. We can then rule out air depletion and probably heat stress. The spewed out material remains the prime suspect since the men seemed to have had direct contact with material from a single drum. Even if it appears to be a "quick knock down" agent, we don't have a real reason to fear widespread contamination or to evacuate the site.

Jones and Smith were wearing splash suits of PVC on nylon, as are the rest of the crews. The two standby men at the decon line are partially attired in PVC on nylon coveralls with available SCBA and butyl slip-on aprons and sleeves. We guess that the PVC on nylon is permeable to the material with rapid breakthrough and a high (relative) permeation rate.

With this preliminary information which you would think of faster than you could read this, you are ready for action.

3) <u>Request assistance</u>

Since anyone who has been unconscious for any reason requires a medical checkup, you start an ambulance to the site by calling the local rescue squad.

4) <u>Response</u>

Simultaneously, you send in your standby team with their butyl gear and Stokes litters and advise them to avoid contamination as much as possible. You also divert 2 men from the barrel crusher and 2 men from Section 4 to assist and serve as litter bearers.

5) <u>Survey</u>

The standby men, one trained in CPR and the other an EMT, report that both men are breathing on their own but they seem to be wheezing and salivating and their eye pupils are equal but are contracted to almost pinpoints.

6) <u>Stabilization</u>

The men are not trapped so extrication is not necessary, but the EMT immediately began to stabilize the two by insuring an open airway.

7) <u>Decontamination</u>

Decontamination is begun at the scene during the EMT's survey as the contaminated gear is carefully cut away. Further decontamination sponging is attempted at the decon line while awaiting the ambulance.

10) <u>Transport</u>

The rescue squad transports the two victims who, now shorn of clothing, are covered with disposable sheeting. The two EMT's are each given an already prepared package of disposable coveralls, disposable gloves and organic vapor/acid gas and particulate filtering respirators for their protection. Some respiratory protection is given to Jones and Smith by the non-rebreathing oxygen masks supplied with a slight excess of oxygen.

11) <u>Recovery</u>

The rescue isn't over until you are ready to respond again. The cleanup and refilling of equipment must be done carefully, but as soon as possible so that the unit will be prepared to respond to the next rescue operation. This is the last step. You're through.

While this is, of course, a fictitious case for illustration, such events happen. The difference between a smooth operation, such as this one, and chaos is up to you. The key is adquate planning.

APPENDIX C: Summary Worksheet for Recording Information
Required by Selection Guide (Part II) and
Calculation Worksheets (Part III)

## APPENDIX C: Summary Worksheet for Recording Information Required by Selection Guide (Part II) and Calculation Worksheets (Part III)

### Instructions for Summary Worksheet

The following worksheet is intended for the mission planner's use. All pertinent information should be logged in as required on the worksheet. This information should be as complete as possible to provide for the best possible selection of equipment and adjustment of mission. The completed Worksheet will serve as a reference to the mission planner working through Parts II and III of this manual.

Summary Worksheet for Recording Information
Required by Selection Guide (Part II)
and Calculation Worksheet(Part III)

SITE______________________ Date___________

___________

___________

A. Location:

Emergency Telephone Numbers:

Fire:______________________ EMS:______________________

Police_____________________ Hospital___________________

OSC________________________
___________________________
___________________________ Physician__________________

Lead Agency____________________________________________

Other______________________
___________________________

Site Safety Plan? YES NO

Rescue Plan? YES NO

Summary Worksheet (continued)

SITE____________________ Date:_______________

Topo. Map:____________________________ County: ____________________________

Sketch (1" = 100 ') Indicate North (mag.)

Summary Worksheet (continued)

SITE________________ Date:____________

B. Substance Identification

Substance A

Name:__________________________________ CAS:__________________

Classification: DOT__________________ EPA___________________

Airborne Concentration:_______________________________________

Detector Tube: Time:_____________________(24 hr)

| Name | Results | Name | Results |
|---|---|---|---|
| 1.______ | ______ | 6.______ | ______ |
| 2.______ | ______ | ______ | ______ |
| 3.______ | ______ | ______ | ______ |
| 4.______ | ______ | ______ | ______ |
| 5.______ | ______ | ______ | ______ |

Tentative Chemical Classification:________________________________

Toxicology:

PEL/TLV®/MPC:_________________________
Source:___________________

Skin effects:___________________________

IDLH:__________________________________

Warning Properties:____________________________________________

Threshold(s):__________________________

Protection Factor = $\frac{\text{Airborne concentration}}{\text{PEL/TLV}^{\circledR}\text{/MPC}}$ = _________

Fire and explosion:

Flammability Class (NFPA 704)_______________Reactivity class________

Summary Worksheet (continued)

SITE__________________ Date:______________

## Substance A (continued)

Flashpoint______________________ LFL_______________________

MEC ________________________ Shock Sensitive? YES NO

Blast/Fragmentation? YES NO Quantity (#)__________________

Chemical/Physical properties:

Sublimes/Decomposes) YES NO

Vapor Pressure (mmHg)_________

State _______________________

Mixture ______________________

Permeation, Suit _____________

Degradation, Suit ____________

Respirator:

Sorbent efficiency ___________

Desorption ___________________

Heat of Reaction _____________

Radiological

Radioactive other than aerosol? YES NO

Attenuation Required? YES NO

Attenuation ___________________

Summary Worksheet (continued)

SITE ____________________ Date: __________

B. Substance Identification (continued)

Substance B

Name: ______________________________ CAS: ____________________

Classification: DOT ____________________ EPA ____________________

Airborne Concentration: ______________________________

Detector Tube: Time: ____________________ (24 hr)

| Name | Results | | Name | Results |
|---|---|---|---|---|
| 1. ________ | ________ | 6. | ________ | ________ |
| 2. ________ | ________ | | ________ | ________ |
| 3. ________ | ________ | | ________ | ________ |
| 4. ________ | ________ | | ________ | ________ |
| 5. ________ | ________ | | ________ | ________ |

Tentative Chemical Classification: ______________________________

Toxicology:

PEL/TLV®/MPC: ______________________________
Source: ____________________

Skin effects: ______________________________

IDLH: ______________________________

Warning Properties: ______________________________

Threshold(s): ______________________________

$$\text{Protection Factor} = \frac{\text{Airborne concentration}}{\text{PEL/TLV®/MPC}} = \_\_\_\_\_\_\_\_$$

Fire and explosion:

Flammability Class (NFPA 704) ____________ Reactivity class __________

Summary Worksheet (continued)

SITE__________________ Date:______________

Substance B (continued)

Flashpoint______________________ LFL______________________

MEC ________________________ Shock Sensitive? YES NO

Blast/Fragmentation? YES NO Quantity (#)__________________

Chemical/Physical properties:

Sublimes/Decomposes)YES NO

Vapor Pressure (mm Hg)____

State ______________________

Mixture ______________________

Permeation, Suit __________

Degradation, Suit ___________

Respirator:

Sorbent efficiency ________

Desorption ___________________

Heat of Reaction ________

Radiological

Radioactive other than aerosol? YES NO

Attenuation Required? YES NO

Attenuation __________________

Summary Worksheet (continued)

SITE ____________________ Date: __________

B. Substance Identification (continued)

Substance C

Name: ______________________________ CAS: ______________

Classification: DOT ______________ EPA ______________

Airborne Concentration: ______________________________

Detector Tube: Time: ______________ (24 hr)

| | Name | Results | | Name | Results |
|---|---|---|---|---|---|
| 1. | ________ | ________ | 6. | ________ | ________ |
| 2. | ________ | ________ | | ________ | ________ |
| 3. | ________ | ________ | | ________ | ________ |
| 4. | ________ | ________ | | ________ | ________ |
| 5. | ________ | ________ | | ________ | ________ |

Tentative Chemical Classification: ______________________________

Toxicology:

PEL/TLV®/MPC: ______________________
Source: ______________

Skin effects: ______________________

IDLH: ______________________

Warning Properties: ______________________________

Threshold(s): ______________________

Protection Factor = $\frac{\text{Airborne concentration}}{\text{PEL/TLV®/MPC}}$ = ______________

Fire and explosion:

Flammability Class (NFPA 704) ______________ Reactivity class ______________

Summary Worksheet (continued)

SITE:__________ Date: __________

Substance C (continued)

Flashpoint____________________

LFL ____________________

MEC ____________________

Shock Sensitive? YES NO

Blast/Fragmentation? YES NO

Quantity (#)________________

Chemical/Physical properties:

Sublimes/Decomposes) YES NO

Vapor Pressure (mmHg)________

State ____________________

Mixture ____________________

Permeation, Suit ____________

Degradation, Suit ________

Respirator:

Sorbent efficiency ___________

Desorption ________________

Heat of Reaction ___________

Radiological

Radioactive other than aerosol? YES NO

Attenuation Required? YES NO

Attenuation __________________

Summary Worksheet (continued)

SITE:____________________Date:_________

C. Mission

Job description: ________________________________________

Involve fire fighting? YES NO

Other operations: __________________________________

Estimated:

Speed (mph) ____________________

Workrate (kcal)__________________________

Minute volume (1)_________________________

Service life ____________________________

Distance to explosive or radioactive materials ____________________

Flotation? YES NO

Mobility? YES NO

Spot exposures? YES NO

Summary Worksheet (continued)

SITE:__________________Date:_________

D. Environment

Terrain:______________________________________________________________

______________________________________________________________________

______________________________________________________________________

Slope: ___________________

Weather: _____________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

Dry bulb temperature ($^{o}C$) _______________ RH _______________

Barometric pressure _________________________

Percent Oxygen _____________________

Oxygen deficiency
(less than 19.5%, 148 mm Hg $pO_2$, or 104 $pAO_2$)_______________________

E. Equipment

Anticipated Ensemble:

Configuration _________________________

Material _____________________________

Clo Value ____________________________

Weight (kg) __________________________

# GLOSSARY

acclimatization:

a physiological change occurring within the lifetime of an organism which reduces the strain caused by stressful changes in the natural climate (e.g., seasonal or geographical).

J. APPL. PHYSIO.
35:6 12/73 p. 941

breakthrough time:

the elapsed time between initial contact of the hazardous liquid chemical with the outside surface of a protective clothing material and the time at which the chemical can be detected at the inside surface of the material by means of the chosen analytical technique.

ASTM F 739-81

chemical resistance:

the ability to resist chemical attack. (Note - The attack is dependent on the method of test and its severity is measured by determining the changes in physical properties. Time, temperature, stress, and reagent, may all be factors that affect the chemical resistance of a material.)

ASTM F 412 F-17

CLO:

a unit to express the relative thermal insulation values of various clothing assemblies. 1 clo = $0.18^{o}C\ m^2\ h\ C^{-1}$

J. APPL. PHYSIO.
35:6 12/73 p. 941

Clo:

a Clo unit is equivalent to the amount of insulation provided by the clothing a person usually wears at room temperature.

closed-circuit apparatus:

an apparatus of the type in which the exhalation is rebreathed by the wearer after the carbon dioxide has been effectively removed and a suitable oxygen concentration restored from sources composed of compressed oxygen, or chemical oxygen, or liquid-oxygen.

30 CFR 11.70(a)(1)

decontamination:

those procedures taken to minimize contamination of personnel and equipment, minimize translocation of hazardous materials by external contamination, and reduce external contamination by removal, neutralization or chelation.

degradation:

a deleterious change in the chemical structure of a plastic.

ASTM D 883, D-20; F 412, F-17

flammable (explosive) limits:

the minimum concentration of vapor to air below which propagation of a flame will not occur in the presence of an ignition source.

NFPA FPH 15th 4-29

hazardous materials:

any materials capable of causing an acute or chronic human illness or injury as result of an acute exposure.

hazardous materials incidents

a release of a hazardous material to the extent that human exposure could result in acute or chronic injury or illness.

immediately dangerous to life or health (IDLH):

conditions that pose an immediate threat to life or health or conditions that pose an immediate threat of severe exposure to contaminants, such as radioactive materials, which are likely to have adverse cumulative or delayed effects on health.

30 CFR 11.3(t)

open-circuit apparatus:

an apparatus of the following types from which exhalation is vented to the atmosphere and not rebreathed:

demand-type apparatus:

an apparatus in which the pressure inside the facepiece in relation to the immediate environment is positive during exhalation and negative during inhalation.

pressure-demand-type apparatus:
an apparatus in which the pressure inside the facepiece in relation to the immediate environment is positive during both inhalation and exhalation.

30 CFR 11.70(a)(2)

oxygen deficient atmosphere:
an atmosphere which contains an oxygen partial pressure of less than 148 millimeters of mercury (19.5 percent by volume at sea level).

30 CFR 11.3(aa)

penetration:
the flow of a hazardous liquid chemical through zippers, stitched seams, and pinholes or other imperfections in a protective clothing material.

ASTM F 739-81

permeation:
the process by which a hazardous liquid chemical moves through a protective clothing material on a molecular level. Permeation involves: (1) sorption of molecules of the liquid into the contacted (outside) surface of a material; (2) diffusion of the sorbed molecules in the material; and (3) desorption of the molecules from the opposite (inside) surface of the material into the collecting medium.

ASTM F 739-81

steady-state permeation:
the constant rate of permeation that occurs after breakthrough when all forces affecting permeation have reached equilibrium.

ASTM F 739-81

protection factors:
the respirator protection factor indicates how much protection a respirator provides. It is the ratio of the contaminant concentrations outside and inside the respirator.

NIOSH 76-189

rule out:
to eliminate as a possibility.

Webster's Unabridged
Dictionary, 3rd edition,.

threshold limit value-ceiling (TLV®-C):
the concentration that should not be exceeded even instantaneously.

ACGIH TLV® LIST 1982

threshold limit value-short term exposure limit (TLV®-STEL):
the concentration to which workers can be exposed continuously for a short period of time without suffering from 1) irritation, 2) chronic or irreversible tissue change, or 3) narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency, and provided that the daily TLV®-TWA also is not exceeded. It is not a separate independent exposure limit, rather it supplements the time-weighted average (TWA) limit where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature. STELs are recommended only where toxic effects have been reported from high short-term exposures in either humans or animals.

ACGIH TLV® LIST 1982

STEL:
a 15-minute time-weighted average exposure which should not be exceeded at any time during a work day even if the eight-hour time-weighted average is within the TLV®. Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should be at least 60 minutes between successive exposures at the STEL. An averaging period other than 15 minutes may be recommended when this is warranted by observed biological effects.

ACGIH TLV® LIST 1982

threshold limit value-time weighted average (TLV®-TWA):
the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

ACGIH TLV® LIST 1982



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