PROJECT HEROES
Homeland Emergency Response Operational and Equipment Systems

Task 1: A Review of Modern Fire Service Hazards and Protection Needs

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EXECUTIVE SUMMARY

The first task of Project HEROES was undertaken by the International Association of Fire Fighters (IAFF) to examine and define the protection needs of fire fighters and other first responders during a broad array of different missions. This task began with a review for how the fire service and its responsibilities have changed over the past 20 years since personal protective equipment (PPE) was then affected by Project FIRES. In that 20 year period, the fire service has evolved to gain responsibility for a larger number of missions. Fire suppression is no longer the chief responsibility for most fire departments, but rather responses to a wide range of missions, including emergency medical aid, technical rescue, and more recently the prospect for terrorism events involving weapons of mass destruction. As America's fire fighters attempt to keep up with these changing roles, it is noted that the level of preparedness and PPE needed to safety carry out the different missions is often lacking. In an age of increasing specialization, it is not fiscally possible for most departments to equip their fire fighters with all of the different ensembles that would be required for protection against different hazards.

A review of fire fighter fatality and injury information reveals some trends for protection needs. This information coupled with a comprehensive review of the various hazards that fire fighters and other emergency responders face, shows a number of concerns for protective the health and safety of fire fighters with current PPE. The application of a risk assessment matrix for the different primary missions for the fire service against the types of hazards present at the emergency scene further identifies how the basis for protection varies extensively as different missions are undertaken. For any mission, there are tradeoffs between protection and fire fighter functionality and comfort; however, some tradeoffs appear to be difficult to achieve as serious risks exist in each of the primary mission areas.

The intent of the information provided in this report is to create the basis for future tasks in Project HEROES. The risk assessment will be refined as current protection strategies are evaluated, including the standards used to establish minimum protection. The risk assessment can then be used to identify gaps in protection and focus energies on new and emerging technologies that may solve these problems. Overall, the main focus of this project will be develop product technology, specifications, evaluation methods, use practices, and care procedures that affords the fire fighter of the future to be a better equipped and safer responder.

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CHAPTER 1 – INTRODUCTION

In 1971, the International Association of Fire Fighters (IAFF) requested the National Aeronautics and Space Administration (NASA) to initiate a technology transfer program to develop state-of-the art protective clothing and equipment for structural fire fighters. In 1976, NASA, with additional funding from the United States Fire Administration (USFA), initiated Project FIRES (Firefighters Integrated Response Equipment System) with the full support and participation of the IAFF. The objective of Project FIRES was to design, fabricate, laboratory test and field test an integrated protective clothing ensemble for fire fighters that would address the known limitations of then available equipment, including severe heat stress, interference with movement, and inadequate protection, especially from the heat experienced during flashovers and back drafts.

The IAFF assumed responsibility and began managing and directing Project FIRES activity in 1983. The IAFF performed additional research on much of the ensemble's components; initiated and completed a revamped field study of over 300 garments in 10 cities; developed performance and purchase specifications; and developed and successfully conducted product awareness programs that stimulated and encouraged universal use of the final Project FIRES ensemble. The results of the research from Project FIRES and the associated Project FIRES Model Criteria were reported by the IAFF in the mid-1980s. This research and testing effort not only was successful in providing fire departments and fire fighters with state-of-the-art protective ensembles but also served as the impetus for changing industry standards addressing fire fighters protective clothing and equipment.

Since that time, there have been significant advances in materials, sensor technology and testing for garments for structural fire fighting. Much more remains to be done to insure optimal protection of fire fighters, particularly under the changing emergency missions that fire fighters increasingly face.

Project HEROES

The nation's first responders to fires, emergency medical incidents, special operations, hazardous materials incidents, and terrorist attacks are fire fighters, and their primary protective clothing is a structural fire fighting ensemble. While other ensembles of specialized protective clothing and equipment have been established, the availability of these ensembles is limited and the processes for deciding how and when to use these ensembles are not always evident. As a consequence, the IAFF has proposed an initiative called "Project HEROES" (Homeland Emergency Response Operational and Equipment Systems) to capitalize on the technological advances of the last 20 years as well as on emerging technologies for personal protection. The Project HEROES ensemble will optimize the fire fighter's protective equipment for all homeland emergency responses, which could include structural fire fighting, search and rescue, and initial response and rescue activities for emergencies involving hazardous materials, biological materials and other weapons of mass destruction.

The project goal is to develop new personal protective clothing and equipment that will save lives, reduce injuries and safely increase the work capacity of fire fighters engaged in high-risk operations in extreme environments.

Project HEROES will involve the conduct of research and will develop, integrate, evaluate and accelerate the use of advanced, emerging and future protective technologies (clothing, equipment, electronics, and integrated systems) through the establishment of a multi-disciplinary team of fire service, academic, private sector, and governmental entities. The Project HEROES team will also leverage the research and development efforts of the military programs on protective clothing and equipment for the current soldier and warrior of the future to enhance the protection for the fire fighter of the future. Project HEROES will incorporate the military methodology for treating the human platform as a "system" with careful consideration of integration versus modularity of technology. The Project HEROES team will also directly interact and partner with the Natick Soldier Center and its National Protection Center to leverage directly from programs such as the Object Force Warrior.

Initial Task Assignment

The purpose of this initial task was to define the various environmental, physiological and biomechanical stresses on the fire fighter and how these hazards compare to the current fire fighter protective clothing and equipment when responding to emergency incidents, including fire, emergency medical, and special operations (including hazardous materials operations, urban search and rescue, and incidents involving weapons of mass destruction). This task essentially comprised a risk and needs assessment that will be used throughout Project HEROES to help establish the ensemble technology, design, and performance goals for the future fire fighter protective ensemble.

CHAPTER 2 – OVERVIEW OF THE FIRE SERVICE

In order to determine the needs of the fire service in terms of personal protection, it is important to understand exactly what the fire service has become in the last several years. Well over 25 years ago, fire fighters were principally engaged in responding to structural fires. Areas of specialization were not yet considered though fire fighters still responded to a wide range of emergencies. Now, in 2003, fire fighters have a vast number of different mission areas, each with different hazards. Their ability to respond to different types of incidents depends on several factors, including:

- Department staffing
- Level of training for personnel
- The system in place for incident response
- The type of response equipment, including personal protective equipment

These attributes vary with the department and its resources. Therefore, the development of a Project HEROES ensemble, requires understanding the specific characteristics of the fire service and how particular needs can be addressed through a modern, comprehensive response ensemble that will benefit the broadest range of fire fighter over the broadest range of missions.

The National Fire Protection Association (NFPA) recently completed the report, "A Needs Assessment of the U.S. Fire Service" (U.S. Fire Administration Report, FA-240/December 2002).[1] This report examines the current state of the fire service in terms of personnel, levels of training, preparedness for different missions, and adequacy of equipment based on fire department demographics.

Types of Fire Departments and Staffing Levels

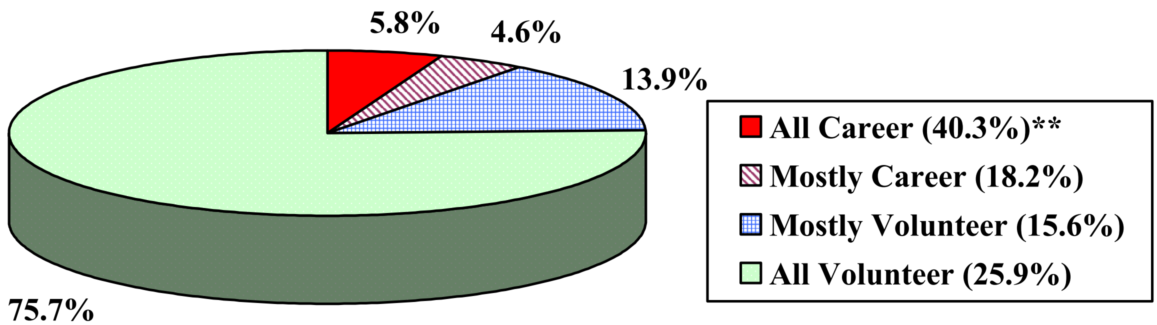
Even though the most of fire departments in the United States are volunteer fire departments, the majority of the United States's population is protected by career fire fighters. Figure 1 shows the number of fire departments by type and the percentage of the population that these departments protect. Table 1 lists the number of fire departments by type for the size of the community. As the NFPA points out that "Three of every four U.S. fire departments are all-volunteer fire departments, but only one of every four U.S. residents is protected by such a department. Only one in 17 fire departments is all-career, but two of every five U.S. residents are protected by such a department."

As would be expected, volunteers are concentrated in rural communities, while career fire fighters are found primarily in the larger communities. Departments that consist of all- or mostly-career fire fighters account for all of the fire departments that protect communities with a population of 1 million or more. This percentage drops to 90% of the fire departments protecting communities having populations numbering from 250,000 to 999,999, but further declines with all- or mostly-career departments still accounting for a majority of the fire departments for communities having a population of at least 25,000. As defined by the U.S. Bureau of Census,

[1] This publication is referred to throughout this report as the 2002 NFPA Survey.

rural communities having a population with less than 2,500 population are almost exclusively protected by all- or mostly- volunteer departments.

Figure 1. Types of Departments and Percentage of Population Protected*



* **Source:** FEMA, U.S. Fire Administration 2002 Survey of the Needs of the Fire Service
** Figure in parentheses refers to percent of population protected

Table 1. Number of Career and Volunteer Fire Fighters by Size of Community Served*

Population Protected	Career Fire Fighters	Volunteer Fire Fighters	Total Fire Fighters
1,000,000,000 or more	32,700	150	32,850
500,000 to 999,999	28,400	4,900	33,300
250,000 to 499,999	26,600	4,250	30,850
100,000 to 249,999	39,750	8,550	48,300
50,000 to 99,999	37,750	11,000	48,570
25,000 to 49,999	40,000	29,300	69,300
10,000 to 24,999	38,850	86,050	124,900
5,000 to 9,999	12,200	112,300	124,500
2,500 to 4,999	5,050	157,600	162,650
Under 2,500	4,800	408,750	413,550
TOTAL	**266,100**	**822,850**	**1,088,850**

* **Source:** 2002 NFPA Survey Statistics

While most of the emergency responses occur in larger communities, the same types of incidents may occur in many parts of the United States depending on local industry and the types of activities that may take place within that community. There are also differences in the roles undertaken by individual fire departments. For example, not all fire departments engage in emergency medical operations or have hazardous materials response teams. Nevertheless, these statistics would suggest that the primary benefits for improved fire fighter ensembles should be aimed at those departments where greatest risks exist and most people are protected.

Areas of Responsibility and Levels of Training and Preparedness

As previously pointed out, fire departments engage in an increasing level of specialization to provide fire responder services to the communities they serve. While these services may be defined in several different ways, the following classifications are used in this report:

- Structural fire fighting
- Emergency medical services (EMS)
- Hazardous materials response
- Wildland fire fighting
- Technical/urban search and rescue operations

The definitions of and discussions of the types of response activity included in each classification are provided in Chapter 4. It is important to note that these classifications do not account for all fire department activities that extend to community service roles such as fire education and building inspection, or to very specialized functions including response to chemical/biological terrorism incidents.

In reviewing which departments currently provide the five classes of different response services, the 2002 NFPA survey yielded the following data, indicating the percentage of fire departments providing each service by size of community protected.

Table 2. Services Provided by Size of Community Served*

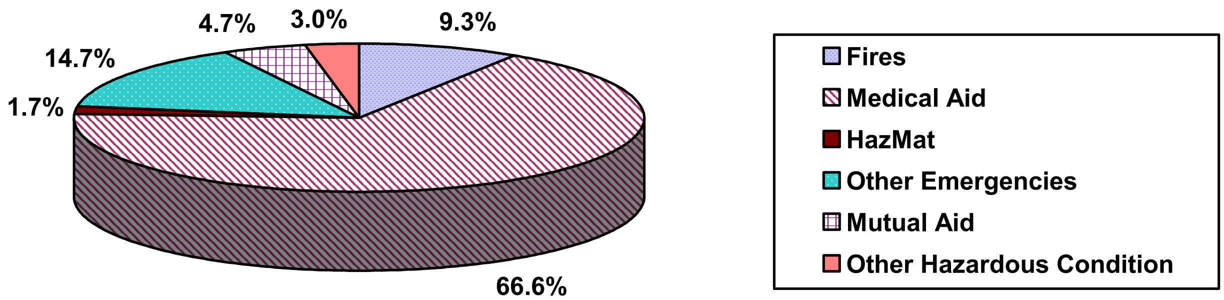
Population Protected	**Total No. Depts.**	**Structural Fire Fighting**	**EMS**	**Hazardous Materials Response**	**Wildland Fire Fighting**	**Technical Rescue Operations**
1,000,000,000 or more	13	100.0%	100.0%	100.0%	69.2%	100.0%
500,000 to 999,999	38	100.0%	100.0%	100.0%	68.4%	100.0%
250,000 to 499,999	64	100.0%	98.4%	100.0%	65.6%	100.0%
100,000 to 249,999	215	100.0%	97.2%	95.8%	68.8%	93.0%
50,000 to 99,999	487	100.0%	92.8%	95.7%	66.4%	86.9%
25,000 to 49,999	1,053	100.0%	88.4%	94.9%	62.6%	83.3%
10,000 to 24,999	2,843	100.0%	76.1%	91.8%	71.3%	72.6%
5,000 to 9,999	3,629	99.9%	68.7%	87.5%	83.0%	67.0%
2,500 to 4,999	4,572	99.9%	65.1%	82.2%	86.2%	58.5%
Under 2,500	13,440	98.5%	57.5%	67.2%	88.8%	43.5%
TOTAL	**26,354**	**99.2%**	**64.7%**	**77.3%**	**84.0%**	**55.6%**

* **Source:** 2002 NFPA Survey Statistics

As should be expected, nearly all fire departments provide structural fire fighting services. The few that do not are limited to the smallest of communities that provide defensive activities only. Fire departments serving larger communities are more likely to offer the full range of services including emergency medical services, hazardous materials response, and technical rescue operations. The only exception is wildland fire fighting, which appears to be more a function of the urban-wildland interface for the particular community being served. In contrast, fire departments of smaller communities are less likely to provide a full range of services. For instance, many small communities do not have access to hazardous materials teams or technical rescue services, which tend to be services associated with cities with larger manufacturing capabilities and infrastructures in place.

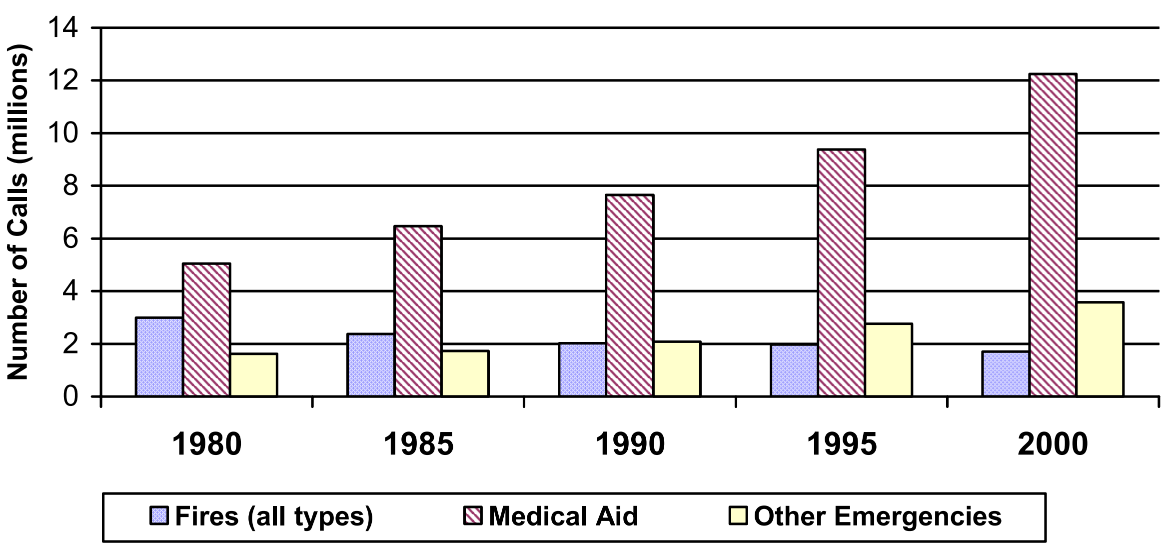
The provision of service and the level of that service for fire departments can differ significantly. As Figure 2 shows, emergency medical service calls (medical aid) provide the highest proportion of alarm response activity among all fire service calls.

Figure 2. Proportion of Fire Department Responses by Type of Alarm · 2001



In fact, as seen in Figure 3, the trend for non-fire calls has generally been increasing over the past 15 years.

Figure 3. Historical Changes in the Type of Fire Department Calls



These statistics show not only a rise in the total number of fire department calls, but growing increases in EMS and other emergency calls at the same time that fire calls are declining.
Despite changes in the patterns for fire department roles and the growing proportion of non-fire responses, this does not mean that all community fire departments are appropriately staffed, equipped, or trained to deal with the broader range of emergencies. With respect to training and the levels of preparedness among fire fighters, the following conclusions were provided in the 2002 NFPA survey report:

- In communities with less than 2,500 population, 21% of fire departments, nearly all of them all- or mostly- volunteer departments, deliver an average of 4 or fewer volunteer fire fighters to a mid-day house fire. Because these departments average only one career fire fighter per department, it is likely that most of these departments often fail to deliver the minimum of 4 fire fighters needed to safely initiate an interior attack on such a fire.

- An estimated 73,000 fire fighters serve in fire departments that protect communities of at least 50,000 population and have fewer than 4 career fire fighters assigned to first-due engine companies. It is likely that, for many of these departments, the first arriving complement of fire fighters often falls short of the minimum of 4 fire fighters needed to safely initiate an interior attack on a structure fire, thereby requiring the first-arriving fire fighters to wait until the rest of the first-alarm responders arrive.

- An estimated 233,000 fire fighters, most of them volunteers serving in communities with less than 2,500 population, are involved in structural fire fighting but lack formal training in those duties.

- An estimated 153,000 fire fighters, most of them volunteers serving in communities with less than 2,500 population, are involved in structural fire fighting but lack certification in those duties.

- An estimated 27% of fire department personnel involved in delivering emergency medical services (EMS) lack formal training in those duties, most of them serving in communities with less than 10,000 population.

- The majority of fire departments do not have all their personnel involved in emergency medical services (EMS) certified to the level of Basic Life Support, and almost no departments have all those personnel certified to the level of Advanced Life Support.

- An estimated 40% of fire department personnel involved in hazardous material response lack formal training in those duties, most of them serving in smaller communities.

- More than four out of five fire departments do not have all their personnel involved in hazardous material response certified to the Operational level, and almost no departments have all those personnel certified to the Technician level.

- An estimated 41% of fire department personnel involved in wildland fire fighting lack formal training in those duties, with substantial needs in all sizes of communities.

- An estimated 53% of fire department personnel involved in technical rescue service lack formal training in those duties. In every population group of communities with less than 500,000 population, at least 40% of fire department personnel involved in technical rescue service lack formal training in those duties.

- An estimated 792,000 fire fighters serve in fire departments with no program to maintain basic fire fighter fitness and health, most of them volunteers serving communities with less than 5,000 population.

Clearly, the level of preparedness and capability is not uniform among the fire departments. Perhaps the most telling statistics from the 2002 NFPA Survey are found in the following responses for fire departments' ability to challenging emergency situations:

- Only 11% of fire departments can handle a technical rescue with EMS at a structural collapse of a building with 50 occupants with local trained personnel.
  - Nearly half of all departments consider such an incident outside their scope.
  - Only 11% can handle the incident with local specialized equipment.
  - Only 19% have a written agreement to direct use of non- local resources.
  - All needs are greater for smaller communities.

- Only 13% of fire departments can handle a hazmat and EMS incident involving chemical/biological agents and 10 injuries with local trained personnel.
  - Two- fifths of all departments consider such an incident outside their scope.
  - Only 11% can handle the incident with local specialized equipment.
  - Only 21% have a written agreement to direct use of non- local resources.
  - All needs are greater for smaller communities.

- Only 26% of fire departments can handle a wildland/urban interface fire affecting 500 acres with local trained personnel.
  - One-third of all departments consider such an incident outside their scope.
  - Only 22% can handle the incident with local specialized equipment.
  - Nearly half the departments that consider such an incident within their scope, and 33% overall, have a written agreement to direct use of non- local resources.
  - All needs for local resources are greater for communities of 5,000 to 249,999 population, and the need for written agreements is greater for smaller communities.

- Only 12% of fire departments can handle mitigation of a developing major flood with local trained personnel.
  - The majority of departments consider such an incident outside their scope.
  - Only 11% can handle the incident with local specialized equipment.
  - Only 13% have a written agreement to direct use of non- local resources.
  - All needs are greater for smaller communities.

Availability of Personal Protective Equipment

The 2002 NFPA Survey also investigated a number of issues related to the availability and state of personal protective equipment and related safety equipment for individual fire fighter. Specific areas of investigation included:

- The availability of fire fighting (structural) protective clothing for each fire fighter and what proportion of this gear was over 10 years old.

- The availability of self-contained breathing apparatus (SCBA) for active individual fire fighters assigned to a shift and the proportion of SCBA that was over 10 years old.

- The availability of personal alert safety systems (PASS) devices for active individual fire fighters assigned to a shift.

- The availability of portable radios active individual fire fighters assigned to a shift and the proportions of these radios that were water-resistant and intrinsically safe for use in explosive atmospheres.

- The number of departments that were equipped with specialized safety equipment and capabilities such as thermal imaging cameras.

Table 3 summarizes the NFPA's findings and estimates in this area of their investigation.

Table 3. Availability of Personal Protective Equipment to Fire Fighters*

Population Protected	Total Number of Fire Departments	All Fire Fighters		Active Fire Fighters Each Shift					
		Lack protective clothing	Prot. clothing > 10 yrs old	Lack SCBA	SCBA > 10 yrs old	Lack PASS	Lack Portable Radios	**Radios not water-resistant	**Radios not intrinsically safe
1,000,000,000 or more	13	0%	7%	0%	26%	0%	18%	21%	46%
500,000 to 999,999	38	0%	16%	2%	13%	1%	26%	40%	39%
250,000 to 499,999	64	0%†	48%	2%	21%	3%	28%	38%	53%
100,000 to 249,999	215	0%†	17-18%	2%	24%	3%	25%	48%	53%
50,000 to 99,999	487	0%†	15-16%	3%	25%	3%	23%	40%	48%
25,000 to 49,999	1,053	1,000	19%	7%	27%	8%	24%	45%	53%
10,000 to 24,999	2,843	1,000	24%	13%	33%	13%	29%	48%	61%
5,000 to 9,999	3,629	4,000	30-31%	26%	38%	27%	40%	57%	70%
2,500 to 4,999	4,572	8,000	36%	37%	41%	40%	47%	64%	77%
Under 2,500	13,440	42,000	45%	48%	53%	58%	51%	72%	84%
TOTAL	**26,354**	**57,000**	**37-38%**	**36%**	**45%**	**42%**	**45%**	**64%**	**76%**

* **Source:** 2002 NFPA Survey Statistics ** Maximum NFPA estimate † Close to zero, but not zero

In the area of specialized safety equipment, the 2002 NFPA Survey uncovered the following information (repeated verbatim from the survey report):

- One quarter of fire departments now own thermal imaging cameras, but most that do not already have them – and two- fifths of all departments – have no plans to acquire them.

- Only one department in 50 has advanced personnel location equipment, though one-fifth of the fire departments protecting communities of at least 500,000 population have them. Plans to acquire them vary considerably by department size, but four-fifths of departments overall have no plans. The survey did not provide details on what constituted advanced personnel location equipment, which raises the possibility that departments differed in their views of the kind of equipment that would qualify as such.

- Only one department in 23 has equipment to collect chemical or biological samples for remote analysis, though most of the fire departments protecting communities of at least 250,000 population have such equipment. Only one department in 12 overall has plans to acquire such equipment.

Fire Fighter Fatalities and Injuries

Different fire fighter groups maintain varying levels of fire fighter injury information. For example, the IAFF publishes an annual Death and Injury Survey,[2] which provides specific information for the respective year, including:

- The breakdown of line-of-duty deaths by cause
- A comparison of the proportion of fire service fatalities per 100,000 workers with other professions
- The number of job related injuries and illnesses per 100 workers as compared with other professions
- The distribution of fire departments by lost work hours from job related injuries and illnesses per 100 workers
- The distribution of line-of-duty injuries by the response activity
- The distribution of line-of-duty injuries by the type of injury

In the latest available IAFF survey for 2000, the statistics continue to show burns and asphyxiation after being trapped as the leading cause of line-of-duty fatalities for career fire fighters. This is followed by other causes, heart attack and stroke, and internal trauma, as shown in Figure 4 (a comparison with 1994 is also provided). For line-of-duty career fire fighter injuries, sprains and strains have consistently been ranked as the most common type of injury, followed by laceration and contusions, other unclassified injuries, burns, and exposure to hazardous materials. Figure 5 provides a comparison of the type of line-of-duty injuries for career fire fighters in both 1994 and 2000.

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[2] 2000 Death and Injury Survey, International Association of Fire Fighters, Washington, DC, 2003. Later surveys (for 2001 and 2002) are not currently available.

Figure 4. Comparison of Causes for Line-of-Duty Fatalities for Career Fire Fighters Between 1994 and 2000

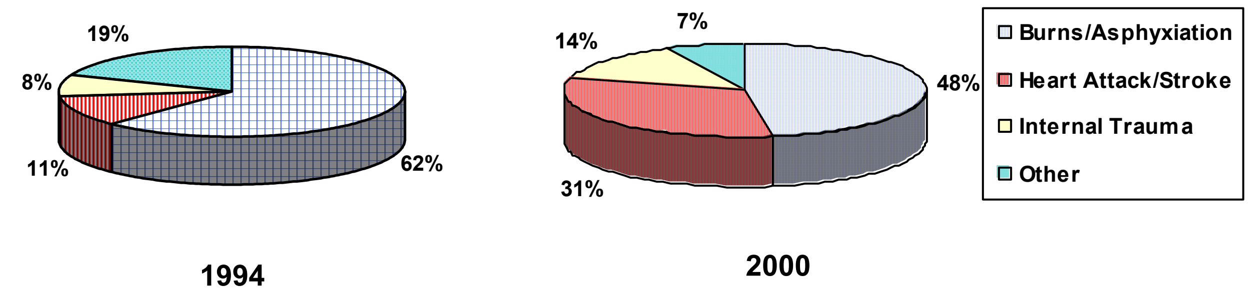
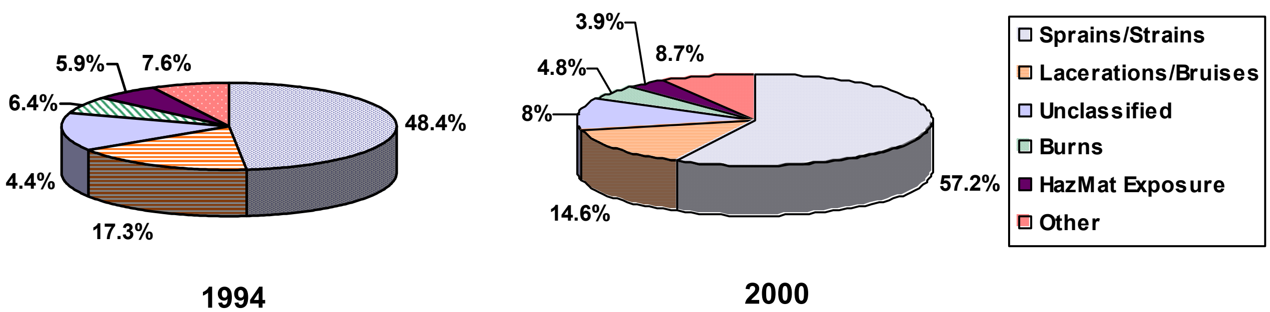
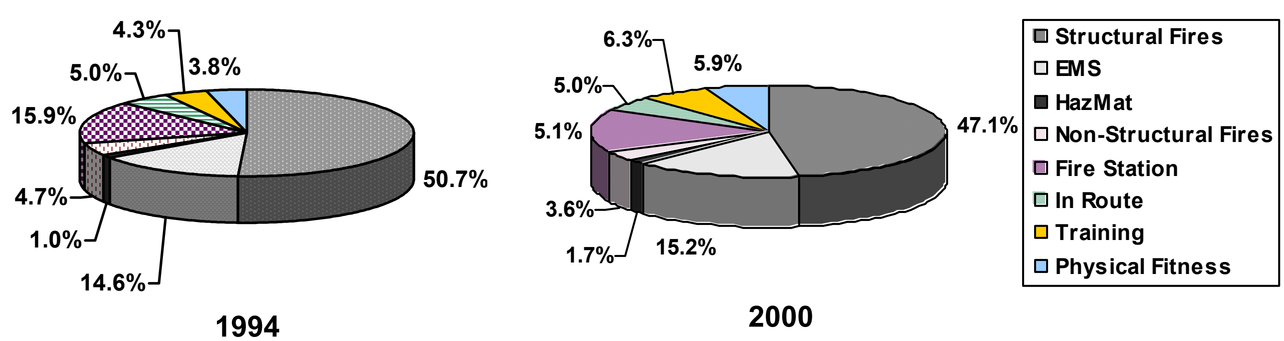


Figure 5. Comparison of Causes for Line-of-Duty Injuries for Career Fire Fighters Between 1994 and 2000



According to IAFF statistics in 2002, 71.0% of the total line-of-duty injuries occurred during response activities (structural fire suppression, EMS, HazMat, and non-structural fire suppression). A comparison of 1994 and 2002 statistics are shown in Figure 6.

Figure 6. Comparison of Line-of-Duty Injuries by Activity for Career Fire Fighters Between 1994 and 2000



One revealing statistic provided in the IAFF Death and Injury Survey is the relative proportions of the percent of alarms versus the percent of injuries for three of the leading response activities. Table 4 provides this comparison between 1994 and 2002.

Table 4. Distribution of Line-of-Duty Injuries at Emergency Scenes by Type of Incident for 1994 and 2002

Type of Incident	1994		2002	
	Percent of Alarms	Percent of Injuries	Percent of Alarms	Percent of Injuries
Fire Suppression	9.0%	77.9%	3.2%	64.8%
Hazardous Materials	1.5%	1..4%	1.2%	0.9%
EMS	64.6%	20.7%	80.1%	20.9%

Even though fire calls are declining, fire suppression, due to the severe hazards involved, accounts for the greatest number of injuries. Unfortunately, these statistics do not provide sufficient detail to permit an analysis for the role of protective clothing in these injuries.

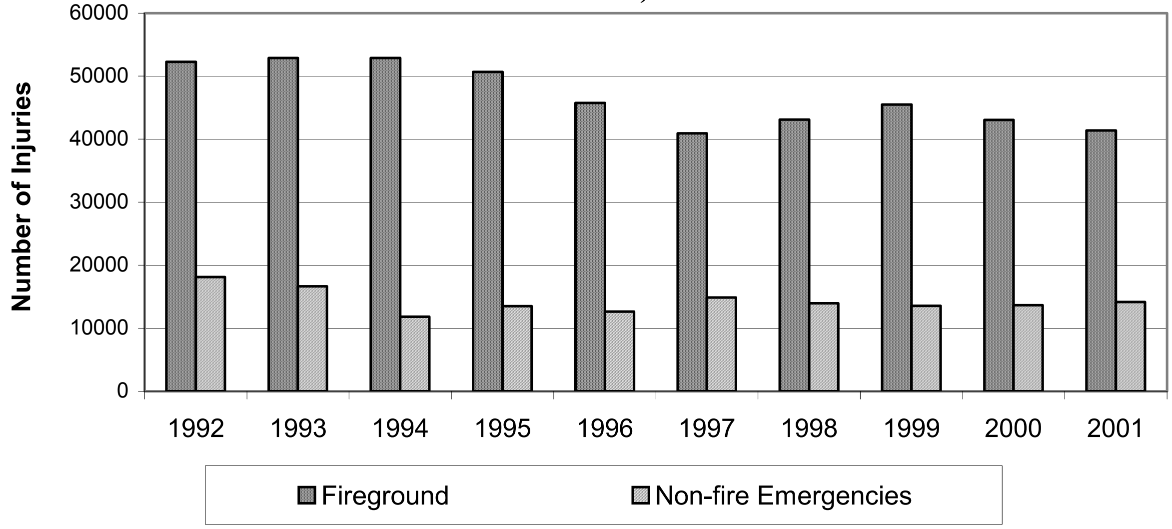
The National Fire Protection Association (NFPA) also annually acquires data related to fire fighter fatalities and injuries. Fatality information is generally published in the July/August issue of the NFPA Journal while injury statistics are published in the November/December issue of the NFPA Journal, but the NFPA also maintains a database of information that is available to NFPA members. The information collected by the NFPA is very similar to the same information provided by the IAFF but includes data for both career and volunteer fire fighters. The primary source for the NFPA's injury information is the U.S. Fire Administration's Fire Incident Reporting System (*see below*), from whose data NFPA analysts derive specific searches and analyses of general interest. Annually, the NFPA reports:

- The number of fatalities by cause of fatal injury, type of duty, and nature of fatal injury:
  - Causes of fatalities are divided between stress, being struck by or having contact with an object, being caught or trapped, falling, or other cause.
  - Type of duty includes responding to or returning from an incident, on the fireground, at non-fire emergencies, during training, and for other on-duty activities.
  - The nature of fatalities is differentiated between heart attack, internal trauma, asphyxiation, crushing, burns, drowning, or other.

- The number of injuries by nature of injury and type of duty;
  - The nature of injury includes burns (fire or chemical); heart attack or stroke; strain, sprain, and muscular pain; and thermal stress (frostbite or heat exhaustion).
  - Injuries are reported for responding to or returning from an incident, on the fireground, at non-fire emergencies, during training, and for other on-duty activities.

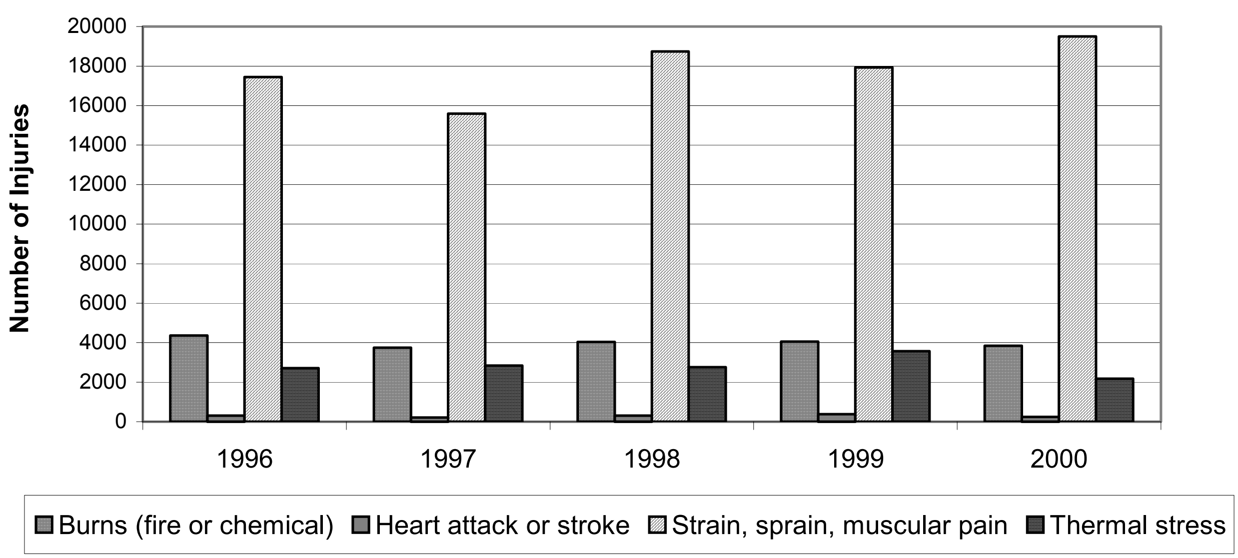
Overall NFPA injury data for the past 10 years, shown in Figure 7, distinguish between fireground and non-fire emergencies.

Figure 7. Fireground and Non-fire Emergency Injuries by Year (1992-2001)



A detailed breakdown of fire fighter injuries by nature of injury and type of duty for 2001 is provided in Table 5. Figure 8 follow the changes in specific fire fighter injury causes over a 5 year period.

Figure 8. Selected Fireground Injuries by Year (1996-2000)



Consistent with the IAFF injury data, the majority of injuries are associated with strains, sprains, and muscular pain. Nevertheless, fire and chemical burns, together with thermal stress, occur at a significant frequency.

Table 5. Fire Fighter Injuries by Nature of Injury and Type of Duty – 2001*

Nature of Injury	Responding to or Returning from an Incident		Fireground		Non-fire Emergency		Training		Other on-duty		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Burns (Fire or Chemical)	65	1.4	3,255	7.9	185	1,3	345	5.0	245	1.6	4,095	5.0
Smoke or Gas Inhalation	115	2.5	2,580	6.2	185	1.3	40	0.6	105	0.7	3,025	3.7
Other Respiratory Distress	60	1.3	1,345	3.3	100	0.7	40	0.9	165	1.1	1,730	2.1
Burns and Smoke Inhalation	75	1.6	1,190	2.9	30	0.2	80	1.1	95	0.6	1,470	1.8
Wound, Cut, Bleeding, Bruise	960	20.7	9,210	22.2	2,420	17.1	1,380	20.0	2,780	18.3	16,750	20.4
Dislocation, Fracture	205	4.4	1,145	2.8	2255	1.8	200	2.9	545	3.6	2,350	2.9
Heart Attack or Stroke	85	1.8	310	0.7	115	0.8	30	0.4	345	2.3	885	1.1
Strain, Sprain, Muscular Pain	2,250	48.5	16,410	39.6	8,025	56.8	3,860	55.8	8,185	54.0	38.730	47.1
Thermal Stress (frostbite, heat exhaustion	115	2.5	2,315	5.6	100	0.7	295	4.3	200	1.3	3,025	3.7
Other	710	15.3	3,635	8.8	2,725	19.3	625	9.0	2,495	16.5	10,190	12.4
TOTALS	4,640		41,395		14,140		6,915		15,160		82,250	

* Source: NFPA's Survey of Fire Department for U.S. Fire Experience (2001), NFPA Fire Analysis and Research Division, Quincy, MA 02269

Over a similar 10-year period, the NFPA reports that the total number of fire fighter fatalities has remained relatively within the range of 75 (in 1992) with a high of 112 in 1999 (this does not include the 340 fire fighter deaths at the World Trade Center). Figures 9, 10, and 11 show the proportions of fatalities among the different types of duty, causes of fatal injury, and nature of fatal injury, respectively.

Figure 9. Fire Fighter Fatalities in 2002 by Type of Duty

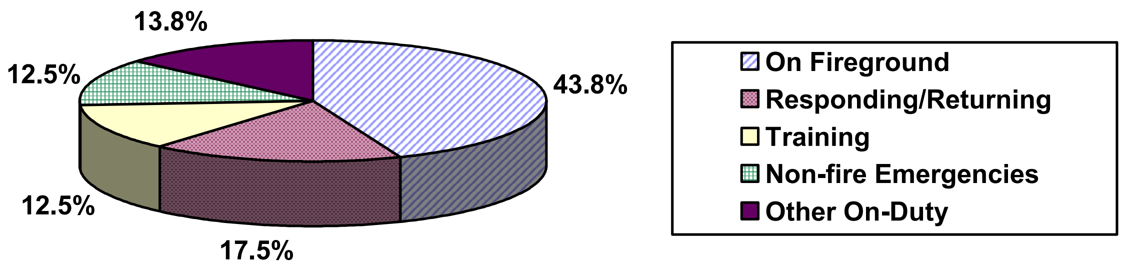


Figure 10. Fire Fighter Fatalities in 2002 by Cause of Fatal Injury

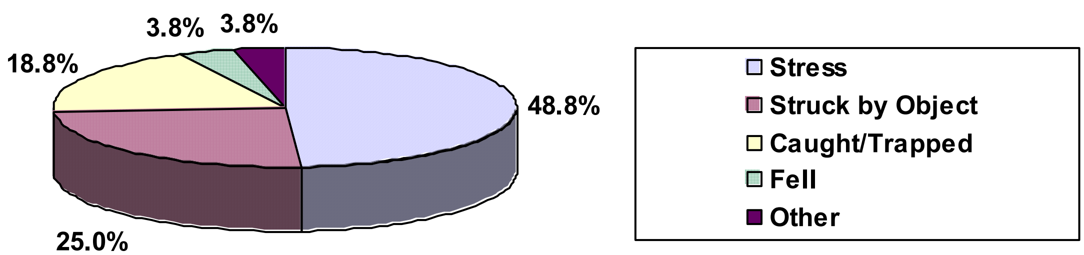
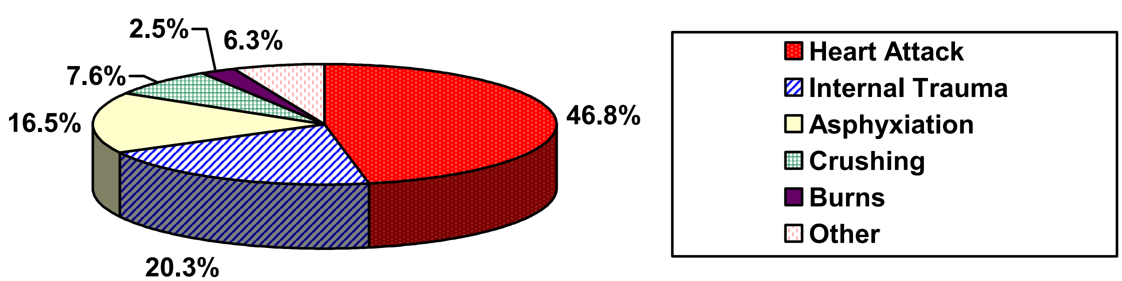


Figure 9 shows the majority of fatalities during structural fire fighting, though a significant number of fatalities have been associated with vehicle accidents while in route or returning from the response. Although different methods of classifying the cause of fatalities exists among the organizations providing fire fighter fatality statistics, the leading causes are very similar.

Figure 11. Fire Fighter Fatalities in 2002 by Nature of Fatal Injury



Relation of Fire Fighter Injuries to Protective Clothing

The U.S. Fire Administration maintains a National Fire Incident Reporting System (NFIRS), which captures national data on fire incidents, including fire fighter injuries. While the data in this system are somewhat general, it was possible to acquire more specific information about fire fighter injuries that are related to protective clothing use. Data were obtained for the time frame of 1989 through 1998; however, a change occurred in the coding of data after 1995. For this reason, only two different years were evaluated to determine if any specific trends could be tied to the type of injury, the portion of the body affected, and the wearing of protective clothing. Figures 12 and 13 show these the results of these two analyses. Only the data that included injuries where the wearing of PPE was known were included in the analyses.

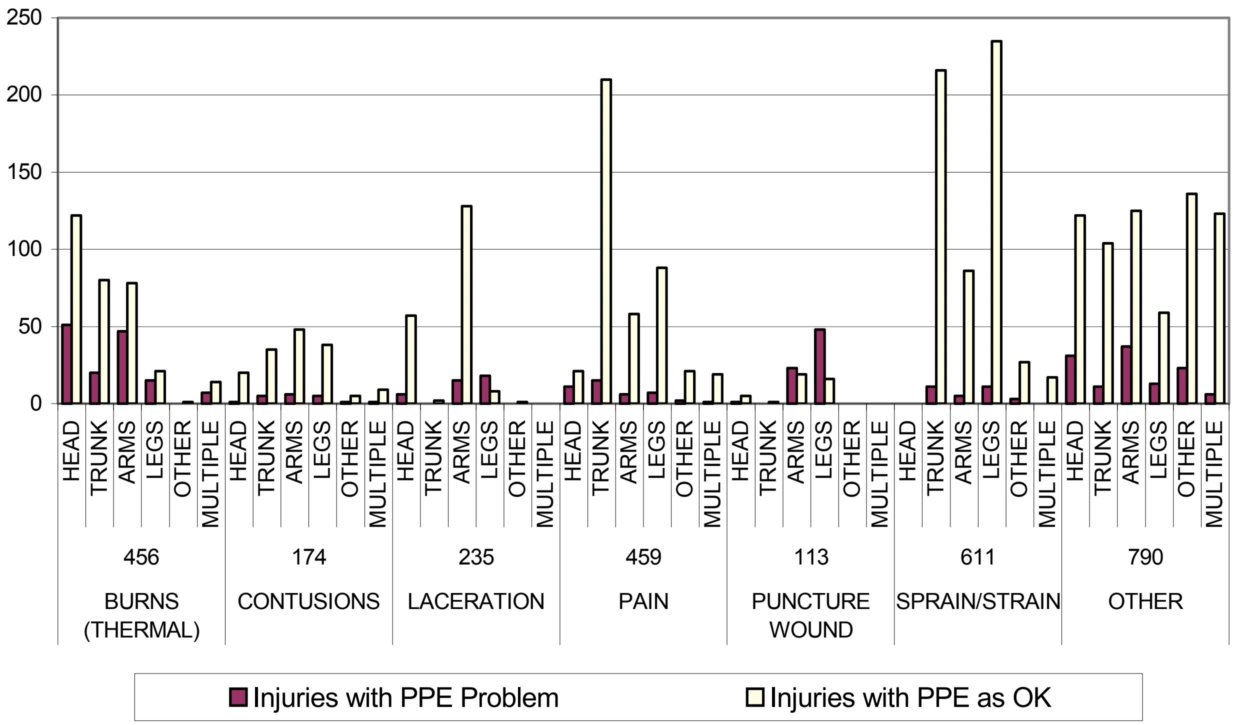


Figure 12. 1996 Fire Fighter Injuries by Type and Body Part (Source: NFIRS)

As a means for showing a more in-depth analysis, a third figure (Figure 14) isolates burn injuries by portion of the body. Data for 1996 and 1998 are compared. These data show a drop in overall burn injuries for the two years with the majority of burns on the head, trunk, and arms. Leg burns were reported at a lower frequency.

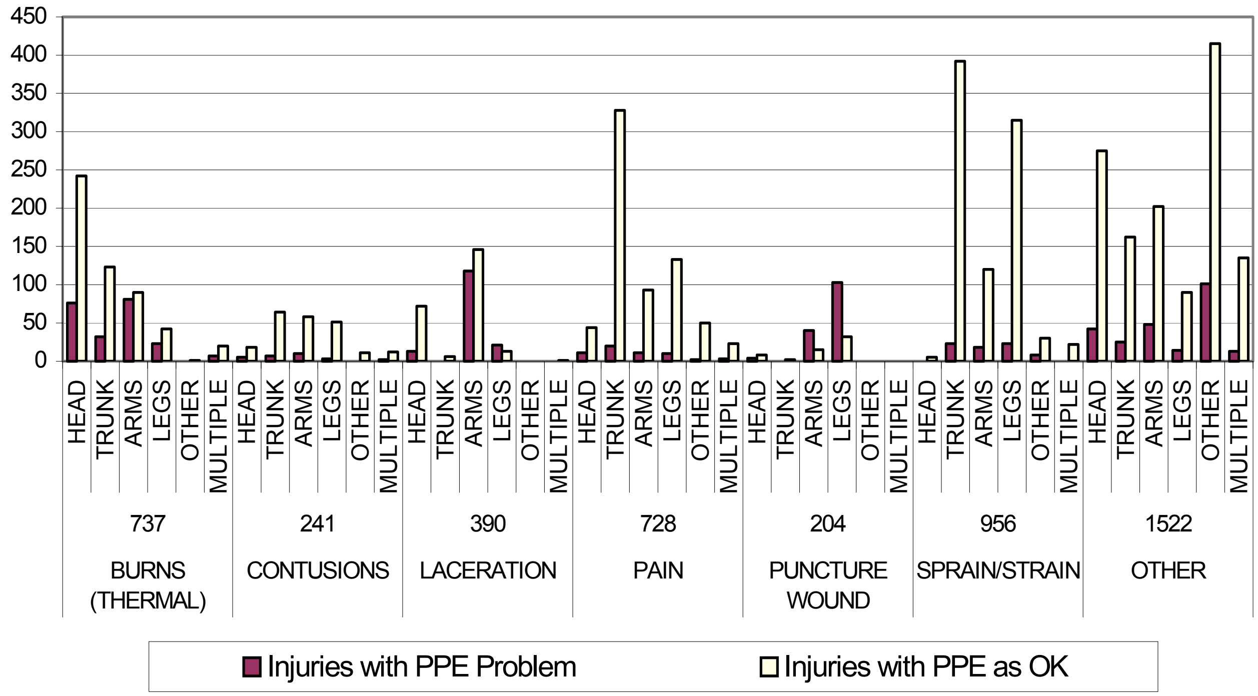


Figure 13. 1998 Fire Fighter Injuries by Type and Body Part (Source: NFIRS)

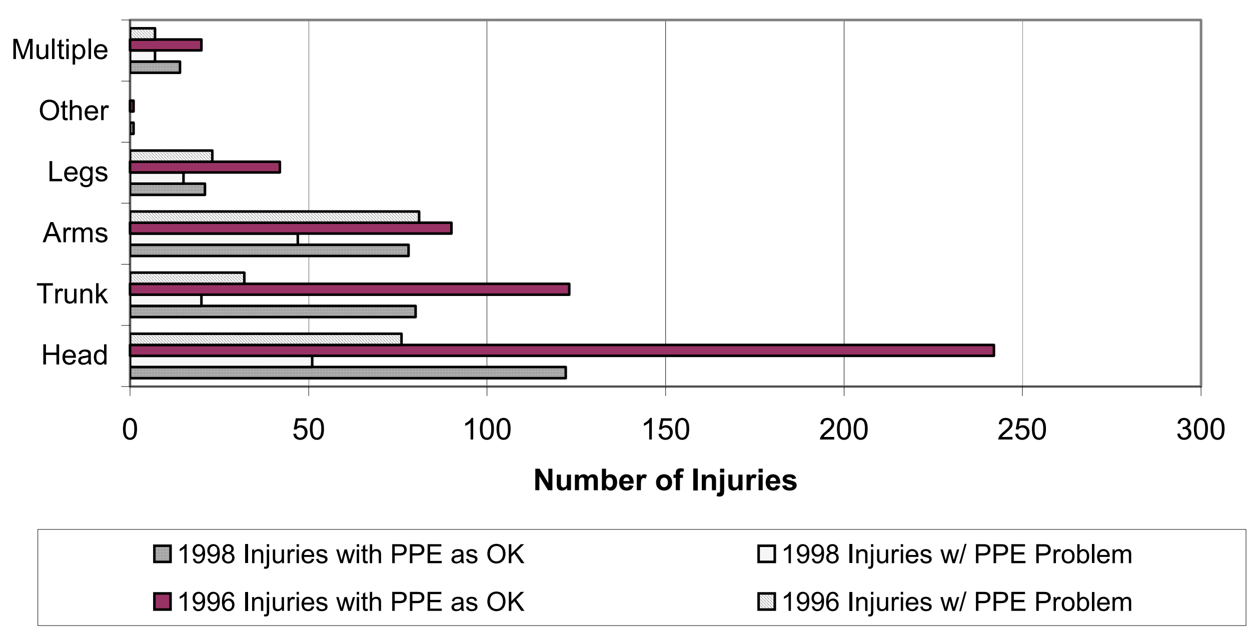


Figure 14. Comparison of Fire Fighter Burn Injuries (Source: NFIRS)

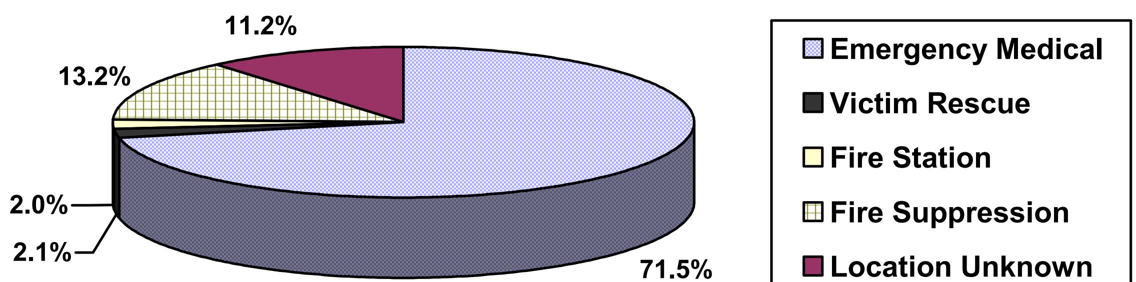
As with all of the injury and fatality data presented in this chapter, there is no specificity in which to relate specific clothing with the occurrence of burn injuries. The IAFF, NFPA, and NFIRS data generalize the impact of protective clothing on fire fighter injuries because specific clothing materials or features cannot be related to burn injury statistics. Consequently, the project team had to look to other sources to find relevant issues for fire fighter protective clothing design and performance.

Fire Fighter Communicable Disease Exposures

In addition to injuries, fire fighters are susceptible to communicable diseases as a result of their contact with the public and exposure during medical aid calls. Over the last 15-20 years, the increase in these exposures to fire fighters has been substantial particularly with the AIDS epidemic and increases in many other transmittable diseases. Several years ago, one southwestern department in a large metropolitan area reported that over 15% of its fire fighter work force tested positive for tuberculosis. Though relatively new, disease exposure has become a significant factor in fire fighter operations.

As part of its annual Death and Injury Survey, the IAFF has compiled statistics related to the location where the disease transmission was suspected of occurring. Figure 15 provides a breakdown of communicable disease exposure by activity.

Figure 15. Distribution of Communicable Disease Exposures by Activity - 2000

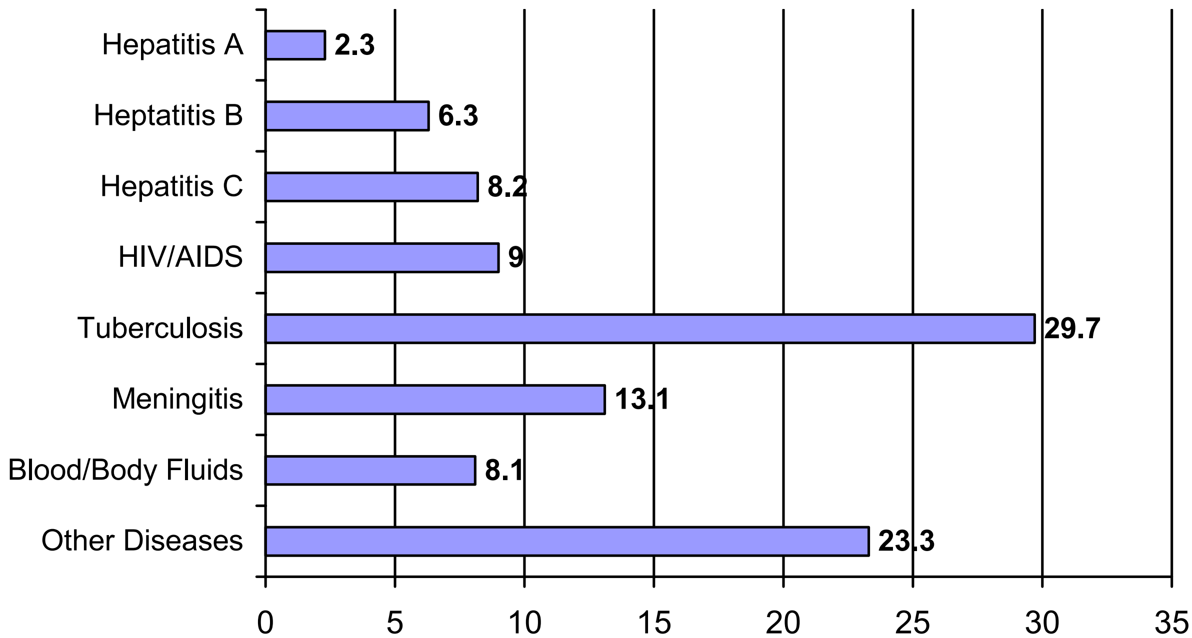


The above figures show that 88.8% of the fire fighter communicable disease exposures occurred at the scene of an emergency incident.

The IAFF also reported that 1 out of every 29 fire fighters in 2000 was exposed to a communicable disease. In comparison, earlier years, such as 1994, showed that 1 in 16 fire fighters had been exposed; this suggests a trend towards overall improvement. This improvement has been credited to greater awareness among first responders for disease transmission and the use of "Universal Precautions," where all blood and body fluids are assumed to be contaminated and all victims to be potential disease carriers.

The most frequent forms of communicable disease exposures are tuberculosis, hepatitis, HIV/AIDS and meningitis, as shown in Figure 16.

Figure 16. Distribution of Fire Fighter Communicable Disease Exposures (Percentage)



Overall Needs Based on the State of the Fire Service

This chapter provides several significant findings that should be considered in the development of new protective ensembles.

- Fire fighter demographics play an important role in the types of fire service responsibilities and missions performed. While larger communities typically engage in larger range of response activity, small communities tend to be more strained to perform different fire service missions.

- Clothing availability suggests that much of the fire service is using relatively old gear with limited capabilities. The likelihood for these departments to have access to a variety of different protective ensembles is very low.

- While declining, injury and fatality statistics still show a high incidence of lack of protection to several hazards. More details analyses are not possible because the majority of the provided data do not link specific personal protective equipment features with specific injuries. Little information is provided to judge the adequacy of personal protective equipment in protecting against the various exposure hazards.

CHAPTER 3 - FIREGROUND/EMERGENCY SCENE HAZARDS

Given the wide range of environments and conditions in which fire fighters must operate, a wide range of hazards are possible. In addition, hazards arise from the specific characteristics of response location (such as operating near highway, at elevation, or near water) and even from the personal protective equipment that is worn by the fire fighters. Each hazard serves as an individual stressor on the fire fighter, that given its relative intensity, length of exposure, and the degree to which protection is provided, creates specific risks of injury, disease, or death.

The following list provides the categories used in this chapter for discussing potential fireground and emergency scene hazards:

- Physical hazards
- Environmental hazards
- Chemical hazards
- Biological hazards
- Thermal hazards
- Electrical hazards
- Radiation hazards
- Person-position hazards
- Person-equipment hazards

In addressing specific hazards, it is important to assess not only the specific manner in which the exposure occurs, such as its source, but the portion of the body that will be affected. For example, dust particles in the air may be primarily a hazard that affects the fire fighter's respiratory system, but high ambient heat and humidity are conditions that present a heat stress hazard to the entire body. Some hazards may have less obvious effects on the fire fighter. Loud noises will not only affect the fire fighter's hearing but also create the additional hazard of distracting the fire fighter and preventing good judgment in assessing a particular emergency situation.

The individual types of hazards in each of the categories are discussed below. Table X presents a hazards / risk matrix.

Types of Physical Hazards

Physical hazards include those hazards which are mechanical in nature or involve contact with an object that causes harm in some way. General categories of physical hazards include:

- Falling objects
- Flying debris
- Projectiles
- Abrasive or rough surfaces
- Sharp or jagged edges
- Pointed objects

Table 6. General Hazard – Risk Matrix for Emergency Response

Hazard Category	Body Area of Body System Potentially Affected									
	Entire Body	Trunk or Torso	Head	Eyes/ Face†	Arms	Hands	Legs	Feet	Respiratory System	Hearing
Physical										
Environmental										
Chemical										
Biological										
Thermal										
Electrical										
Radiation										
Person-position										
Person-equipment										

† includes vision

- Slippery surfaces
- Excessive vibration

Depending on the activity and orientation of the fire fighter, some portions of the body may be more likely to be exposed to physical hazards than others. Table X provides a summary of physical hazards, including the portions of the body affected, and example of these hazards found on the fireground or at the emergency scene.

Falling Object Exposures. Falling object hazards typically involve heavy objects falling from above the fire fighter onto his or her head, hands, or feet, or heavy objects falling from a work surface onto the worker's feet. Falling object hazards are most common in any type of interior response operation where integrity of the structure is in question, but these hazards are also present when personnel are handling any type of heavy equipment. In the absence of engineering or administrative controls, protection from falling objects is best provided by providing PPE which resists impact and attenuates the imparted energy.

Flying Debris Exposures. Flying debris hazards typically involve very small objects which are subject to forced air circulation through machinery or other unnatural means. While any part of the body may be struck by flying debris, the face and eyes are the most susceptible to exposure. Flying debris may also present a significant hazard to the respiratory system in conjunction with other hazards. On the fire ground, flying debris hazards can be encountered during cutting operations.

Projectile/Ballistic Exposures. Hazards from projectiles primarily include exposure to bullets or other high speed objects such as fragments from explosions. The sudden pressure forces from an explosion also constitute a hazard. All portions of the body are at risk, but the head and torso are considered most vulnerable. The fire fighter's hearing can also be affected from the overpressure of the explosion. The relative hazard is based on the size and shape of the projectile, its velocity, and the angle of its impact.

- Most bullet projectiles weigh from a few grains to several ounces.
- Velocities of projectiles can reach several thousand feet per second.
- An item of PPE may be able to stop a projectile at one velocity but the same projectile can penetrate at a higher velocity.

Instances where projectile hazards are like to occur include any type of civil strife, terrorism, or during an explosion. The principal types of protection used are vests or similar garments which are constructed of materials capable of absorbing and dissipating the energy of the impacting projectile. Anti-fragmentation clothing is used in some special applications but relatively unavailable to most first responders.

Abrasive or Rough Surface Exposures. Abrasive or rough surface hazards typically involve potential for fire fighter contact with a surface which will abrade or lacerate the skin either by worker movement or by movement of the rough surface. Hands, feet, arms, and legs are most likely to be affected. Abrasive or rough surface hazards are most common in tasks performed on asphalt or other rough surfaces.

Table 7. Overview of Emergency Scene Physical Hazards

Physical Hazard	Body Areas Usually Affected	Examples During Emergency Response	Mitigation Methods
Falling objects	Head Hands Feet	Falling ceiling materials during structural fires; Structural collapse	PPE which resists impact/attenuates transmitted energy
Flying debris	Face and eyes Respiratory system	Machine cutting operations	Enclosed chambers or guards on equipment; Puncture/impact-resistant PPE
Projectile/ ballistic	Entire body	Explosive device detonation; Operation near law enforcement activities	PPE which resists impact, absorbs and dissipates energy
Abrasive/rough surfaces	Hands Arms Feet Legs	Operations on rough surfaces; Operations with moving belts or machinery	Equipment guards; PPE reinforcement and abrasion-resistant materials
Sharp edges	Hands Arms Feet Legs	Operations with extraction tools; Working around broken glass or metal objects	Equipment guards; Cut-resistant PPE
Pointed objects	Hands Feet	Operations with pointed tools, syringes, or involving drills or punches	Equipment guards; Puncture-resistant PPE
Slippery surfaces	Hands Feet	Wet operations; Work on smooth surfaces	Non-skid work surfaces; Slip-resistant footwear; Good "grip" gloves
Excessive vibration	Entire body; Hands	Driving vehicles; Operation of large machines; Use of power towers	Modification of vibration frequency; Reduction of exposure time; PPE which attenuates vibration energy

Sharp Edge Exposures. Sharp edge hazards typically involve sharp tools/machinery or materials which have a cut or sharp edge which moves across the body, usually in a slicing action. The response environment may also contain sharp edges in the form of rough edges or unprotected machinery. Most sharp edge exposures involve the fire fighter's use of his or her hands; arms, feet, or legs may also be affected by this hazard. The use of extrication tools or chainsaws is an example of this hazard.

Pointed Object Exposures. Pointed object hazards involve a sharp point which is capable of puncturing PPE or the fire fighter. Pointed object exposures differ from sharp edge exposures by the way that the force is applied behind the object (puncturing versus slicing action). Hands and feet are the most likely portions of the body to be affected by pointed object hazards.

Slippery Surface Exposures. Slippery surface hazards are typically presented by handling of smooth objects or walking on surfaces that may also be wet or covered with some other liquid. Hand grip and foot traction are generally affected by slippery surface hazards. Hands and feet are the most likely portions of the body to be affected by slippery surface hazards. Slippery surface hazards are most common in the following activities:

- Wet operations
- Handling wet or smooth objects
- Walking on smooth surfaces which may become wet

Protection from slippery surfaces can be addressed by providing non-skid work surfaces, using protective gloves with improved grip, and using slip-resistant footwear which has a high level of traction.

Excessive Vibration Exposures. Excessive vibration hazards exist from exposure to vibrating machinery or tools in the absence of any cushioning or energy absorbing materials. Fire fighter tolerance to vibration is defined as the level of vibration at which effects on performance of a motor or visual task are detectable. Worker tolerance to vibration is affected by the vibration's frequency, acceleration, and duration.

Worker tolerance to vibration in terms of duration generally decreases with increasing acceleration. Whole body tolerance to vibration is lowest for vibrations of 4 to 8 Hertz. For hands, vibrations at frequencies from 8 to 500 Hertz are of concern. Hands and the whole body are most often affected by excessive vibration. Repeated or prolonged exposure to excessive vibration can cause Cumulative Trauma Disorders (CTDs). Vibration is also known to cause other whole body physiological effects such as:

- Abdominal pain
- Loss of equilibrium
- Nausea
- Muscle contractions
- Chest pain
- Shortness of breath

Excessive vibration for hands causes these effects:

- Stiffness
- Numbness
- Pain
- Loss of strength

The most common sources of excessive vibration include whole body vibration associated with prolonged driving of fire apparatus and other vehicles, especially those with poor suspension or when traveling on rough surfaces, and segmental vibration associated with the operation of power tools, such as chipping hammers, chain saws, or grinders

The American Conference of Governmental Industrial Hygienists (ACGIH) establishes Threshold Limit Values (TLVs) for whole body and hand-arm (segmental) vibration in its annual publication, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. TLVs are expressed in frequency, weight, component accelerations, or gravitational units based on the daily duration exposure. Protection against excessive vibration is met by:

- Substituting processes which remove the worker
- Modifying the frequency of vibration source
- Decreasing the duration of exposure
- Using protective clothing with materials which attenuate the energy of the vibration source

Types of Environmental Hazards

Environmental hazards are encountered in the response environment, typically from the presence of extreme conditions. Environmental hazards include:

- Exposure to high heat and humidity conditions (not extreme heat or thermal hazards)
- Exposure to cold temperatures
- Exposure to wetness
- Exposure to bright light
- Exposure to excessive noise

Table 8 provides an overview of emergency scene environmental hazards.

High Heat and Humidity Exposures. Exposure to high temperature and humidity encompasses worker exposure to temperatures and relative humidities which may be either natural or unnatural (such as those encountered in some industrial processes). Excessively hot temperatures associated with high heat and flame exposures are covered in the section on thermal hazards. High heat and humidity exposures are common during many emergency response operations, since these activities involve heavy work performed outdoors under warm or humid conditions, particularly while wearing encapsulating PPE.

Table 8. Overview of Emergency Scene Environmental Hazards

Environmental Hazard	Body Areas Usually Affected	Examples During Emergency Response	Mitigation Methods
High heat/humidity (ambient)	Entire body	Outdoor response activities involving moderate to high levels of work; Response efforts inside hot facilities (power generation facilities); Responses efforts while wearing encapsulating clothing	Provide air conditioning in fire apparatus and vehicles in route to emergency scene; Provide increased staffing for controlling work/rest cycles; Provide appropriate fire fighter rehabilitation following response efforts; Use cooling devices in conjunction with PPE; Use 'breathable' PPE
Ambient cold	Entire body Face Hands	Outdoor response activities during winter; Response efforts to refrigeration plants or work around liquefied gases or cryogenic liquids	Limit cold exposure times; Provide heat spaces for rest and rehabilitation; Use insulated PPE
Wetness	Entire body Hands	Outdoor response activities during inclement weather; Disaster relief efforts (hurricanes, flooding, tornadoes); Hose spray during fire fighting	Provide shelter, as possible; Use water-resistant PPE
High wind	Entire body	Outdoor response activities during inclement weather; Disaster relief efforts (hurricanes, flooding, tornadoes)	Provide shelter, as possible; Use insulated PPE
Insufficient or bright light	Eyes (vision)	Outdoor work under bright conditions; Responses efforts in dark or smoke-filled buildings; Response activities with excessive or insufficient illumination	Provide external lighting; Use anti-glare surfaces; Provide eyewear with shaded lenses; Use thermal imaging equipment
Excessive noise	Hearing	Use of power tools; Emergency vehicle sirens	Limit vehicle noise through engineering controls; Use ear protectors

Exposure to temperature extremes affects the fire fighter's body heat balance. Body temperature must be maintained within a narrow range for fire fighter comfort and safety. The body heat balance is affected by:

- Metabolic heat gain from the physical work load on the fire fighter
- Convective heat gain or loss represented by the air velocity and the difference in temperature between the air and the fire fighter's skin
- Radiative heat gain or loss resulting from the difference between the fire fighter's skin temperature and the temperature of surfaces in the environment
- Evaporative heat loss as determined by the difference between the water vapor pressure of a fire fighter's skin and the relative humidity of the environment as well as air velocity
- Conductive heat gain or loss based on the difference of the fire fighter's skin temperature and the temperature of surfaces contacted

When rises in body temperature cannot be offset by loss of body heat through other means, heat stress may occur. This includes the following heat-related disorders:

- Heat rash
- Heat cramps
- Heat stroke
- Heat exhaustion

Heat rash may result from continuous exposure to heat or humid air. Heat cramps are caused by heavy sweating with inadequate electrolyte replacement. Signs and symptoms include muscle spasms and pain in the hands, feet, and abdomen. Heat exhaustion occurs from increased stress on various body organs including inadequate blood circulation due to cardiovascular insufficiency or dehydration. Signs and symptoms include:

- Pale, cool, moist skin
- Heavy sweating
- Dizziness
- Nausea
- Fainting

Heat stroke is the most serious form of heat stress. Temperature regulation fails and the body temperature rises to critical levels. Immediate action must be taken to cool the body before serious injury or death occurs. Competent medical help must be obtained. Signs and symptoms are:

- Red, hot, usually dry skin
- Lack of or reduced perspiration
- Nausea
- Dizziness and confusion
- Strong, rapid pulse
- Coma

The risk for fire fighter heat stress increases with:

- Higher temperature and relative humidity – Several indices have been established regarding safe working limits in different environmental conditions but few of these are adaptable to fire fighting and emergency response operations.

- Increased level of work activity – Higher work activities produce earlier onset of heat-stress-related symptoms for given environmental conditions and work/rest cycles.

- Increasing amounts of clothing - The heavier, insulated clothing worn in emergency response while protecting the responder from outside heat also prevent the escape of heat. The use of clothing barrier materials further prevents or inhibits moisture vapor transfer and diminishes evaporative cooling.

Individuals vary in their susceptibility to heat stress. Factors which affect individual susceptibility include:

- Physical condition (more physically fit persons general have better tolerance)
- Level of acclimization to work environment
- Age
- Gender
- Weight

The American Conference of Governmental Industrial Hygienists (ACGIH) establishes Threshold Limit Values (TLVs) for heat exposure in its annual publication, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. TLVs are expressed as the maximum Wet Bulb Globe Temperature (WBGT) of the work environment for a given work load and work-rest regimen. However, these TLVs do not account for heavily insulated or barrier clothing, and individuals engaged in emergency response quickly exceed these thresholds.

Most of the common approaches for managing heat stress cannot be fully applied to emergency response activities:

- Modification of the work environment is generally not possible. Some changes that can be made include providing shade and ventilation for rehabilitation at the emergency scene and use of fire apparatus and vehicles that use air conditioning.

- Modification of the task is usually not an option, since reducing the level of effort by responders may result in loss of life or property. Nevertheless, the use of lighter weight tools and increased staffing are two aspects that can be accomplished.

- Employment of protective clothing that provides the maximum achievable breathability provides some benefit, but there is a tradeoff between protection and comfort/functionality of the worker that must be considered.

- Auxiliary cooling devices, such as static ice vests, supplied air ventilation, and circulating water cooling systems, have not proven effective and often add to the weight and burden of the fire fighter.

- Improving the physical conditioning of the individual as part of fire service wellness programs can help provide individual fire fighters with better tolerance to stressful environmental conditions.

Exposure to Cold Temperatures. Exposure to cold temperatures can occur in environments which are either natural or unnatural (such as those encountered in some industrial processes such as responses in refrigeration plants or those involving environments containing liquefied gases and cryogenic liquids). Exposure to cold for emergency responders is most likely to occur during winter months during outdoor response activities. The major concern about whole body exposure to the cold is the development of serious hypothermia and subsequent effects on the body.

- The body defends core temperature by intense shivering to increase metabolic heat. Exhaustion of this resource for generating heat is implied when body temperature falls below 95^{o}F (35^{o}C).

- Frostbite of the face or extremities may result from exposure to extreme cold, often in combination with high air velocities, or from prolonged exposure to less severe cold but with high humidity. Exposures may result in cold injury to exposed flesh at equivalent temperatures of -32^{o}F (-35^{o}C). For individuals working outdoors in the cold, body heat losses associated with high winds can be very significant.

- Local cold discomfort, most often in the hands, feet, and face, is usually the major cause of complaints in the cold discomfort zone. The hands begin to exhibit some loss of flexibility and manipulation skills at ambient dry bulb temperatures of 60^{o}F (16^{o}C) over a few hours of exposure.

- A 20% decrement in performance is not unusual in manual tasks at ambient temperatures of 7^{o}F (-14^{o}C), dry bulb.

- Extended exposure to cold conditions leads to frostbite which in turn can lead to permanent injuries if left untreated.

Susceptibility to cold is primarily a function of:

- Environmental conditions (temperature, humidity, and wind velocity)
- Length of exposure
- Level of work activity
- Amount of clothing worn

The American Conference of Governmental Industrial Hygienists (ACGIH) establishes Threshold Limit Values (TLVs) for cold exposure in its annual publication, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. TLVs are expressed as maximum work period and the number of necessary breaks based on air temperature and the wind velocity. In the absence of engineering or administrative controls, protection from cold is best achieved through the addition of clothing with several layers of insulation.

Wetness Exposures. Response activities may often involve wet conditions. Aggressive interior attacks during structural fire fighting involve exposure to hose spray. Outdoor response activities may further be conducted during inclement weather of varying conditions (including high wind and cold conditions). Flooding and swiftwater rescues will involve a large degree of exposure to different wet condition. These tasks will include exposure to water temperatures that range from comfortable to very uncomfortable.

The effect of working in wet clothing on tolerance times for high and low temperatures is strongly influenced by:

- Duration of exposure
- Area of contact of the skin
- Level of work activity
- Air velocity

Wetness may reduce the insulative value of clothing, so that in cold temperatures, skin temperature is reduced and heat loss from the body is increased. In hot temperature environments, water in clothing can act as both a heat sink and a conduction medium. When there is air flow, water contacting the skin and clothing in hot environments helps increase evaporative heat loss without sweating. Thus fire fighter tolerance is higher in the heat when the clothing is wet than when it is dry.

Loss of finger flexibility and tissue injury may result when the hands are immersed in hot or cold water. Temperatures of liquids in which a worker may immerse his or her hands are seldom below 34^{o}F (1^{o}C) or above 158^{o}F (70^{o}C).

Protection from wetness requires protective clothing which prevents the penetration of water under the conditions of use and for the expected exposure.

High Wind. High winds pose hazards by disrupting response tasks or making it difficult for fire fighters to function. High winds may also be associated with wetness or flying debris (*see above*). High winds are most likely to affect the whole body or face and eyes when exposed. High winds are most likely to be encountered in outdoor operations or emergency response during poor weather (thunderstorms, tornados, and hurricanes). Protection against high winds can be achieved by limiting work activity in adverse conditions, using shelters for breaks, wearing barrier protective clothing (such as wind breakers or rain suits), and wearing eye and face protection to prevent debris from blowing into eyes.

Insufficient or Extreme Light Exposures. Sufficient light is needed to safely carry out most response tasks including identification of hazards, rescue of victims, and mitigation of hazardous conditions. When there is insufficient illumination during responses, especially in the presence of other hazards, great risk exists for fire fighters to expose themselves to greater hazard and possible injury or disease. In addition, poor visibility hampers efficient completion of response tasks.

Probably the most common circumstance for limited visibility is fire fighting inside a closed structure with the accumulation of smoke. Visibility is also affected during most emergencies by the curtailment of power for indoor lighting or for emergencies that occur during nighttime.

Extreme light exposures are likely to occur from excessive lighting or light from certain sources that may be hazardous to the fire fighter's eyes (*see later section on Non-ionizing radiation*). The direction of provided light may also result in glare that can also affect task productivity and cause fire fighter eyestrain.

Strategies for eliminating insufficient or extreme light include providing additional lighting at the emergency scene, using anti-glare surfaces on equipment where possible, providing faceshields and appropriate eye protection, and using thermal imaging cameras for enhancing fire fighter detection capabilities in environments where there is poor lighting.

Excessive Noise Exposures. Excessive noise during emergency response activities may:

- Contribute to hearing loss
- Interfere with communication
- Annoy or distract individuals
- Alter the performance of some tasks.

Hearing loss represents irreversible damage to the inner ear. The degree to which hearing is affected depends on:

- Noise intensity
- Noise frequency spectrum
- Noise duration
- Individual susceptibility

Although noise levels below 85 (decibels) dBA probably do not contribute to hearing loss problems, they may contribute to performance decrements due to distraction or annoyance. Noisy environments can reduce the effectiveness of communications and make it difficult for the fire fighter to concentrate on some types of tasks. Since effective communications during emergency response is paramount, steps should be taken to improve the noise levels in the environment.

Noise may affect performance in a number of ways. Noise features which are most likely to degrade performance include:

- Variability in level or content
- Intermittency
- High-level repeated noises
- Frequencies above 2000 Hz
- Any combination of these features

OSHA 29 CFR 1910.95 sets specific requirements for protecting workers against the effects of noise exposure. These include:

- Defining the need for noise protection by the noise exposure in terms of the octave band sound pressure levels (in decibels) and the band center frequency in cycles per second
- Setting permissible noise exposure levels in terms of duration and sound level in decibels
- Establishing a noise conservation program
- Monitoring of noise exposure
- Notifying employees when noise exposures exceed 85 dBa
- Allowing employees to observe noise exposure monitoring
- Conducting audiometric testing of employees
- Providing hearing protectors
- Maintaining records

Ear protectors must be used for noise in excess of OSHA levels. The American Conference of Governmental Industrial Hygienists (ACGIH) establishes Threshold Limit Values (TLVs) for both continuous/intermittent and impulsive/impact noise exposures in its annual publication, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Continuous or intermittent noise TLVs are expressed in permissible maximum sound level in decibels based on a specific daily duration. Impulsive or impact noise TLVs are expressed in the permitted number of noise impulses or impacts per day for a given sound level. Ear protectors may diminish the fire fighter's ability to communicate or hear work-related signals.

Types of Chemical Hazards

Fire fighters encounter chemicals in a variety of different response activities, not just hazardous materials calls. The increasing presence of chemicals through industry and in households results in response environments, where chemicals are likely to be present. Each chemical poses different levels of hazards associated with its exposure. These hazards may include:

- Toxicity (poisonous)
- Corrosiveness
- Irritation
- Flammability
- Reactivity (explosiveness or oxidation)

Table 9 summarizes the types of chemical hazards, the body areas or body systems affected, examples of exposures for fire fighters, and how these hazards are prevented or minimized.

Nature of Chemical Hazards. Most chemicals present multiple hazards and have the potential to affect the entire fire fighter's body or specific areas of the fire fighter's body. Exposures in turn are affected by the chemical's properties. Key chemical properties include:

- Density
- Vapor density (determines whether chemicals will be lighter or heavier than air, thus affecting rate of dispersal)
- Specific gravity (determines whether chemical will be lighter or heavier than water, thus affecting how it will behave when in water)

Table 9. Overview of Emergency Scene Chemical Hazards

Chemical Hazard	Body Areas Usually Affected	Examples During Emergency Response	Mitigation Methods
Inhalation	Respiratory system	Any response scene with possible exposure to chemicals as vapors or gases; Potential terrorism threats	Avoid contaminated areas; Use respirators
Skin absorption or contact (vapor contact)	Entire body; Hands	Any response scene with possible exposure to chemicals as vapors or gases; Use of solvents; Potential terrorism threats	Avoid contaminated areas; Use vapor- protective clothing
Skin absorption or contact (liquid contact)	Entire body; Hands	Any response scene with possible exposure to chemicals as liquids; Use of solvents; Potential terrorism threats	Avoid contaminated areas; Use liquid-splash protective clothing
Skin absorption or contact (particulate contact)	Entire body	Any response scene with possible exposure to chemicals as particles or dusts; Potential terrorism threats	Avoid contaminated areas; Use particle-protective clothing
Ingestion	Digestive system	Any response scene with possible exposure to chemicals	Practice good hygiene; Cover mouth with PPE
Injection	Entire body	Any response scene with possible exposure to chemicals	Avoid contact with sharp or pointed objects; Use cut- and puncture-resistant protective clothing
Chemical freezing	Entire body	Responses involving liquefied gases or cryogenic liquids	Avoid contact; use insulated chemical protective clothing
Chemical flashover	Entire body	Any response scene with possible exposure to chemicals which can reach flammable limits; Example – broken gas line, leaking volatile flammable chemical in closed space	Use explosive meter for detection of hazardous vapor concentrations; Avoid entering area with vapors in flammable range; Wear flame-resistant, heat insulative protective clothing
Chemical explosions	Entire body	Any response scene with possible exposure to chemicals which can reach flammable limits; Example – broken gas line, leaking volatile flammable chemical in closed space	Same as above; however, protective clothing does little to attenuate the effects of the energy from explosions

- Viscosity (a liquid's resistance to flowing)
- Odor (affecting ease of detection)
- Flash point (method for rating chemical flammability)
- Flammable limits (indicates chemical concentration in air needed for ignition)
- Melting point (temperature at which solid changes to a liquid)
- Boiling point (temperature at which liquid changes to a gas)
- Solubility (ability of chemical to dissolve or completely mix with a solvent)

One of the best sources of information on a chemical's hazards and properties is its Material Safety Data Sheet (MSDS) although this information is not always available to the fire fighter.

Obviously, the potential for fire fighter exposure to chemical hazards exists during any incident involving chemicals. Generally, this will include all hazardous materials response calls. Nevertheless, hazardous materials show up increasingly in many other fire fighter operations. Many structural fires, while primarily being a fire fighting operation, in reality often involve hazardous materials in the form of stored chemicals in houses and industrial facilities. The presence of toxic gases in fire smoke constitutes a chemical exposure, particularly since soot adsorbs fire gases and many other combustion products of a fire. The number and concentrations of hazardous fire gases has increased with greater use of synthetic materials used in construction. A structural collapse will likewise create chemical exposure situations ranging from burst gas pipes to broken chemical storage vessels, and asbestos air contamination.

Chemicals can be grouped by the relative hazards they create as well as the manner in which the chemical enters the body. The toxic, corrosive, and irritant effects of chemicals can collectively be considered health effects. The flammability and reactivity effects of chemicals are different hazards that can be classified separately.

Chemical health hazards are rated by the National Fire Protection Association:

0 – Materials that on exposure under ordinary conditions would offer no perceivable health hazard
1 – Materials that an exposure would cause irritation but only minor residual injury even if no treatment was given
2 – Materials that an intense or continued exposure could cause temporary incapacitation or possible residual injury unless prompt medical treatment was given
3 – Materials that on short exposure could cause serious temporary or residual injury even though prompt medical treatment was given
4 – Materials that on very short exposure could cause death or major residual injury even though prompt medical treatment was given

Chemicals may enter the body and cause adverse health effects to the body through:

- Inhalation
- Skin absorption
- Injection
- Ingestion

Inhalation Exposures. Any of the normal constituents of atmospheric air in greater than normal concentrations or any other substance present in the atmospheric air may be regarded as an air contaminant. Displacement of normal air below its normal oxygen concentration of 20.9% constitutes an oxygen deficiency. When the oxygen content in air is less than 19.5%, the situation is considered extremely hazardous and requires respiratory protection. Air contaminants vary in form (gas, vapor, liquid, and solid) and composition (atomic particles, ions, and molecules). The two primary classes of air contaminants are aerosols and gaseous air contaminants.

Aerosols – Solid or liquid particles suspended in air are known as aerosols. Aerosols may be classified by the process by which they are formed, their physical type, their particle size, and their physiological effects on the body. Aerosols are created and dispersed by mechanical means (such as grinding, crushing, drilling, blasting, or spraying) or condensation (produced by physicochemical reactions such as combustion, and vaporization). Physical types of aerosols include:

- Dusts (solids dispersed in the air mechanically)
- Sprays (liquids dispersed in the air mechanically)
- Fumes (solids dispersed in the air by condensation)
- Mists (liquids dispersed in the air by condensation)
- Fogs (a mist which obscures vision)
- Smokes (a combination of liquids and solids caused by the incomplete combustion of organic substances)

Aerosol particle sizes range from fractions of a micrometer to several micrometers. The range of interest for respiratory hazards is usually from 0.1 to 10.0 μm in diameter. Particles smaller than 0.1 μm generally remain suspended in air and are exhaled. Particles larger than 0.1 μm are generally removed from the inspired air in the nasal cavity and are carried in the mucous to the pharynx and then to the mouth by ciliary action where they are either expectorated or swallowed. Some smaller or larger particles are still hazardous for skin and eye contact depending on other physical or chemical hazards.

Aerosols may be classified by their physiological effect on the body:

- Nuisance and/or relatively inert (the aerosol may cause discomfort or irritation without injury; examples include marble and gypsum dusts)
- Pulmonary fibrosis producing (the aerosol produces nodules and fibrosis in lungs; examples include silica dust and asbestos fibers)
- Carcinogens (the aerosol causes cancer in some person after long latent period; examples are chromate dusts and asbestos fibers)
- Chemical irritants (the aerosol produces irritation, inflammation, and ulceration of respiratory tract; examples include acidic or alkaline particles)
- Systemic poisons (produce toxic pathological reactions in various parts of the body; examples are lead and cadmium dusts)
- Allergy producing (cause allergic, hypersensitive type reactions in the body; examples include paint isocyanates)
- Pneumoconiosis (deposition of any dust in lungs)

Gaseous Contaminants – Gaseous air contaminants are gases or vapors mixed in air. Gaseous air contaminants may be classified by their chemical composition or their physiological effects on the body. Their chemical classifications include:

- Inert (do not reaction with other substances or harm body, but can displace air; examples are helium, neon, and argon)
- Acidic (produce low pH substances or acids in water; examples include hydrogen chloride, hydrogen fluoride, sulfur dioxide, hydrogen sulfide and hydrogen cyanide)
- Alkaline (produce high pH substances or bases in water; examples include ammonia, amines, phosphine, and arsine)
- Organic (contain carbon atoms; examples are several types of structures such as hydrocarbons, alcohols, ketones, aldehydes, ethers, esters, halides, amides, nitriles, isocyanates, amines, epoxies, and aromatics)
- Organometallic (contain metals that are chemically bonded to organic groups; examples include tetraethyl lead and organophosphates)
- Hydrides (contain hydrogen bonded to metals; examples include diborane and pentaborane)

The physiological effects of exposure to gaseous air contaminants include:

- Asphyxiation (contaminant interferes with supply or utilization of oxygen in the body; simple asphyxiants include nitrogen, methane, and helium; chemical asphyxiants include carbon monoxide, hydrogen cyanide, and nitriles)
- Irritation (contaminant causes irritation or inflammation of respiratory tract; examples are ammonia, hydrogen chloride, formaldehyde, chlorine, and phosgene)
- Anesthesia (contaminant causes loss of feeling or sensation; examples are nitrous oxide, hydrocarbons, and ethers)
- Systemic poisoning (contaminant produces injury to specific organs or specific parts of the body; examples include mercury vapor, carbon tetrachloride, and hydrogen sulfide)
- Carcinogeneity (contaminant causes cancer; examples include vinyl chloride, benzene, and hydrazine)

There are several sources established for acceptable exposure levels to chemicals in air. OSHA 29 CFR 1910.1000 provides the permissible exposure limits (PELs) of several air contaminants for an 8-hour work period representing the normal length of a shift for an industrial worker. The 8-hour time-weight average concentration is provided as the PEL for most chemicals. The time weighted average equals cumulative exposure divided by 8 hours. Some substances have PELs preceded by a "C' which denotes a ceiling value. Exposure to these substances can at no time exceed the ceiling value. The American Conference of Governmental Industrial Hygienists (ACGIH) annually publishes *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. This publication also establishes specific limits for several substances, including:

- Threshold Limit Value-Time Weighted Average (TLV-TWA); the time-weighted average concentration for a normal 8-hour workday and a 40-hour to which nearly all workers may be repeatably exposed, day after day, without adverse effect.

- 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 irritation, chronic or irreversible lung damage, or narcosis of sufficient degree as to increase the likelihood of accidental injury, impair self-rescue, or materially reduce work efficiency. The TLV-STEL is based on a 15 minute exposure.

- Threshold Limit Value-Ceiling (TLV-C); the concentration that should not be exceeded during any part of the working exposure.

- Indications whether the substance is a confirmed human carcinogen, suspected human carcinogen, or animal carcinogen.

The National Institute for Occupational Safety and Health (NIOSH) further establishes recommended exposure levels for most substances. It is important to note the values set by OSHA, ACGIH, and NIOSH do not always agree. However, it is equally important to understand that these values are primarily set for controlling respiratory exposures in the workplace, not for emergency response operations.

Of greater interest to fire fighters are chemicals at concentrations that are immediately dangerous to life of health (IDLH) as this criterion is principally used as the deciding factor of whether to use supplied air respirators or self-contained breathing apparatus. IDLH concentrations are defined as the maximum concentration of a chemical that poses an immediate threat of loss of life, immediate or delayed irreversible adverse effects on health, or acute eye exposure that would prevent escape from a hazardous atmosphere.

The primary strategy for protecting against inhalation hazards is the use of a respirator. The majority of fire fighter and related response activities are performed with a self-contained breathing apparatus when air contaminants are present. Some applications, particularly those involving longer term chemical exposures at concentrations less than IDLH levels are performed with air-purifying respirator. Therefore, the type of substance, its concentration, and health affects are considered in providing respiratory protection.

Skin Absorption Hazards. The skin acts as a two-way barrier, preventing entry of environmental toxins while preventing the loss of water, electrolytes, and other substances necessary to maintain homeostasis. Four possible actions can occur when a chemical contacts the skin:

- The skin can act as a barrier preventing the chemical from causing injury or penetrating into the body.
- The chemical can act directly on the skin surface to cause injury.
- The chemical can penetrate the surface of skin and injure the skin tissues beneath the surface.
- The chemical can penetrate the skin, enter the blood stream, and be dispersed throughout the body where it can produce injury to various parts of the body.

Chemical exposure to the skin can cause several skin disorders, including:

- Irritant dermatitis, a localized inflammatory reaction following a single or repeated exposure to a chemical, which may be of three types. The first type causes skin redness and swelling of the exposure area to a single chemical exposure. A second type shows no visible reaction to the first exposure, but upon repeated exposure, produces redness, chapping, fissures, and cracks in the skin. The third type occurs on repeated exposure but results in a chronic dermatitis which is not easily reversible. Common irritants include detergents, various organic solvents, acids, and bases.

- Allergic contact dermatitis is similar to irritant dermatitis but occurs through skin sensitization of a long period. Occupational skin sensitizers include chromium, cobalt, and nickel.

- Phototoxicity, analogous to irritant dermatitis, but requiring UV or visible light for activation. Examples of phototoxic chemicals include polycyclic aromatic hydrocarbons and coal-tar derivatives. Some of these substances are common in structural fires.

- Follicular diseases, disorders of the hair follicles, such as chloracne. Follicular diseases can be cause by dioxin, petroleum derivatives, and halogenated hydrocarbons.

- Skin cancers or tumors

- Pigmentation responses, changes in skin coloration produced by chemical exposure. Hydrogen fluoride and alkyl phenols are known to cause pigmentation responses.

- Systemic toxicity, effects on various organs of the body from the permeation of hazardous chemicals into the body.

Many chemicals can permeate through the skin without any apparent skin damage. The skin is susceptible to permeation by chemicals to varying degrees depending on the properties of the chemical:

- Simple, polar non-electrolytes penetrate the skin at rates similar to water.
- Electrolytes do not penetrate the skin readily.
- Dilute solutions of anionic and cationic surfactants penetrate the skin readily.
- Many non-aqueous solutions do not alter skin integrity, but do permeate the skin.
- Some low-weight volatile organic solvents alter skin properties allowing permeation.

Both OSHA 29 CFR 1910.1000 and the ACGIH *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices* provide a skin designation or notation for those chemicals where the overall exposure to the individual by the cutaneous route (through skin absorption) is significant. However, there are currently no Permissible Exposure Limits (PELs) or Threshold Limit Values (TLVs) in use for determining acceptable skin exposure to chemicals.

Protective clothing that provides a barrier to the specific chemical(s) is used to prevent skin absorption. However, the effectiveness of that clothing is highly dependent on the overall integrity of the clothing with respective to the outside environment and the clothing material's barrier properties.

Ingestion Exposures. While the ingestion of hazardous chemicals is not a likely exposure in emergency response, ingestion of hazardous chemicals can occur from:

- Accidental swallowing
- Contamination of food, tobacco, cosmetics, or other personal items which may contact the mouth
- Inhalation of particles which are soluble in the mucous membranes of the respiratory tract and are carried to the mouth cavity and digestive system by the motion of cilia lining the respiratory tract

Chemicals which make it into the digestive tract can:

- Fail to absorb into the blood and be eliminated from the body
- Be diluted by food and liquid, decreasing the substance's toxicity
- React with food and liquid to become toxic
- Pass through the walls of the digestive tract and be absorbed by the blood to be carried to other parts of the body.

The simple strategies for preventing ingestion chemical exposures involve, clear separation of work areas from eating or rest areas, good personal hygiene (hand washing, proper decontamination, storage and disposal of PPE), and ensuring that PPE is worn in chemical exposure situations that covers the mouth.

Injection Exposures. Injection can occur when a syringe or other sharp object containing chemical penetrates the skin and releases chemical directly into the blood stream. Because injection bypasses the body's natural defenses to chemical, exposure to chemicals by injection can result in the more rapid onset of symptoms produced by chemicals compared to skin absorption. Injection of chemicals can occur in any process involving potential for chemical exposure. Certainly, many emergency response environments contain sharp contaminated objects that could provide a source of chemical injection. The prevention or minimization of this hazard means avoiding and contact with sharp or pointed objects in chemical-containing environments and using cut/puncture resistance chemical protective clothing.

Chemical Freezing Exposure. The storage conditions and state of some chemicals present unique hazards to the fire fighter. Liquefied gases are gases that are stored under pressure at temperatures ranging from 70^{o}F (21^{o}C) to under -130^{o}F (-90^{o}C) below zero. Common liquefied gases include ammonia and chlorine that are frequently encountered at refrigeration and water treatment plants. Contact with liquefied gases can cause skin burns, but the rapid expansion of the liquid as it warms can also create high concentrations of the gas in the atmosphere. Cryogenic liquids are chemicals that have a boiling point less -130^{o}F (-90^{o}C) at ambient pressure. The chief hazard for the majority of cryogenic liquids is immediate frostbite and thermal burns from contact with the liquid. However, with liquid oxygen, other hazards also exist as contact with liquid oxygen can cause instantaneous combustion of organic substances (such as oil and grease). The rapid expansion of oxygen from a cryogenic source can also create overpressurization hazards (as with the other cryogenic liquids) as well as enriched oxygen environments that more readily support combustion.

Protection against liquefied gases and cryogenic gases typically takes the form of using insulated clothing.

Chemical Flammability Exposures. Many chemicals may be flammable as gases, liquids or solids. The principal properties used to determine the potential for flame hazards from chemicals include:

- Flammability limits: the range of chemical concentration of air which will support combustion; usually represented in terms of its lower flammability or explosive limit and upper flammability or explosive limit
- Flash point: the minimum temperature at which a substance produces sufficient vapors to form an ignitable mixture
- Autoignition temperature: the temperature at which a material will self-ignite (spontaneous combustion)

The U.S. Department of Transportation provides several classifications and categories of flammable substances:

- Gases are classified as flammable when their Lower Explosive Limit is less than 13% and the gas has a flammable range of more than 12% (examples include hydrogen, methane, and acetylene).
- Liquids are classified as flammable when they have a flash point below 100^oF [38^oC] (examples include methanol, acetone, and gasoline).
- Liquids are classified as pyrophoric when they will spontaneously ignite in air at or below 140^oF [60^oC] (examples are pentaborane and aluminum alkyls).
- Liquids are classified as combustible when they have a flash point between 100^oF and 200^oF [$38\text{-}94^oC$] (examples include kerosene and diesel fuel).
- Solids which cause fires through friction, retaine heat during manufacturing or processing, or which can be readily ignited are classified as flammable (examples include magnesium and titanium).
- Spontaneously combustible solids either ignite within 5 minutes in coming in contact with air or are liable to self-heat when in contact with air but without an energy supply (an example is sodium).

Chemical flammability hazards can be rated by the National Fire Protection Association as follows:

0 – Materials that will not burn
1 – Materials that must be preheated before ignition can occur
2 – Materials that must be moderately heated or exposed to relatively high ambient temperature before ignition can occur
3 – Liquids and solids that can be ignited under almost all ambient temperature conditions
4 – Materials that rapidly and completely vaporize at atmospheric pressure and normal ambient temperatures and burn readily, or are readily dispersed in air and burn readily

Flammable chemicals create specific hazards resulting in ignition and continued combustion of chemical and surrounding materials and chemical flash fires. Continued combustion of chemicals produces intense heat with fuel flame front at temperatures up to 1800^{o}F (980^{o}C), and primarily presents thermal hazards. The ignition of a flammable atmosphere may cause a chemical flash fire. Chemical flash fires are characterized by high rates of heat release of 100-350 kW/m^2, short exposure times ranging from 0.1 to several seconds, and the ignition of combustibles in the area of the chemical flash fire

Flammable hazards associated with chemicals should be avoided. When the potential exists for flame exposure provisions should be made to use reflective, flame-resistant protective clothing over chemical protective clothing. Flame resistant underclothing is also generally recommended.

Chemical Reactivity Exposures. Chemicals may pose reactivity hazards:

- As explosives
- By interacting with other substances to undergo violent reactions (e.g., oxidizers and water-reactive substances)
- By interacting with itself under specific conditions to undergo a violent reaction (e.g., polymerization)

Explosives are materials that function by a rapid release of energy that is highly destructive. These materials are generally designed to explode and have the following characteristics:

- Heat and shock sensitive
- Sensitive to contamination
- Produce thermal/mechanical effects

The U.S. Department of Transportation provides several categories of explosives:

- Class 1.1 materials present the maximum hazard and function by detonation with shock waves that travel faster than the speed of sound (examples include dynamite and trinitrotoluene).
- Class 1.2 materials function by rapid burning, known as deflagration, with shock waves slower than the speed of sound (an example is rocket propellent)
- Classes 1.3 and 1.4 materials contain small amounts of Class 1.1 or 1.2 explosives (examples are fire works or ammunition).
- Class 1.5 materials are harder to detonate than Class 1.1 or 1.2 explosives but produce the same level of destruction (examples are ammonium nitrate and fuel/oil mixtures).

Oxidizers are chemicals that yield oxygen readily to stimulate combustion of organic materials. Oxidizers have the following characteristics:

- Heat and shock sensitive
- Unpredictable behavior
- Problems with contamination
- Reactivity

The U.S. Department of Transportation provides two categories of oxidizers:

- General oxidizers react chemically or by heating to evolve oxygen and heat (examples include sodium chlorate and perchloric acid).
- Organic peroxides contain a bivalent oxygen to oxygen bond which readily release oxygen when in contact with combustible materials and under high temperature conditions (an example is benzoyl peroxide).

Water-reactive chemicals violently react when contacted by water (examples include sodium metal, potassium superoxide, and some organic metallic compounds). Some chemicals may undergo rapid polymerization with detonation or the release of heat under high temperature or pressure conditions unless inhibited (examples include acrylonitrile and methyl methacrylate). Many chemicals are incompatible with other chemicals or substances. For example, acrylonitrile will react violently with bases, amines, and copper-based metals.

Chemical reactivity hazards can be rated by the National Fire Protection Association ratings:

0 - Materials that are intrinsically stable, even when exposed to fire, and that do not react with water
1 – Materials that are intrinsically stable, but which can become unstable at elevated temperatures, or react with water with some release of energy, but not violently
2 – Materials that are intrinsically unstable and may readily undergo violent chemical change, but do not detonate, or react violently with water, or form explosive mixtures with water
3 – Materials that are intrinsically capable of detonation or explosive reaction, but require a strong initiating source, or must be heated under confinement before initiation, or must be combined with water
4 – Materials that and pressures are intrinsically capable of detonation or of explosive decomposition or reaction at normal temperatures

Proper handling and prevention of chemical contact with incompatible substances is necessary to avoid reactivity hazards of chemicals. Some forms of protective clothing and equipment may offer limited protection against reactive substances. For some substances, there is no PPE available to offer acceptable protection to violent reactions or explosions.

Types of Biological Hazards

Principal biological exposures include:

- Bloodborne pathogens
- Tuberculosis, anthrax, and other airborne pathogens
- Biogenic toxins
- Biogenic allergens

Table 10 summarizes the types of biological hazards, the body areas or body systems affected, and how these hazards are prevented or minimized.

Table 10. Overview of Emergency Scene Biological Hazards

Biological Hazard	**Body Areas Usually Affected**	**Examples During Emergency Response**	**Mitigation Methods**
Bloodborne pathogens	Entire body, primarily exposed mucous membranes	Response activities involving any victim bleeding; Handling of sharps and other contaminated materials; Potential terrorism threats	Universal precautions; Proper personal hygiene (handwashing); Hepatitis B vaccinations; Use of PPE to prevent blood/body fluid contact with mucous membranes or skin; Puncture-resistant PPE to prevent accidental inoculation
Tuberculosis or airborne pathogens	Respiratory system	Medical aid to infected persons or disease-laden areas; Potential terrorism threats	Isolation of affected persons; Proper personal hygiene; Use of particulate filtering respirators
Biological toxins	Entire body Respiratory system	Response activity in outdoor locations over extended period of time	Proper personal hygiene; Use of PPE (respirators, gloves, and clothing)
Biogenic allergens	Entire body Respiratory system	Response activity in outdoor locations over extended period of time	Proper personal hygiene; Use of PPE

Types of Biological Agents. Biological agents include microorganisms or other living matter which are pathogenic to humans, including:

- Viruses, a submicroscopic pathogen consisting of a single nucleic acid enclosed by a protein coat, able to replicate only within a living cell
- Bacteria, a unicellular microorganism, existing as a free-living organism or as a parasite
- Chlamydiae, an intracellular parasite that multiplies by means of a unique development cycle
- Rickettsiae, small microorganism that can only multiply within a host, usually carried by ticks and fleas
- Mycoplasmas, the smallest cells capable of independent existence differing from bacteria by not having a cell wall
- Fungi, either as unicellular yeasts or branching filaments of cells in molds

Each type of microorganism requires a set of parameters affecting its growth, metabolism, development, and reproduction. The microorganism must have an environment that provides favorable conditions for its survival and growth. Environmental factors affecting survival of microbes include:

- Moisture content
- Temperature
- pH balance
- Osmotic pressure
- Oxygen tension
- Nutrients
- Lighting

Routes of Exposure. The primary routes of entry for infectious biological agents include:

- Ingestion
- Inhalation
- Inoculation
- Skin and mucous membrane penetration
- Animal and insect bites

Ingestion occurs frequently as the result of poor personal hygiene such as through handling infectious materials without gloves and/or failing to wash contaminated hands before eating. Inhalation exposure occurs primarily through contact with infected persons (through coughin), particularly closed or confined areas. Inoculation most frequently occurs as the result of accidental injections with contaminated needles or cuts with contaminated sharp instruments.

Penetration of skin or contact of mucous membranes with microorganisms is usually the result of poor hygiene or failure to use protective devices. Subcutaneous exposures may also occur through existing abrasions, cuts, or other areas of non-intact skin. Wild animals and insects can also transfer infectious agents to workers through bites and stings.

Bloodborne Pathogen Exposures. Common bloodborne pathogens include:

- Hepatitis A
- Hepatitis B
- Hepatitis C
- Human Immunodeficiency Virus

The primary modes of transmission of Hepatitis B and HIV in occupational settings are:

- Direct inoculation through the skin
- Contact with an open wound
- Contact with non-intact skin (chapped, abraded, weeping skin)
- Needle sticks and cuts with sharp instruments
- Mucous membrane exposure (eyes and mouth) with blood or body fluids containing blood

OSHA 29 CFR 1910.1030 regulates occupational exposure to bloodborne pathogens, which includes emergency response personnel. These regulations require:

- Developing an exposure control plan
- Using methods for eliminating or minimizing fire fighter contact with bloodborne pathogens, including use of universal precautions and use of PPE which keeps bloodborne pathogens off the fire fighters's skin or underclothing
- Applying proper cleaning and decontamination during medical care
- Providing Hepatitis B vaccinations for affected fire fighters
- Communicating hazards to fire fighters
- Conducting training
- Keeping appropriate records

Tuberculosis and Airborne Pathogen Exposures. Tuberculosis (TB) is caused by the tubercle bacillus (i.e., *Mycobacterium tuberculosis*) and is spread by airborne particles expelled when persons with pulmonary TB sneeze, cough, speak, or sing. TB is not equally prevalent throughout the United States. Susceptibility to infection depends on the health of the individual's immunity system. Protection from transmission of TB can be accomplished by:

- Isolating those emergency victims with TB infection or active TB
- Use of personal protective equipment including surgical masks and respirators
  - Face masks may limit exposure but are not an effective PPE item against airborne pathogens because these masks do not provide an air-tight seal to the face of the wearer.
  - The National Institute for Occupational Safety and Health (NIOSH) recommends NIOSH-certified, powered, half mask respirators equipped with HEPA filters.

Other airborne pathogens, such as influenza, are similarly transmitted. Microorganisms must remain viable for transmission to occur. Strategies for preventing exposure involve isolation and respiratory protective equipment and sometimes other forms of protective equipment.

More recent exposures of firefighters to anthrax and sudden acquired respiratory syndrome (SARS) illustrate the first responder susceptibility to airborne pathogens. As the EMS responsibilities for the fire service increase, the likelihood for fire fighter exposure will increase and greater needs for fire fighter respiratory protection will be needed.

Biological Toxin Exposures. Biological toxins include primarily biogenic toxins. Biogenic toxins are naturally-occurring substances that can cause acute toxic disease in addition to long-term reproductive and carcinogenic effects. Biogenic toxins include those of bacterial, algal, fungal, plant, or animal origin. Examples of biogenic toxic effects are:

- Botulism
- Tetanus
- Diphtheria
- Dysentery
- Poison ivy
- Animal bites or stings

The primary route of exposure is by inhalation, but some toxins are spread by dermal contact (e.g., poison ivy) or injection (animal bites or stings). The potential for fire fighter exposure to biotoxins can occur in any indoor environment where there is extensive growth of microorganisms or outdoors from direct contact with plants, animals, or their products. Generally speaking, fire fighters are at no greater risk for biotoxin exposure than the general population; however, wildland fire fighting and disaster scenes can constitute environments where the risk of exposure is increased. Protection from biogenic toxins is best achieved by good hygiene and use of respirators equipped with appropriate filtering material and clothing to cover skin to protect from animal bite or insect stings.

Biogenic Allergen Exposures. Biogenic allergens are substances produced or derived from plants, animals, or microorganisms that can elicit an immune response from certain individuals. Normally the immune system has a protective role, but repeated exposure to antigens (produced by the body in response to exposure by biogenic allergens), can cause an excessive immune reactions (hypersensitivity), such as allergic asthma, pneumonitis (inflammation of the lungs), and contact dermatitis. Biogenic allergens arise from animal products and insects, plants, wood dust, and microorganisms. Like biotoxins, fire fighters are no more likely than the general population to come in contact with these substances. The use of protective clothing and equipment helps to minimize exposures.

Types of Thermal Hazards

Thermal hazards include exposure to thermal energy from:

- High heat sources (convective or radiant heat)
- Flame impingement
- Hot liquids and gases (hot water and steam)
- Molten substances
- Hot solids and surfaces

Table 11. Overview of Emergency Scene Thermal Hazards

Thermal Hazard	Body Areas Usually Affected	Examples During Emergency Response	Mitigation Methods
High heat (radiant and convective)	Entire body, especially exposed skin	Structural fires Proximity fires Wildland fires	Provide insulative shielding to individual; Limit time of exposure; Use flame-resistant protection clothing which insulates from convective, radiative, and conductive heat
Flame	Entire body, especially exposed skin	Structural fires Proximity fires Wildland fires	Isolate worker from flame contact; Use flame-resistant, non-melting, heat insulative protective clothing
Hot gas or liquid	Entire body, especially exposed skin; Respiratory system	Response efforts into steam plants or around boilers; Structural fires Proximity fires Wildland fires	Isolate worker from hot gas or liquid contact; Use flame-resistant, non-melting, heat insulative protective clothing which provide barrier to hot liquids and gases Use respirators to protection against hot gases
Molten substances or hot solids	Entire body, especially exposed skin	Sustained structural or large scale fires; Welding	Isolate worker from flame contact; Use flame-resistant, non-melting, heat insulative protective clothing which sheds molten metals

As previously described, thermal exposure may also be present from chemical flash fires. Thermal energies may also be encountered in electrical arc exposures (see below). Table 11 summarizes the types of physical hazards, the body areas or body systems affected, and how these hazards are prevented or minimized.

Nature of Thermal Hazards. Thermal hazards will affect any exposed area of the human body including the respiratory system when hot gases are breathed in. The principal injury resulting from exposure to high amounts of thermal energy is burn injury. Burn injury occurs when the skin absorbs a sufficient amount of heat energy to damage the skin or underlying tissue:

- First degree burn injury occurs when the skin temperature reaches 111^{o}F (44^{o}C); the skin appears reddened and is tender to the touch.
- Second degree or partial thickness burn injury occurs when the skin temperature reaches 119^{o}F (49^{o}C); 2nd degree burns produce blistering.
- Third degree or full thickness burn injury occurs when the skin temperature reaches 131^{o}F (55^{o}C); 3rd degree burns involve destruction of the skin.

Burn injury may be also referred to in terms of its depth. The depth of burn is assessed by observing the color and texture of the burn a well as the presence of blisters. An assessment of sensation in the wound is also helpful. Partially burned skin is painful, red, macerated, and extremely tender. Full thickness burns are leathers, not blistered, and insensitive. Severe burn injury (2nd or 3rd degree burns) are generally preceded by the sensation of pain, which can act as an early warning that thermal injury is imminent. However, the amount of elapsed time between the sensation of pain to the onset of burn injury will vary with the exposure circumstances and in some cases will be near instantaneous for relatively severe exposures.

Burn injury is a function of incident thermal energy and time or heat dose. As would be expected, higher incident thermal energies cause burns earlier. Given a sufficient time, exposure to elevated thermal energy will cause burn injury as the body's ability to dissipate heat in the region of exposure fails to keep up. Energy may also be stored in surrounding objects and skin that is prestressed (already at an elevated temperature) may quickly sustain a burn injury as contact with the hot object occurs. An example of this phenomenon occurs when hot clothing comes in contact with the skin when the clothing is pushed into the skin. Burn injury can also happen with heat transfer through the clothing, or when clothing or equipment worn by the individual ignites, melts, or otherwise loses its effectiveness.

High Heat Exposures. Heat transfer may occur by:

- Conduction
- Convection
- Thermal radiation

Conduction involves heat transfer as the result of direct contact of the individual or his or her clothing with a hot surface. Heat flows through the resulting continuity of surfaces. Heat conduction is further affected when the protective clothing is wet or compressed. Water can provide a bridge between surfaces that might not otherwise touch, increasing the chances of heat conduction by displacing insulating air between and within the layers of clothing. Water can also act as an insulator since water has a relatively high heat capacity increasing the overall mass of the material system and extending the time it can absorb heat. Compression may bring surfaces closer together, permitting greater transfer of heat between clothing layers. Direct unprotected skin contact with surfaces that are above 140°F (60°C) will cause pain and tissue damage.

Convection entails heat transmission through the movement and the density of surrounding gases or liquids (normally air or water). Convection also affects the transfer of heat within layers of clothing and between these layers and the body. Some convective heat loss occurs by evaporation of wearer's sweat. Spaces within the clothing or between clothing layers, if filled with air, provide convective air currents affecting heat transfer through protective clothing. Tolerance times for specific heat exposures depend on the exposure heat energy and duration of exposure.

Thermal radiation depends upon the temperature difference between two surfaces, the distance between two surfaces, and the reflectivity of each surface. Thus, heat exchange by radiation does not depend on the temperature of the air between each surface. Thermal radiation does not always depend on the clothing color (e.g., a darker color in the visible spectrum of light may actually be more reflective in the near infrared region than a white color, depending on the physical properties of the textile and dyes).

High heat exposures are a principal hazard in most structural and related fires. Different means exist for classifying heat exposures (see Fire Fighter Missions), but generally fire fighters are at risk to all forms of heat transfer during a fire response with the intensity varying with their role on the fire ground and the characteristics of the fire. For example, fires involving bulk flammable fuels and aircraft generally involve extremely high levels of radiant heat. The rapidly changing conditions of the fire environment further produce convective and conductive heat exposure hazards.

Fire fighters rely on their protective clothing for preventing burn injury, but as with any hazard, there are limitations to amount of protection that can be offered. Clothing material response to heat typically proceeds through the following stages:

- Temperature rise and subsequent heat transfer through the material
- Decomposition and change in physical form
- Ignition and combustion (for those materials that are flammable or lose their flame resistant characteristics) or disintegration.

The selection of heat protective clothing and equipment is therefore based on PPE that offers:

- Heat and flame resistance (materials that resist the degradation effects of heat and flame contact)
- Thermal capacity and insulation (materials that either store heat or limit its transfer through the clothing)
- Reflectivity (materials that reflect heat, predominantly for radiant heat protection)

Flame Exposures. A flame exposure is a specialized form of heat exposure which generally involve the combination of convection and thermal radiation; a typical flame exposure involves incident thermal energies of 15 to 110 Btu/ft^2 (4 to 30 cal/cm^2) and a mix of 30-50% radiant energy and 50-70% convective energy. Depending upon the distance from the fire, thermal loads vary from that of the radiant heat energy of a JP-4 fuel flame front (982°C or 1800°F) to the mixture of radiant heat and convective heat typical in a smoky structural fire (93° to 315°C or 200° to 600°F). Other than burn injury, the principal hazard from exposure to flame is the ignition of clothing. Protection strategies for minimizing hazards from flame exposure are based on the use of PPE which is flame resistant. Flame resistance may be imparted by treating PPE materials with flame retardants or using materials which are intrinsically flame resistant.

Hot Liquid or Gas Exposures. Contact with hot liquids or gases provide primarily convective thermal exposures. Hot liquids or gases may penetrate clothing causing increased heat transfer to the individual. Steam is an example of a hot vapor which transfers heat by penetration and direct contact with the skin. Hot gases may affect all areas of the body while hot liquids are most likely to affect hands and feet. Hot gases also pose a respiratory system hazard. Protection from hot liquid or gas exposure involves principles similar to those used for protection from high heat but also requires the provision of a barrier material which prevents penetration of the liquid or gas.

Molten Substances and Hot Solids. Given the extremes of many fireground environments, the presence of solids at elevated temperatures or molten substances is a common hazard during structural other sustained fires. Continued burning at fires will melt metals, such as aluminum, which can either drip from elevated portions of the structures or pool on flat surfaces. The array of plastic synthetic substances gives further rise to items capable of causing burns at fires or immediately after the fire before cooling has occurred. Emergency responders involved in cutting operations may also be at risk for contact for welding splatter and molten metals. Molten substances pose hazards from heat conduction and ignition of clothing fabrics. Therefore, the selected PPE must be flame resistant, limit heat transfer of molten substances, and allow molten substances to readily run off. Not all fabrics used in firefighter protective clothing provide this property. For example, molten aluminum will adhere to aramid fabrics.

Types of Electrical Hazards

Electricity may create three possible forms of hazards:

- Exposure to electrical shock
- Exposure to electrical arcs
- Exposure to static electricity

Table 12 summarizes the types of electrical hazards, the body areas or body systems affected, and how these hazards are prevented or minimized. OSHA 29 CFR 1910.139 addresses specific concerns for electrical hazards as related to PPE, but is more intended for electrical workers.

Electrical Shock Exposures. Line-to-ground electrical hazards are the most common type of electrical hazard. Electrical shock hazards are difficult to detect because the electric device may continue to operate normally. Examples of electrical shock hazards include:

- Ground wire of a power cord broken or not connected
- Improper electrical connections

Table 12. Overview of Emergency Scene Electrical Hazards

Electrical Hazard	**Body Areas Usually Affected**	**Examples During Emergency Response**	**Mitigation Methods**
Electric shock	Entire body Head Hands Feet	Any exposure to poor, improper, or damaged wiring; Emergency response activities into damaged structures or community infrastructure	Use insulated and grounded equipment; Ensure power is shut off to the response scene when damage is suspected; Avoid use of metallic jewelry or conductive items; Use PPE with electrical insulation qualities
Electric arc	Entire body Head Face and eyes Arms Hands	Public utilities and power generation; Facility plant generation	Isolate workers from potential electrical arcs; Use flame resistant PPE which provide thermal and electrical insulation from electrical arcs
Static charge generation	Entire body	Work in potentially flammable or explosive atmospheres	Provide insulated, grounded and intrinsically safe tools and equipment in hazardous environments; Use static removing treatments on clothing; Use conductive or static charge generation resistant protective clothing

- Ungrounded wall receptacles
- Electrical insulation failure in a heating element
- Power lines short circuit to the equipment case

Fire fighters most often encounter electrical shock hazards during emergencies where destruction of property takes place, often breaking power lines and leaving cables and wires live until properly shut off. A common hazard is for a fire fighter to touch or step on a live electrical cable that has been dislocated during the structure's damage. Water at the scene worsens the hazard.

Individuals have different body resistance to electrical shock, which is affected by body size, gender, and age. The severity of the electric shock can be related to the amount of voltage or current involved in the exposure. The susceptibility of an individual to and seriousness of an electrical shock is also influenced by the presence of moisture on the individual's skin.

Electrical shock can affect processes in the body which are controlled by electrical activity such as muscle contraction, sensory processes, and heart action. An applied external voltage can create the following effects on the body:

- Increased threshold perception (tingling or warm sensation)
- Pain
- Sustained muscle contraction
- Ventricular fibrillation
- Cardiac arrest
- Convulsions
- Burns

Strategies for reducing the possibility of electrical shock include installing and maintaining electrical circuits, equipment, and devices to electrical codes, using insulated and guarded electrical equipment, and providing PPE for the wearer's head, hands, and feet that insulate from electrical shock.

Electrical Arc Exposures. An electric arc is produced by the passage of an electrical current between two electrodes in ionized gases and vapors. In industrial power systems, electrical arcs are normally short in duration, 1 second or less, produce very high energy levels, primarily radiant energy (2 to >100 cal/cm^2), and have temperatures as high as 20,000^{o}F. The electrical energy from the arc can be converted to other forms of energy and create other hazards:

- Intense thermal radiation
- Damaging noise levels
- Explosive expansion of the air surrounding the arc due to rapid heating
- Melting/vaporization of arc electrodes (producing molten metal hazards)
- Significant damage of electrical equipment
- Ignition or melting of normal wearing apparel in the vicinity of the arc

Injuries are typically second or third degree burns. Ignited fabrics can cause burn injuries over a high percentage of the body. Electrical arc hazards are most likely to be encountered in the power generation facilities of utilities and major plants. Most ordinary fire fighting activities would not involve the voltages necessary to cause electrical arc explosions. Approaches to protecting personnel from electrical arcs involve the use of PPE including flame resistant clothing, hooded visors, gloves, and footwear.

Static Charge Exposures. Protection from static charge and discharge can result in nuisance effects to extreme danger. The consequences from static discharge range from minor physical discomfort to the ignition of a flammable atmosphere resulting in a chemical flash fire. Static charge is characterized by its lack of warning; it has no odor, color, or sound and is usually only detected by clothing clinging to skin. It is typically not detected until it discharges. The principal concern to the emergency responder is the potential discharge of static electricity in a flammable or explosive atmosphere. The discharge of a spark will ignite a flammable environment; charges over 12.5 kV/in will typically ignite a gas requiring 0.2 milliJoules for ignition.

Since fire fighters and other emergency responders cannot control their environment, techniques for minimizing static include the use of grounded and insulated tools, using conductive fibers in clothing for dissipating charges, and applying topical antistatic treatments for increasing the surface conductivity of fabrics; these treatments help by spreading the charge generated or induced by clothing fabrics.

Types of Radiation Hazards

Radiation hazards are classified as either:

- Ionizing radiation or
- Non-ionizing radiation

Table 13 summarizes the types of radiation hazards, the body areas or body systems affected, and how these hazards are prevented or minimized.

Ionizing Radiation. Ionizing radiation includes X-rays and radiation emitted from radioactive materials. Radiation associated with radioactive materials is produced by the spontaneous transformation of the element to other elements or isotopes produced either naturally or unnaturally from man-made process (usually by neutron bombardment). Radioactivity is not affected by the physical state or chemical combination of the element. The time associated with the radioactive disintegration process is characteristic of the specific element. The time period during which an amount of a radioactive isotope decays to half the value is called the half life.

The energy of this process is emitted in the form of:

- Alpha particles
- Beta particles
- Gamma rays

Table 13. Overview of Emergency Scene Radiation Hazards

Radiation Hazard	Body Areas Usually Affected	Examples During Emergency Response	Mitigation Methods
Ionizing radiation (alpha/beta particles)	Entire body Respiratory system	Responses involving nuclear power plants; Nuclear terrorism	Shielding and distance from radioactive source; PPE which provide protection from particulates
Ionizing radiation (gamma rays)	Entire body	Responses involving nuclear power plants or in facilities using radioisotopes, equipment with radioisotope sources, special sterilization or polymerization processes; Nuclear terrorism	Shielding and distance from radioactive source; Specialized PPE with heavy shielding
Ionizing radiation (X-rays)	Entire body	Responses involving nuclear power plants or in facilities using radioisotopes, medical equipment, special sterilization or polymerization processes; Nuclear terrorism	Shielding and distance from radioactive source; Specialized PPE with heavy shielding
Non-ionizing radiation	Entire body; Eyes	Arc welding; Hot metal operations; Microwave ovens and transmission towers; Radar; Electric power transmission lines	Shield or isolation from some non-ionizing radiation sources; Use of PPE to attenuate non-ionizing radiation energy; Use of eyewear which attenuates non-ionizing radiation energy

Alpha particles are doubly ionized nuclei of helium having relatively little penetrating power and are considered an internal hazard that can be absorbed into the body through the respiratory tract, ingestion, open wounds, or body orifices. Beta particles are negatively charged particles identical to electrons and have a wide range of energies. Beta particles are considered to be intermediate between alpha and gamma radiation in their penetration and are capable of penetrating the outer layers of the skin, through they are usually easily shielded against. Consequently, beta particles are primarily (although not always) more of an internal hazard. Gamma rays are electromagnetic radiation of extremely short wavelengths and intensely high energy. Gamma rays can penetrate many objects, including the human body and are best absorbed by dense materials like lead and depleted uranium.

Another form of ionizing radiation are X-rays. X-rays are electromagnetic radiation of extremely short wavelengths emitted as the result of electron transitions in the inner orbits of heavy atoms bombarded by cathode rays in a vacuum tube. X-rays have the following characteristics and hazards:

- Penetrate solids of moderate density (such as human tissue, but not bone)
- Ionize gases through which they pass
- Able to destroy or damage diseased tissue

Overexposure to X-rays permanently destroys cells and tissue structures. As with other forms of ionizing radiation, the damage is cumulative. Other types of ionizing radiation may also include neutrons, high speed electrons, high speed protons, and other atomic particles.

Ionizing radiation hazard can be found in nuclear power generating plants, at military facilities, in laboratories which use radioactive substances or conducting experiments involving ionizing radiation, and within health care and other specialized equipment which uses ionizing radiation. While fire fighters are less likely to encounter ionizing radiation unless operating in a facility with radioactive sources, the threat of nuclear terrorism or dirty bombs creates a possible hazard to first responders.

Radiation can damage body tissue in various ways. Radiation primarily affects the cells of living tissues. The energy emitted from the radioactive source is deposited in tissues and disrupts cells either directly or indirectly. Large doses of radiation directly destroy cell components and cause death of the affected cells or prevent reproduction. The genetic material in cells is particularly sensitive to radiation effects which disrupting reproduction. Radiation can further interact with cell chemical components and can lead to the development of cancer.

Specific whole body biological effects of short term radiation exposure include:

- Doses of 100 to 200 rem cause nausea and vomiting.
- Doses of 200 to 600 rem affects the levels of circulating blood cells.
- Doses of 300 rem or more cause hair loss.
- Doses between 600 and 1000 rem cause infection and hemorrhage, and other symptoms of decreased bone marrow functioning, which may take months to occur.

- Doses over 1000 rem result in irreversible damage of the small intestine lining causing death with weeks.
- Doses over 5000 rem have severe effects on gastrointestinal, cardiovascular, and central nervous systems with death occurring in hours.

Specific acute local biological effects of short term radiation exposure also have significant effects on individuals. Large doses may also cause skin burns which are similar to thermal burns but take longer to develop. Doses of 10 to 15 rem cause temporary sterility in men; Permanent sterility occurs in men and women at doses over 200 rem. Depending on the stage of development, fetuses have different sensitivities to radiation.

Long term exposures to radiation can cause cancer of the skin, bone marrow, lungs, breast, stomach, and thyroid. Long term exposures to ionizing radiation also lead to genetic effects or mutations of the genes in reproductive cells, producing birth defects in offspring or succeeding generations.

Radiation Exposure Levels. Radioactivity is measured in several different ways:

- A *roentgen* (R) is the amount of radiation that produces sufficient ion pairs in a cubic centimeter of air to carry one electrostatic unit of electrical charge (used for measuring gamma rays and X-rays).
- A ***r**adiation **a**bsorbed **d**ose* or *rad* is the amount of radiation that results in the absorption of 100 ergs of energy by 1 gram of a material.
- A *curie* is the amount of radioactivity which decays at the same rate as 1 gram of Radium 226, equivalent to 3.7×10^{10} disintegrations per second.

The biological effects of radiation depend on the type of radiation in addition to the dose. The *relative biological effectiveness* (RBE) is the ratio of the absorbed dose of gamma radiation to the absorbed dose of the given radiation which gives the same biological effect (RBE are tabulated for various types of radiation). A ***r**oentgen **e**quivalent **m**an* or *rem* is RBE multiplied by the dose in rems and indicates the amount of biological damage from radiation.

The U.S. Department of Transportation classified radioactive materials into three categories:

- *Radioactive I*: Materials which register 0.5 millirems per hour or less on the external surface of the container
- *Radioactive II*: Materials which register less than 1 millirem per hour at 3 feet from external points of the container
- *Radioactive III*: Materials which register more than 50 millirems per hour at the external surface or more than 1 millirem 3 feet away from the package surface

Normal (natural) background exposures rates for gamma radiation are 0.01 to 0.02 milliroentgen per hour (mR/hr) and may vary from region to region. Permissible exposure levels to ionizing radiation are set by two organizations. OSHA 29 CFR 1910.96 prohibits exposure of individuals to ionizing radiation at the following levels:

- Whole body – head and trunk, active blood forming organs, lens of eyes, or gonads at 1¼ rems per calendar quarter
- Hands and forearms – feet and ankle at 18¾ Rems per calendar quarter
- Skin of whole body at 7½ rems per calendar quarter

The International Commission on Radiation Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) recommend that radiation doses be kept as low as reasonably achievable, but below the federal OSHA limits. The American Conference of Governmental Industrial Hygienists (ACGIH) establishes a Threshold Limit Value (TLVs) for particulate or electromagnetic ionizing radiation having an energy of 12.4 electron volts in its annual publication, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*.

The principal method for protecting individuals from ionizing radiation involves applying the principles of time, distance, and shielding:

- Reduced exposure time reduces dose
- Increased distance from the radiation source reduces dose
- Shielding reduces dose

Protective clothing effective against particulates will also be effective against alpha and beta particles, however the energy of the beta particles must be taken into account as higher energy beta particles have greater penetrating power. Protection from gamma rays and X-rays requires heavy metal shielding, though new relatively dense polymers appearing in the marketplace provide attenuation of some ionizing radiation for lower level exposures.

Non-Ionizing Radiation. Non-ionizing radiation is electromagnetic energy which does not change the structure of atoms of elements that it contacts. Categories of non-ionizing radiation include:

- Ultraviolet and visible light
- Infrared light
- Microwaves
- Radio frequencies
- Extremely low frequency radiation

Sources of non-ionizing radiation may be natural, such as the sun, or may be from industrial products or processes, including: arc welding, hot metal operations, microwave ovens and transmission towers, radar facilities, and electric power transmission lines.

Health effects from exposure to non-ionizing radiation include alteration of biochemical structures in the skin and eyes, leading to inflammation, such as from ultraviolet radiation (an example is sunburn). Microwave and infrared energies will dissipate in the body in the form of heat. The effects of radio frequencies are still being studied, but new regulations are forthcoming which limit the amount of exposure, particularly from electric power transmission lines.

The American Conference of Governmental Industrial Hygienists (ACGIH) in its annual publication, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, establishes Threshold Limit Values (TLVs) for exposure to:

- Lasers
- Light and near-infrared radiation
- Radio frequency/microwave radiation
- Electromagnetic pulses and radio frequency radiation
- Static magnetic fields
- Sub-radio frequency magnetic fields
- Sub-radio frequency and static electric fields
- Ultraviolet radiation

OSHA 29 CFR 1910.133 sets requirements for shielding the eyes from the light associated with non-ionizing radiation caused by various types of welding and cutting operations. There are no specific protective clothing recommendations, though the use of flame-resistant protective clothing that resists the effects of welding splatter are recommended for these operations.

Types of Person-Position Hazards

The position of the fire fighter in performing response activities can also create hazards, such as:

- Hazards from the worker not being visible
- Hazards from drowning
- Hazards from falling off of elevated surfaces

Table 14 summarizes the types of person-position hazards, the body areas or body systems affected, and how these hazards are prevented or minimized.

Worker Visibility. Fire fighters and other emergency responders who perform tasks outdoors or in areas near vehicular traffic face the potential for being struck and must remain highly visible under a number of circumstances both during the day and at night. Emergency responders are also at risk during busy emergency scenes involving the operation of heavy equipment (e.g., cranes) and must be readily visible. Day time visibility is different from night time visibility since backgrounds and the ability for oncoming motorists to distinguish fire fighters will vary substantially with the lighting conditions. High visibility means conspicuity of the individual against their background.

Emergency responder visibility is best enhanced by the use of high visibility materials:

- Fluorescent or phosphorescent materials should be used to provide enhanced daytime visibility. Fluorescent materials are unnatural in color and provide high contrast during the day.
- Phosphorescent materials absorb radiant energy and reradiate light after the energy source has been removed
- Retroreflective materials should be used to provided enhanced nighttime visibility (retroreflective materials have built in optical systems that redirect incoming light back to the source).

Table 14. Overview of Emergency Scene Person-Position Hazards

Person-Position Hazard	Body Areas Usually Affected	Examples During Emergency Response	Mitigation Methods
Low visibility	Entire body	Operations on roadways; Vehicle-victim extrication; Personnel operating in areas where heavy machinery is being used (e.g., structural collapse)	Use signs, flashing lights or flares to alert traffic to personnel near roadway; Use fluorescent material on PPE to enhance daytime visibility; Use retroreflective material on PPE to enhance night time visibility
Drowning	Entire body	Any response on or next to water or waterways; Swiftwater rescue	Provide guards to prevent workers from falling in water where possible; Require workers to wear U.S. Coast Guard approved Personal Flotation Devices (PFDs)
Falling from elevated platforms	Entire body	Any work on elevated platforms; Roof ventilation operations	Provide guards on elevated platforms, scaffolding, stairs, or manholes where possible; Limit fire fighter traffic on elevated platforms; Use personal fall arrest equipment

Drowning. Emergency responders operating in marine areas may be laden with equipment and may be subject to drowning. Increased risk for drowning exists when water temperatures are near freezing; hypothermia can quickly set in and limit the individual's attempt to self-rescue. Operations during swiftwater rescue further pose serious hazards when rushing water can easily carry untethered responders. The debris traveling along with swift water currents creates further hazards.

OSHA 29 CFR 1926.106 requires that employees working over or near water:

- Be provided with U.S. Coast Guard-approved life jackets or buoyant work vests
- Have ring buoys with at least 90 feet of line available
- Have at least one lifesaving skiff available

Falling from Elevated Surfaces. Fire fighters are constant risk in ventilation operations during roof collapse. The nature of emergency operations at most firegrounds also creates potential hazards for falling as can be the case for other types of response activities. OSHA 29 CFR Subpart M on Fall Protection requires employers to provide fall protection when the worker is 6 feet or more above a lower level, without a guardrail system or safety net. Prevention of falling for emergency responders is be prevented from the use of personal fall arrest systems. Personal fall arrest systems include life lines, ropes, straps, body belts, harness, and related hardware components.

Types of Person-Equipment Hazards

Person-equipment hazards are hazards that are created by the clothing and equipment that the fire fighter or emergency responder is wearing. Examples of person-equipment hazards include:

- Creation of Hazardous Conditions or Environments
- Decrease in fire fighter function
- Increase in fire fighter's potential for heat stress
- Reduction of PPE performance through wear and use (e.g., poor durability)

Person-equipment hazards must be evaluated after the PPE has been chosen since the hazard created by the clothing or equipment will depend on the specific item chosen. Table 15 summarizes the types of person-equipment hazards, the body areas or body systems affected, and how these hazards are prevented or minimized.

Creation of Hazardous Conditions or Environments. In some cases, the PPE itself can create a hazardous environment or condition. Examples of hazards created by PPE include:

- Generation of static charge in a static charge-sensitive environment
- Sensitization and allergic reactions from contact with PPE materials
- Absorption of hazardous materials which then contact the skin (ease of contamination or failure of decontamination to remove hazardous substances)
- Excess clothing or straps which can get caught in machinery or other obstructions

Table 15. Overview of Emergency Scene Person-Equipment Hazards

Person-Equipment Hazard	Body Areas Usually Affected	Examples During Emergency Response	Mitigation Methods
PPE creation of static electricity	Effect on environment	Emergency response involving flammable or explosive atmosphere	Use of static treatments or conductive material in PPE
Sensitization or allergic reaction from PPE contact	Entire body Hands	Any operation involving incompatible materials in PPE	Use alternative materials
PPE retention of contamination	Entire body Respiratory system	Any operation where contamination occurs	Use contamination resistant PPE; Use disposable PPE; Apply proper PPE decontamination
PPE with loose straps or material	Entire body Arms Hands	Operations where loose clothing or straps are used	Use low profile PPE; Secure loose material or straps
PPE with poor interfaces	Neck Head/Face Wrists Ankles	Any operation where exposed or poor protected PPE interface areas can occur	Use PPE designed to work together; Use auxiliary PPE to cover interfaces
PPE reduction in mobility	Entire body Head Arms Legs	Any use of full or partial body PPE	Select PPE which offers least restriction of movement without loss of needed protection
PPE reduction in hand function	Hands	Any use of gloves or other handwear	Select gloves or other handwear which still permits acceptable hand function (dexterity, tactility, grip) without loss of needed protection
PPE impairment of vision	Eyes	Any use of face or eyewear; or other PPE items shielding eyes	Select eyewear, or other PPE which shield eyes to provide acceptable vision clarity and field of vision without loss of needed protection

Table 15. Overview of Emergency Scene Person-Equipment Hazards (continued)

Person-Equipment Hazard	**Body Areas Usually Affected**	**Examples During Emergency Response**	**Mitigation Methods**
PPE impairment of communi-cations	Hearing/Speaking	Any use of PPE which affects wearer hearing	Select PPE which permit intelligible communications; Use alternative devices (e.g., built-in mask radios) to assist communications
Lack of footwear ankle support	Feet	Any use of footwear in operation with uneven ground	Select footwear which provides good support in ankle region without loss of needed protection
Lack of PPE back support	Torso	Any use of PPE where significant lifting is required	Train workers in proper lifting techniques; Ergonomically design work tasks; Use PPE with auxiliary back support or separate back support belts
Difficulty in PPE use	All areas	Any use of PPW where difficulty is encountered in donning, adjusting, using, or doffing	Select PPE which is easiest to use; Train workers in proper use
Increase in potential for heat stress	Entire body	Any use of full or partial body PPE under high heat or humid conditions	See Table 6 for Environmental Hazards (High heat/humidity)
Decrease in PPE performance by wear and use	Entire body	Any use of PPE	Select PPE with sufficient durability to provide needed protection during intended service life
Difficult serviceability	Entire body	Any use of PPE	Select PPE which is easy to inspect/service

PPE Creation of Static Electricity – Creation of static electricity from PPE can ignite flammable or explosive atmospheres (hazardous environments). Static electricity can be controlled by providing surface treatments (anti-static) of PPE or by using conductive fiber material based PPE.

Sensitization or Allergic Reaction from PPE Contact – Materials may contain substances which irritate, cause allergic reactions of the skin, or create toxic reactions. Common examples of PPE skin irritation problems include:

- Latex rubber protein sensitization
- High levels of chromium content in leather
- Organic solvents in adhesives used for construction of PPE items

Materials should be tested for biocompatibility before use in PPE. Skin irritation or allergic reactions can be prevented by substitution of materials or use of PPE materials which have demonstrated biocompatibility. For example, the replacement of latex examination gloves with gloves made from nitrile rubber.

PPE Retention of Contamination – Some reusable PPE can retain chemicals, biological materials, and other hazardous substances and must be decontaminated or sterilized before reuse. This is particularly true during many emergency responses where contact with contamination occurs in an uncontrolled fashion. The decontamination or sterilization processes may not always be effective in removing all contaminants. Remaining contamination in PPE can continue to contact skin or become aerosolized or made airborne to create hazards to wearer of PPE upon subsequent wearings. Residual contamination in PPE ('matrix' contamination) can be avoided by using contamination-resistant PPE, selecting disposable or single use PPE or disposable covers for reusable PPE, and by applying proper cleaning, decontamination, and sterilization procedures demonstrated to be effective for specific contaminants.

PPE with Loose Straps or Material – Extra material or straps associated with PPE can create hazards by getting caught on rough surfaces or in machinery. Hazards from loose materials or straps can be minimized by choosing form-fitting PPE which has a low profile and properly wearing PPE by securing loose material or straps (some hazardous materials applications may permit duct tape for this purpose, however, duct tape must be suitable for the full range of expected hazards.)

Lack of Appropriate PPE Interfaces – The use of multiple items of PPE for protection against specific hazards during emergency response often leaves "gaps" in the wearer's protection if the interfaces between PPE items are poorly designed or if dissimilar, non-compatible pieces of equipment and clothing are used. PPE interfaces include:

- Upper and lower torso garment overlap (mid-torso)
- Upper torso garment (collar) to hood interface (neck)
- Hood to respirator or face/eyewear interface (face)
- Garment sleeve end to handwear interface (wrist)
- Garment trouser cuff to footwear interface (ankle)

Potential PPE interface problems include:

- Leakage of hazardous substances through interface areas
- Lower insulation or performance of interface areas
- Accidental separation of PPE item interfaces during use created exposed areas on the wearer's body

PPE interface performance is particularly critical in environments where hazards affect all parts of the body or parts of the body which are covered by multiple PPE items. PPE interface problems can be avoided by using PPE designed to fit together or that can be properly integrated in an ensemble. Use of ancillary items on PPE can assist in proper interface area protection (such as tape, when permitted, or accessory garments).

Decrease in Fire Fighter Function. By virtue of its protective qualities, usually for isolating the worker from the hazard or hazards, PPE creates burdens on the wearer which decrease work function. Examples of PPE effects on fire fighter function include:

- Reduction of responder's mobility or range of motion
- Decline in responder's hand function (e.g., dexterity, tactility, and grip)
- Impairment of responder's vision
- Impairment of responder’s hearing or ability to communicate
- Lack of adequate ankle support for responses on uneven surfaces
- Lack of adequate back support for lifting operations
- Difficulty in donning (putting on) or doffing (taking off) PPE

These person-equipment hazards must be assessed by observing fire fighters and emergency responders using current or intended PPE in actual or simulated tasks. The sizing and fit of PPE is critical to its optimum performance and to limit effects on worker function. Often optimization of worker function represents a tradeoff with PPE protective performance.

PPE Reduction in Mobility – PPE clothing and equipment designs may restrict movement by design or from use of thick, bulky, or heavy materials which encumber worker movement or range of motion. Special applications such as confined space entry may require low profile PPE which enables workers to easily enter and exit confined spaces through restricted doors, holes, or hatchways. Restricted movement may create falling or tripping hazards or lessen worker ability to escape a hazardous situation. The extra energy required for fire fighter or emergency responder movement further created additional physiological stress. Reductions of mobility usually come with the provision of specialized protection and therefore represent tradeoffs between worker protection and ergonomics. Minimization of PPE impact on mobility should be accomplished by selecting PPE which provides the best range of movement without sacrificing needed protection.

PPE Reduction in Hand Function – Gloves often diminish hand function in terms of:

- Dexterity (ability to manipulate objects)

- Tactility (ability to sense objects by touch)
- Grip (ability to grasp and hold onto objects)

Reductions of hand function results from providing specialized protection and therefore represent tradeoffs between firefighter protection and ergonomics. Minimization of glove/ handwear impact on hand function should be accomplished by selecting PPE which provides the best dexterity, tactility, and grip required for fire fighter function without sacrificing needed protection.

PPE Impairment of Vision – Facewear, eyewear, hoods, visors, and other items of PPE which cover the eyes or provide a shield of hazards often restrict worker vision in terms of its clarity and viewable field. The impairment of vision results from providing specialized protection and therefore represents a tradeoff between fire fighter protection and ergonomics. Minimization of PPE impact on worker vision should be accomplished by selecting PPE which provides acceptable clarity and field of vision without sacrificing needed protection.

PPE Impairment of Communications – PPE, Such as respirator facepieces and hoods, which cover the ears and mouth often restrict fire fighter speaking and hearing. As with other forms of protective clothing and equipment, impairment of fire fighter communications results from providing specialized protection and therefore represents a tradeoff between fire fighter protection and ergonomics. However, the impairment of fire fighter communications creates a serious problem, when communications at the emergency scene is essential to proper response actions and the health and safety of the members present. Minimization of PPE impact on fire fighter communications should be accomplished by selecting PPE which provides acceptable understanding communications from speaking and hearing. Several types of special devices are provided by the industry for enhancing communication.

Lack of Footwear Ankle Support - Looseness or poor fit of footwear can create hazards by not properly supporting the ankle leading to possible strains or sprains when walking on uneven or rough surfaces. Given the high incidence of strains and sprains among fire fighters, attention is needed to proper ankle support as provided by choosing footwear with good fit, especially in the ankle area without sacrificing need protection.

Lack of PPE Back Support – Operations involving repeated heavy lifting or other strenuous activity in addition to the wearing of heavy or bulky PPE may create back strain. Back strain may be avoided by:

- Training fire fighters in proper lifting techniques
- Ergonomically designing routine response tasks (such as carrying stretchers and pulling hoses)
- Use of PPE which provides back support
- Use of auxiliary back support belts

Controversy over the effectiveness of back supports continue with one group advocating their use and an opposing group indicating that they do little to prevent back strain.

Difficulty in Donning or Doffing PPE – Difficulty in putting on (donning), adjusting, using, or taking off (doffing) PPE can discourage fire fighters from properly wearing PPE or also extend vital response times. PPE should be selected so that workers can easy don, adjust, use, and doff PPE. Fire departments must ensure that fire fighters are properly trained in using PPE including its donning, adjustment, wearing, and doffing.

Increase in Worker Potential for Heat Stress – Owing to its highly protective qualities, the wearing of many types of fire service PPE causes physiological stress. This physiological stress is increased in hot and humid working environments. Heat stress hazards are described in detail within an earlier section.

Reduction of PPE Performance through Wear and Use. Even if appropriate PPE is selected, the ability for correctly used PPE to provide adequate protection is dependent on the continued protective performance of PPE over its intended service life and the ability to inspect and service PPE.

Poor Durability – Durability-related person-equipment hazards are avoided by carefully selecting PPE which maintains its performance properties throughout the period of intended use and from the proper care and maintenance of PPE. PPE should maintain sufficient performance properties during use period and for any successive period. PPE may be intended for multiple reuses, limited reuse, or be disposable after a single use. The life cycle of PPE is dependent on several factors including durability. Durability is demonstrated when PPE performance properties do not significantly decline following:

- Use or wearing
- Cleaning, decontamination, or sterilization
- Maintenance
- Storage

Limited Serviceability – Since most PPE is recognized to have finite service life, equipment service life can be extended by proper care and maintenance, or serviceability. The inability to properly service PPE can create a hazard; these hazards arise for reusable PPE when PPE cannot be adequately inspected, maintained or repaired. The inability to inspect PPE can also occur and create problems for the fire fighter or emergency responder. In some cases, decreases in PPE performance cannot be readily discerned by the wearer or end user organization. In other cases, the PPE may be designed so that inspections cannot be made (e.g., a liner material with the barrier material facing inside the garment which can only be examined if the inspector disassembles the PPE). PPE may be difficult to maintain or repair because proper instructions (readily understood and detailed) are not provided by the manufacturer or maintenance materials or repair supplies are not available for servicing PPE. PPE reservicing hazards are overcome by selecting PPE which is easily inspected, maintained, and repaired (or serviced).

Summary of Fire Service Hazards

A summary of fire service hazards described in this section is presented in Table 16.

Table 16. Summary of Emergency Scene Hazards

Hazard	Description
Physical Hazards	
Falling objects	Includes objects from heights or items being dropped by responder
Flying debris	Includes small solids (particulates) created by grinding or other causes
Projectile/ballistic	Includes fast moving small objectives (e.g., bullets, explosion fragments)
Abrasive/rough surfaces	Includes any rough surface (e.g., asphalt)
Sharp edges	Includes cut glass or metal or other cut hazards
Pointed objects	Includes nails or other puncture hazards
Slippery surfaces	Includes wet surface for walking or gripping
Excessive vibration	Includes repetitive, high frequency vibration
Environmental Hazards	
High heat/humidity	Includes ambient conditions where temperature exceeds 80^{o}F and/or 80% relative humidity
Ambient cold	Includes temperature below freezing
Wetness	Include any adverse wet weather condition such as rain, sleet, snow or water spray from hose use
High wind	Includes high winds associated with thunderstorms, tornados, hurricanes
Insufficient/bright light	Includes hazards related to responder able to see
Excessive noise	Include hazards from working environment preventing communication
Chemical Hazards	
Inhalation	Includes any airborne health hazard which can be breathed by responder
Skin absorption/contact	Includes contact with liquid chemicals/solid or skin toxic gas/vapor chemicals
Chemical (terror) agents	Includes exposure to chemical agents by terroism or by DOD release
Chemical ingestion/injection	Includes accidental ingestion or injection of chemicals
Liquefied gas contact	Includes exposure to liquefied or cryogenic gases
Chemical flashover	Includes flash fire caused by ignition of chemical vapor cloud
Chemical explosions	Includes explosions caused by reacting chemicals

Table 16. Summary of Emergency Scene Hazards *(continued)*

Biological Hazards	
Bloodborne pathogens	Includes contact with Hepatitis or HIV
Airborne pathogens	Includes any exposure to airborne pathogens such as tuberculosis
Biological toxins	Includes exposure to diseases from plants/animals (from bites)
Biological allergens	Includes exposure to natural substances producing allergic reactions (e.g., poison ivy)
Thermal Hazards	
High convective heat	Includes prolonged exposure (>10 minutes) to high air temperature (>200^{o}F)
Low radiant heat	Includes exposure to heat from radiant sources such as approaching fire (0.05 - 0.5 cal/cm^{2}sec)
High radiant heat	Includes exposures to high heat from radiant sources such as burning fuel or large fires (>0.5 cal/cm^{2}sec)
Flame impingement	Includes direct contact with flame from burning structures
Steam	Include exposure to steam during response
Hot liquids	Include exposure to hot water/other hot liquids at response
Molten metals	Includes exposure to metal objects which become molten at response
Hot solids	Includes exposure to any hot solids (e.g., burning embers) at response
Hot surfaces	Includes short contact (>10 seconds) to hot surfaces (>250^{o}F)
Electrical Hazards	
High voltage	Includes contact with high voltage lines such as from industrial facilities
Electrical arc flashover	Includes exposure to electrical arc created by transforms producing high heat in very short period of time (<1 second)
Static charge buildup	Includes self-generation of static electricity during movement or rubbing against surfaces
Radiation Hazards	
Ionizing radiation	Includes radiation associated with nuclear processes
Non-ionizing radiation	Includes radiation associated with infrared, ultraviolet, microwave, radio transmissions
Person-Position Hazards	
Daytime visibility	Includes ability to be seen during the daytime (especially around traffic)
Nighttime visibility	Includes ability to be seen during nighttime conditions
Falling	Includes falling off elevated surfaces or platforms
Drowning	Includes hazard of falling into water while being burdened

Table 16. Summary of Emergency Scene Hazards *(continued)*

Person-Position Hazards	
Daytime visibility	Includes ability to be seen during the daytime (especially around traffic)
Nighttime visibility	Includes ability to be seen during nighttime conditions
Falling	Includes falling off elevated surfaces or platforms
Drowning	Includes hazard of falling into water while being burdened
Person-Equipment Hazards	
Mat'l biocompatibility	Includes any reactions of skin from wearing of PPE (e.g., latex allergies)
Ease of contamination	Includes buildup of contamination which may occur from repeated responses
Thermal comfort	Includes thermal comfort and potential for heat stress while wearing PPE
Range of motion	Includes head, torso, arm, and leg movement as affected by wearing of PPE
Hand function	Includes impact of gloves on hand dexterity, tactility, and grip
Ankle/back support	Includes degree of support provided by footwear to ankle (for avoiding sprains) and support by other devices (clothing or belts) for back to avoid strain
Vision clarity	Includes ability of wearer to clearly see through visor or other PPE
Communications ease	Includes ability of PPE wearer to hear and to be heard
Fit (poor)	Includes degree of comfort as affected by relative fit of PPE
Ease of donning/doffing	Includes ease of wearing putting on or taking off PPE

CHAPTER 4 – FIRE SERVICE MISSION AREAS

Principal fire service missions include:

- Structural fire fighting
- Proximity fire fighting
- Wildland fire fighting
- Emergency medical services
- Hazardous materials responses
- Urban search and rescue

A relatively new concern, though not historically defined as its own mission is fire fighter response to incidents involving weapons of mass destruction.

The following sections of this chapter provide an overview of each mission area and in particular relate the missions to the types of protection that are needed for the safe accomplishment of tasks regarded as part of the mission area. For each mission area, the risks are assessed for the hazards identified in Chapter 3. Risks are classified as high, moderate, and low based on a review of the information provided and specific analyses conducted by some of the National Fire Protection Association (NFPA) committees that have conducted risk assessments for specific fire service missions.

Structural Fire Fighting

As defined in NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program* (1997 edition), structural fire fighting entails the activities of rescue, fire suppression, and property conservation in buildings, enclosed structures, aircraft interiors, vehicles, vessels, aircraft, or like properties that are involved in a fire or emergency situation.

Clearly the types of fire fighting environments and their hazards vary significantly with the individual emergency. The nature of fires has significantly changed over the last 50 years, particularly the greater use of synthetic materials in building construction. These factors coupled with a variety of ignition sources, combustible materials, and varying environmental conditions contribute to wide variety of specific fire ground conditions and related hazards. Fire departments across the United States have adopted standard operating procedures for conducting fire fighting operations which involve preassigned roles for most fire fighters at the fire scene.

Fireground Tasks. Most fireground operations involve multiple responsibilities among fire fighter personnel. In the typical fire department organization, fire fighters are assigned to engine companies and ladder or truck companies with different assigned tasks. In a normal fire, multiple apparatus are dispatched:

- The first arriving engine company to a structural fire will size up the situation to determine the size of the structure, the type of occupancy, smoke or fire conditions, and whether a working fire exists. If a working fire exists, the first engine company on scene will lay down a hose line.

- The second arriving engine companies are usually responsible for supplying water to the first engine and operating a back up line.

- The first arriving truck company in many departments provides search and rescue operations, ventilation, forcible entry, laddering, and opening of concealed spaces as coordinated by the incident commander.

- Other responding units may include a rapid intervention team for quick rescue, chiefs for further sizing up the incident and establishing an overall plan for handling the emergency, safety offers, and logistical and rehabilitation teams.

The size of the incident will dictate how many units respond as additional units may be added for larger emergencies. In general, a single incident commander will assume control for the incident through its completion. For structural fires, the incident will proceed to overhaul operations after the fire has been suppressed to ensure that all parts of the fire are extinguished.

Fire fighters at the emergency scene are generally all equipped with full personnel protective equipment, although the extent of the ensemble will depend on the specific fire fighter role and stage of the incident. In addition to PPE, fire fighters can be equipped with various tools, lights, radios, and various types of equipment.

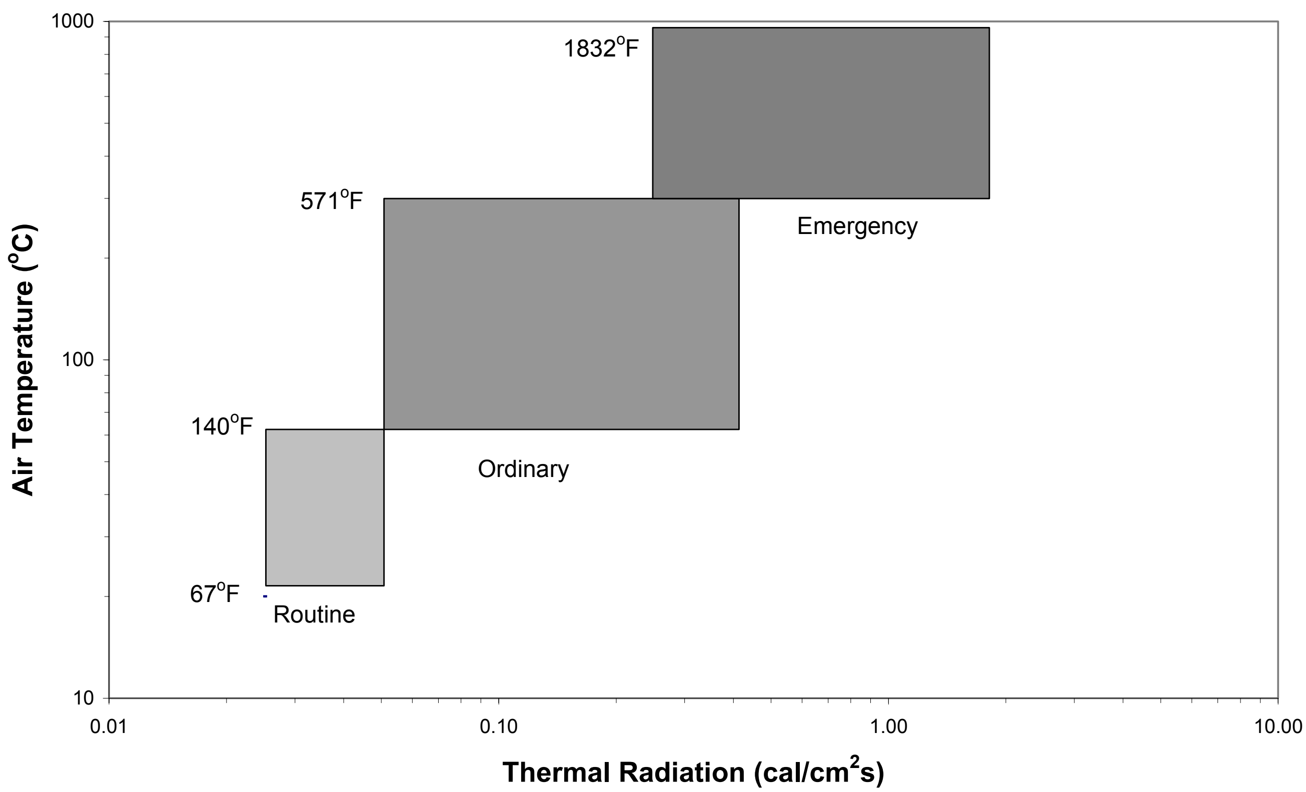
General Fireground Hazards. Undoubtedly, structural fire fighting involves a relatively complex set of different hazards. As the injury and fatality statistics described in Chapter 2 illustrate, the largest proportional number of fire fighter deaths and injuries occur during fire suppression activities. The primary hazards at the fire scene include:

- Immediately dangerous to life and health atmospheres
- Extreme heat and potential for flame contact (high radiant heat, flashovers)
- Exposure to steam or scalding water
- Contact with hot surfaces, solids, and molten metal
- Severe physical hazards created by the destruction of the structure (i.e., broken glass, falling debris)
- The possibility for disorientation and entrapment within the structure due to poor visibility, high heat, and stressful conditions
- Heat stress from high ambient heat and near encapsulating clothing

Several other hazards may also exist depending on the nature of the fire. These may include exposure to various chemicals at the scene based on the structure's contents, contamination with contaminated blood or body fluids during rescue, and contact with live electrical power lines. Fire fighters may also fall from heights or into the structure while performing roof ventilation, be hit by on coming traffic outside the structure, or sustain any number of strains and sprains given the rigorous physical activity required during fire ground operations.

Thermal Environments. In the previous chapter, a description was provided between the different forms of heat transfer. The relationship between increasing thermal radiation (expressed in calories per square centimeter per second or cal/cm^2s) and the resulting rise in air temperature (expressed in degrees Celsius and degrees Fahrenheit) is presented in Figure 17. Possible structural fire fighting situations are illustrated in this figure:

Figure 17. Range of Thermal Conditions Faced by Fire Fighters



- The ***Routine*** region describes conditions where one or two objects, such as a bed or waste basket, are burning in a room. The thermal radiation and the air temperatures are virtually the same as those encountered on a hot summer day. As shown in Figure 1, ***Routine*** conditions are accompanied by a thermal radiation range of 0.025 to 0.05 cal/cm^2 sec and by air temperatures ranging from 68^{o}F to 140^{o}F (20^{o}C to 60^{o}C). Protective clothing for fire fighters typically provides protection under these conditions, but excessively long exposure times may create a burn injury situation.

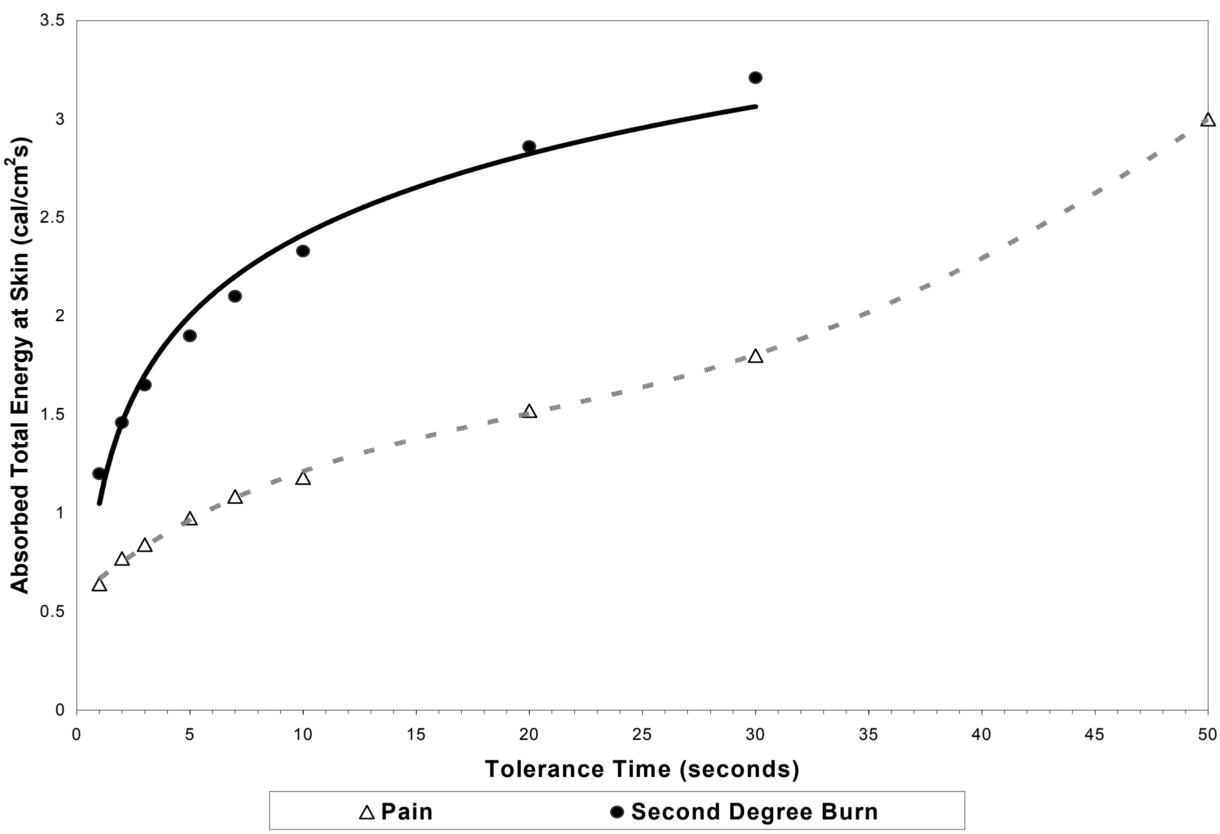
- The ***Ordinary*** region describes temperatures encountered in fighting a more serious fire or being next to a "flash-over" room. ***Ordinary*** conditions are defined by a thermal range of 0.05 to 0.6 cal/cm^2 sec, representing an air temperature range of 140^{o}F to 572^{o}F (60^{o}C to 300^{o}C). Under these conditions, protective clothing may allow sufficient time to extinguish the fire or to fight the fire until the nominal air supply is exhausted (usually less than 30 minutes).

The ***Emergency*** region describes conditions in a severe and unusual exposure, such as those caused inside a "flashed-over" room or next to a flame front. In ***Emergency*** conditions, the thermal load exceeds 0.6 cal/cm^{2}s and temperatures exceed 572^{o}F (300^{o}C). In such conditions, the function of firefighters' clothing and equipment is simply to provide the short time needed for an escape without serious injury.

Clearly, protective clothing and equipment must be able to withstand a wide variety of thermal extremes. Under greater thermal exposure intensities, the outer material of turnout clothing usually is the critical layer and will only protect for a limited time. Under greater exposure times, the thermal barrier becomes the more critical layer and will only protect for a limited time. The addition in moisture in the clothing will have a variety of effects depending on the amount, its location in the clothing, and the type of heat transfer that occurs.

Burn injuries are both time and temperature dependent. The higher the skin temperature, the shorter the time required to blister or burn. As skin temperatures exceed 131^{o}F (55^{o}C), the skin will begin to burn at any heat level. Further, prolonged or repeated high thermal exposures will gradually increase clothing temperatures. This can cause burns even after the fire fighter is no longer exposed to high ambient temperatures. In Figure 2, exposure to thermal radiation in cal/cm^{2}s is related to the time at which pain is felt on unprotected skin, or ***time-to-pain*** (tolerance time), and the time at which unprotected skin begins to blister, or ***time-to-second degree burn*** (blister time).

Figure 18. Human Skin Tolerance to Pain and 2nd Degree Burn Injury



An emergency condition exposure of 0.5 cal/cm^{2}s directly to bare skin results in pain after 1.4 seconds (tolerance time) and reversible injury or blistering of the skin after 3.4 seconds (blister time). If the exposure is raised to 1.0 cal/cm^{2}s, the time to 2nd degree burn is reduced to 1.3 seconds. Further destruction from such intense heat occurs rapidly thereafter because 50% of body tissue is within 1 inch of the body's surface.

An alternative thermal classification of structural fires was developed by the International Association of Fire Fighters (IAFF) under Project FIRES. As above, fires can be classified by their temperature and rate of heat output. In addition, each class of fire can be associated with a structural fire fighting situation and its expected average duration as listed below:

- ***Class I*** occurs in a room during overhaul. Environmental temperatures up to 100^{o}F (311^{o}C) and thermal radiation up to 0.05 watts/cm^2 (0.012 cal/cm^{2}s) are encountered for up to 30 minutes.

- ***Class II*** occurs when a small fire is burning in a room. In this case, environmental temperatures from 100^{o}F to 200^{o}F (311^{o}C to 367^{o}C) and thermal radiation from 0.050 to 0.100 watts/cm^2 (0.012 to 0.024 cal/cm^{2}s) are encountered up to 15 minutes.

- ***Class III*** exists in a room that is totally involved. Environmental temperatures from 200^{o}F to 500^{o}F (367^{o}C to 533^{o}C) and thermal radiation from 0.100 to 0.175 watts/cm^2 (0.024 to 0.042 cal/cm^{2}s) are encountered up to 5 minutes.

- ***Class IV*** occurs during a flashover or backdraft. Environmental temperatures from 500^{o}F to 1500^{o}F (533^{o}C to 816^{o}C) and thermal radiation from 0.175 to 4.2 watts/cm^2 (0.042 to 1.0 cal/cm^{2}s) are encountered up for approximately 10 seconds.

Both systems are useful for understanding the thermal hazards associated with structural fire fighting and have been used in some cases to justify the selection of test temperatures for evaluating fire fighter protective clothing.

Structural Fire Atmospheres and Hazardous Substance Exposures. The combustion of wood releases several combustion products into the atmosphere, principally carbon monoxide and other simple hydrocarbons. With the changes in building materials, the constituents of fire gases have changed considerably. Roofing, insulation, carpets, paints and other construction materials all contribute to an ever growing diversity of chemical products founds at fires. The increased use of plastics and other synthetic materials release different kinds of combustion products, many of them highly toxic or carcinogenic. Some examples of fire combustion products include:

- carbon monoxide and carbon dioxide;
- inorganic gases (hydrogen sulfide, hydrogen cyanide, nitrogen oxides)
- acid gases (hydrochloric acid, sulfuric acid, nitric acid);
- organic acids (formic acid, acetic acid);
- aldehydes;
- chlorinated compounds (carbon tetrachloride and vinyl chloride);
- hydrocarbons (benzene);
- polynuclear aromatic compounds (PANs); and

- metals (cadmium, chromium).

In addition, chemicals at the site of a fire further contribute to hazardous contaminants in fire smoke. A classic example are polychlorinated biphenyls (PCBs), found in electrical transformers and other equipment, which when burned may form dioxin, an acutely deadly substance. Even the normal household will contain cleaning supplies, pesticides, pool chlorine and other substances which contribute to release of toxic substances at fires. Table 17 lists some common fire smoke contaminants, the sources of these substances, and toxic effects from repeated or high concentration exposure to these chemical. Table 18 shows chemicals identified in an analysis of fire smoke for several different fires.

Contact of these chemicals with fire fighting clothing can both penetrate and permeate protective fabrics. Since most firefighter protective clothing uses porous fabrics, the chemical vapors or liquids simply penetrate or pass through the pores of the material. Molecules of chemicals can also permeate into the fibers or coatings of clothing materials and can remain in the material for long periods of time, depending on the types of exposure chemical(s) and care given to the clothing. Chemicals that get into the clothing from either means can directly contact the wearer's skin.

In addition to liquid or vapor chemical contaminants, a tremendous amount of ash, soot, and other solid matter are released during fires and fire fighting activities. This solid matter provides the visible portion of smoke and is the primary cause of residue left on structures and clothing following fires. Soot and ash represent incomplete products of combustion; that is, unburned fuel or agglomerated solids which fail to completely burn during the fire. During combustion, synthetic materials create an increase in the amount of particulate matter, hence the "black" smoke from burning plastics. Since soot particles are very porous, they tend to adsorb other hazardous chemicals. Ash, resins, and other particles from fire smoke can easily become entrapped within the fibers of clothing. Accumulation of soot on protective clothing becomes visible as soiled or "dirty" areas. In some cases, these "soils" are made of melted resins or plastics which, in the heat of the fire, become liquid and spread even further throughout the protective clothing. In other cases, many of the particles are too small to see (less than 10 microns) and can easily penetrate into the inner layers of clothing such as liner and barrier materials contacting the wearer's skin.

Firefighters may be exposed to other particulate hazards. Chemical dusts, lead particles, and asbestos may also be encountered at fires and other responses. For example, though asbestos is principally an inhalation hazard, asbestos can cling to the protective clothing and be released when the responder is not wearing his or her SCBA. Similarly, lead and other toxic dusts can fill clothing pores and contaminate the firefighter's skin after the incident.

Biological Exposures. An on going concern in emergency response is the potential exposure to blood or other body fluids containing pathogens, particularly the Human Immunodeficiency Virus (HIV) or AIDS virus, and Hepatitis B and C viruses. These viruses are extremely small in size and are transmitted by blood or other biological fluids. The risk is high since emergency patient care is major function of many structural fire responses. The extrication of victims from automobile accidents and rescue of injured persons from fires and other incidents all involve the potential for this exposure. Even minute droplets of blood are capable of carrying thousands of virus.

Table 17. Examples for Structural Fire Contaminants

Contaminant	Sources	Toxicology
Polychlorinated Biphenyl (PCBs)	Power transformers/capacitors Televisions Air conditions Carbonless copy paper Hydraulic systems Elevators	PCBs can produce dioxins which are toxic by inhalation and ingestion PCBs also absorb through the skin PCBs cause liver and pancreas
Asbestos	Roofing and shingles Acoustic ceiling tiles Sprayed ceilings Old pipe insulation Old octopus type furnaces Pre-1975 drywall	Principal hazard is inhalation of fibers (<5 microns length) causes cancer Asbestos fibers can be aerosolized from clothing and inspired or and ingested
Creosote	Power poles Railroad ties Treated wood or buildings Lumber yards Piers and docks	Creosotes is toxic through inhalation and skin absorption Causes cancer of skin, prostate, and testicles
Plastic Decomposition Products • Polycarbonates • Polystyrene • Polyurethane • PVC	Electrical insulation Plumbing Furniture Construction materials Insulation and packaging Tools/toys Automobiles	Variety of decomposition products including acrylonitrile, hydrogen cyanide, nitrogen oxides, hydrogen chloride, benzene Various routes of toxicity through skin absorptions, inhalation or ingestion

Table 18. Specific Chemical Contaminants Found in Various Fires

Compound	1(K)	1(K)	2(K)	3(O)	4(O)	5(K)	6(K)	6(O)
Furan	X			X				
C_4H_8 isomers	X		X					
Benzene	X	X	X	X	X	X	X	X
Dimethylfuran	X		X					
Methyl methacrylane	X						X	
Toluene	X	X	X				X	
Furfural	X		X					
Xylene	X		X			X		
Styrene	X		X				X	
Pinenes	X		X				X	
Limonene	X						X	
Indane	X		X			X	X	
Methylcyclopentane	X					X		
2,4-Dimethyl-1-pentene						X		
Ethyl benzene						X	X	
C_3-Alkyl benzene						X		
C_4-Alkyl benzene						X	X	
n-Butane							X	
FreonII							X	
t-Butyl anisole						X	X	
Methyl napthalene						X	X	

K-knockdown; O-overhaul

From: Jankovic, J., W. Jones, J. Burkhart, and G. Noonan, "Environmental Study of Firefighters," *Annals of Occupational Hygiene*, Vol. 35(6),1991, pp. 581-602.

Protective Clothing and Equipment Considerations. The protective ensemble worn by fire fighters for structural fires must account for wide range of hazards. This ensemble consists of garments, helmets, gloves, footwear, hoods, self-contained breathing apparatus (SCBA) and personal alert safety systems (PASS). The protection principles on which the ensemble is based include:

- Flame and heat resistance for nearly all components (some items are tested as whole product and individual components within those products may not pass separately)
- Some level of insulation provided by clothing articles, based on an emergency condition
- Minimum strength requirements for materials and assemblies
- Physical hazard protection, particularly to the head, hands, and feet
- Protection from electrical shock in the helmets and feet
- Overall moisture protection
- Some protection against fireground chemicals and bloodborne pathogens
- Use of visibility materials
- Sustained performance of SCBA and PASS following simulated various fireground conditions (particulates, moisture, temperature, shock, vibration, and flame/heat contact)

The marketplace for this protective clothing and equipment provides a large range of designs, materials, and options. However, little is done in the industry to provide for interfaces between elements of the ensemble and to assess the overall protection of the ensemble itself. While the offered clothing and equipment is substantially affected by available NFPA standards, a detailed discussion of these standards and their impact on the protective ensemble will be the subject of future task report.

Key issues for the use and care of structural fire fighting protective clothing are its durability and service life. The life cycle of most garments is considered to be at an average of 5 years or longer (this is contrast to earlier statistics that show a significant number of fire departments that have clothing that is greater than 10 years old). The ability of clothing and other ensemble items to maintain their performance features with use has come into question and has not been adequately addressed in the standards covering their certification. Therefore, the fire service is often left to judge the adequacy of their clothing based on experience that is often coupled with an inability to perform detailed inspections to assurance continued protective performance.

Proximity Fire Fighting

Specialized fire fighting operations can include the activities of rescue, fire suppression, and property conservation at incidents involving fires producing high levels of radiant heat as well as conductive and convective heat. Specialized thermal protection is necessary for persons involved in such operations due to the scope of these operations and the close distance to the fire at which these operations are conducted, although direct entry into flame is not made. These operations usually are exterior operations but might be combined with interior operations. Proximity fire fighting is not structural fire fighting but might be combined with structural fire fighting operations. Proximity fire fighting also is not entry fire fighting. Examples of proximity fire fighting include fire fighting activities involving aircraft and bulk flammable fuels.

In the United States, proximity protective clothing has evolved from structural fire fighting protective clothing and provides several similarities in design and materials with three key exceptions:

- Proximity protective clothing using an aluminized, reflective outer shell material.
- A hood or shroud is used with the helmet for protecting the face area; the hood visor is a reflective polymer surface.
- Visibility materials are not used on the exterior of the clothing.

For the most part, specialized departments are equipped with proximity protective clothing and may or may not have structural fire fighting protective clothing ensembles depending on the fire tactics used by the department. For example, many military stations use proximity protective clothing for flightline fire fighting and fire suppression aboard ships. On the other hand, it is rare for most municipal fire departments to have proximity fire fighting ensembles except at airport stations or those with specific fire fighting responsibilities for large fuel facilities.

Wildland Fire Fighting

As defined by NFPA, wildland fire fighting involves the activities of fire suppression and property conservation in woodlands, forests, grasslands, brush, prairies, and other such vegetation, or any combination of vegetation, that is involved in a fire situation but is not within buildings or structures. Many fire departments also get involved in the wildland/urban interface. The wildland/urban interface defines line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels [from NFPA 295, *Standard for Wildfire Control*, 1998 edition].

Wildland fire fighters generally operate for long durations (8 - 16 hours/day) exposed to a general radiant heat flux between 1 kW/m^2 to 8 kW/m^2. During increased fire activities and shorter durations of exposures, wildland fire fighters may be exposed to a radiant heat flux of 8 kW/m^2 to 20 kW/m^2. During extreme fire activity and fire over-run or entrapment conditions wildland fire fighters may be exposed to radiant heat flux conditions of 20 kW/m^2 to 100 kW/m^2.

Temperatures can range from an ambient air temperature 25^{o}C - 49^{o}C up to 1200^{o}C in severe fire over-run or entrapment conditions. During extreme fire activity involving fire overrun conditions, no fire fighters Personal Protective Equipment (PPE) can prevent serious to life threatening injuries. As such firefighters PPE should be designed to minimize the risk of injury during wildland fire fighting operations with short term exposure to increased radiant heat flux levels.

Wildland Conditions. As a general guide, wildland fire fighting conditions are based but not limited to the following factors:

- Fine fuel loads
- Fire danger index
- Slope
- Drought factor

- Air temperature
- Relative humidity
- Wind speed
- Fuel size

With the main fuel component of the moving fire front will be fine fuels, mostly made up by cured grass, fallen leaves, needles and small twigs. It is primarily the top layer of fine fuel that contributes to the forward spread of a fire and the high flames of the fire front. It is assumed that the flame front (which contribute most to the radiation output of the fire front) will be a result of the rapid combustion of fine fuels, and therefore will have a residence time which varies from 5 – 12 seconds (grass fires) to 1.5 – minutes for logging slash fires with general wildland fires being in between these times. The length of fires at urban/wildland interfaces is less predictable since the property content of these areas can vary substantially.

Large downed woody material (>6 mm) will not be consumed in the passage of the fire front but instead will be consumed after the fire has passed (ongoing or smoldering stage). The combustion of this material will contribute to the background heat released and will depend upon the amount of the material available to burn and its moisture content.

Fire Danger Index (FDI) and Fire Behavior. The FDI encompasses those variables that affect fire danger and difficulty of suppression. The index goes from 1 (fires will not burn, or burn so slowly that control presents little difficulty) to 100 (fires will burn so fast and hot that control is virtually impossible). The rate of forward spread of the fire is directly related to the FDI and the amount of fine fuel available to burn.

Table 19. Example of a Forest Fire Behavior Model (FDI)

Fuel Quantity (T/h)	Fire Behavior	Fire Danger Index									
		10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	R (km/h)	0.06	0.12	0.17	0.23	0.28	0.34	0.39	0.45	0.50	0.56
	H (m)	0.6	1.5	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	I (kW/m)	150	300	425	575	700	850	975	1125	1250	1400
10	R (km/h)	0.12	0.23	0.34	0.45	0.56	0.67	0.78	0.89	1.00	1.11
	H (m)	2.0	4.0	5.5	7.0	8.5	10.0	11.0	12.0	13.0	14.0
	I (kW/m)	600	1150	1700	2250	2800	3350	3900	4450	5000	5550
15	R (km/h)	0.18	0.35	0.51	0.68	0.85	1.02	1.18	1.35	1.52	1.68
	H (m)	3.5	7.0	9.5	12.0	14.0	14.9	16.9	19.1	21.4	23.4
	I (kW/m)	1350	2625	3825	5100	6375	7650	8850	10125	11400	12600
20	R (km/h)	0.24	0.48	0.72	0.96	1.20	1.44	1.68	1.82	2.16	2.39
	H (m)	5.0	9.0	13.0	15.3	18.4	21.5	24.6	26.5	30.9	33.9
	I (kW/m)	2400	4800	7200	9600	12000	14400	16800	18200	21600	23900
25	R (km/h)	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00
	H (m)	7.0	12.0	15.7	19.6	23.5	27.4	31.3	35.2	39.1	43.0
	I (kW/m)	3750	7500	11250	15000	18750	22500	26250	30000	33750	37500

R = Rate of spread of fire in km/hr; H = Flame height in m; I = Intensity of fire in kW/m

Clothing Conditions. In order to provide the correct blend of protection against heat and flame and metabolic heat and heat stress, wildland fire fighters protective clothing should therefore:

- Permit free evaporation of sweat and be loose fitting, light, well-ventilated and permeable to water vapor.
- Shield firefighters from radiant heat
- Completely dissipate metabolic heat
- Allow free evaporation of 1 to 2 liters of perspiration per hour
- Sustained thermal equilibrium and comfort despite wide variation in fire intensity, weather, work integrity and duration
- Minimize the risk of burn injuries
- Minimize episodes of heat exhaustion

Respiratory Conditions. The components of wildland fire smoke are generally made up of:

- Respirable particulates (majority at 0.1µm, decreasing in number up to 3.5µm diameters)
- Carbon monoxide
- Carbon dioxide
- Benzene
- Formaldehyde
- Acrolein

The relationship of the concentration of these components to the health and safety of wildland fire fighters is still being researched and there are no agreed maximum permissible exposure values set for wildland firefighters (with the exception of respirable particulate which is primarily 0.1µm up to 3.5µm) that relate to wildland fire fighting. Once these values are defined, respiratory protection systems may have to be re-evaluated.

The presence of genetically modified products and the presence of pest control sprays or other additives etc to assist disease control or growth (off gassing during combustion) has been highlighted as an issue that may need to be further investigated. As the temperature reached cannot always be controlled, the ability of wildland fires to produce other combustion and offgasing products which are unknown at this stage.

Over-Run or Entrapment Conditions. Wildland fire over-run or entrapments can occur and should be considered as any risk assessment. Generally good resource management and training practices, minimizes the risk of fire over-run or entrapments occurring, however several such events have occurred. As wildland firefighters wear primarily single layer garments, protection to minimize the risk of burn injury is generally set at a maximum of 4-6 seconds of direct flame contact.

Wildland fire over-run or entrapment is an incident in which a fire fighter may be caught in a temporary escalation in severe to extreme fire behavior. The fire fighter is usually unable to retreat and becomes engulfed by flames. This entrapment can occur when fire fighters are on foot or in a vehicle. Table 20 provides examples for three different entrapment events.

Table 20. Examples of Recorded Fire Entrapment Events

Temp (^oC)	Relative Humidity (%)	Avg. Wind Speed (km/h)	Fuel type	Years since burnt	Fuel load (tons/ha)	Slope (^{o})	FDI
41	13	35	Heath/open Woodland	15	16.5	15-25	68 Extreme
30	27	10	Low forest	Long	14	15-20	18 High
28	24	44	Tall forest 20m+	long	15	6	22 High

From these three examples in Table 20, it can be seen that very high to extreme fire danger is not needed for a over-run or entrapment situation to occur. As an example, the low forest fire was extinguished by rain minutes after the burn-over. The combination of unexpected or under-appreciated fire behavior with long unburned fuels on slopes can quickly result in a fire fighter being caught unaware and in the path of a fire front.

Wildland/Urban Interface. The wildland/urban interface can be described as an area where various structures (most notably private homes) and other human developments meet or are intermingled with forest and other vegetative fuel types. Wildland fire fighters PPE can be used in a defensive role in these cases but fire fighters may need to upgrade their PPE when firefighters become involved in offensive property firefighting.

Summary of Important Factors. Wildland fire fighting PPE needs to provide a compromise between flame, elevated temperature exposures while at the same time allowing the wildland fire fighter the ability to work for extended durations by minimizing the buildup of metabolic heat and heat stress as well as ensure the PPE is durable to meet the conditions and terrain.

Many other wildland fire factors may play a role in a wildland fire environment that may pose a risk that a fire fighter may face therefore wildland firefighters need to understand the limitations of their PPE and the protection that it will provide.

Emergency Medical Services

Medical aid is increasing becoming the dominant role within fire departments. While difference classifications are used throughout the country, the following general definitions are accepted in the fire service:

- *Advanced Life Support.* Functional provision of advanced airway management, including intubation, advanced cardiac monitoring, manual defibrillation, establishment and maintenance of intravenous access, and drug therapy.

- *Basic Life Support.* Functional provision of patient assessment, including basic airway management; oxygen therapy; stabilization of spinal, musculo-skeletal, soft tissue, and shock injuries; stabilization of bleeding; and stabilization and intervention for sudden illness, poisoning and heat/cold injuries, childbirth, CPR, and automatic external defibrillator (AED) capability.

- *Emergency Medical Care.* The provision of treatment to patients, including first aid, cardiopulmonary resuscitation (CPR), basic life support (EMT level), advanced life support (Paramedic level), and other medical procedures that occur prior to arrival at a hospital or other health care facility. [from NFPA 1581, *Standard on Fire Department Infection Control Program*, 2000 edition] In this report, reference is made to "EMS" or "emergency medical service," which is the service of providing emergency medical care.

- *First Responder (EMS).* Functional provision of initial assessment (i.e., airway, breathing, and circulatory systems) and basic first-aid intervention, including CPR and automatic external defibrillator (AED) capability.

General Hazards. The physical environment for EMS is considerably different than fire fighting operations and is characterized by the following features:

- EMS personnel are more likely to come in contact with the public.
- The principal hazards include exposure to diseases and contaminated blood and body fluids.
- A number of physical hazards may still be present at the emergency scene, but generally these will be moderate, except at vehicle or transportation accidents.
- Visibility hazards increase as many EMS incidents occur along roadways.
- The potential for thermal, chemical, and electrical hazards is significantly reduced.

Protective Clothing and Equipment Use. The protection strategy for most EMS responders is based on infection control (defined in NFPA 1581). The application of universal precautions dictates that EMS personnel treat all body fluids as potentially contaminated. In terms of protective clothing, the following practices are generally followed:

- Examination gloves are used for nearly all incidents, regardless of the presence of blood or body fluids.
- Splash resistant eyewear, primarily surgical style masks and goggles, are used for incidents involving any potential contact with blood or body fluids.
- Fluid-resistant clothing is used when large quantities of blood or body fluid are expected at the incident such as in the case of vehicle accidents and childbirth.
- Cleaning gloves are used for operations involving disinfection of equipment following an incident.

While all gloves are considered disposable, departments vary in their preference for disposable or reusable clothing. Levels of compliance with national standards generally are considered to be low.

Given the increased incidence of tuberculosis in some cities and the recent epidemic of sudden acquired respiratory syndrome (SARS), respirator use among EMS first responders has increased. The specified use of respirators has created some confusion. Original recommendations were based on the older classification of facepieces with HEPA filters, whereas the newer classifications dictate the use of at least N95 particular filtering facepieces. Most current practices are based CDC guidelines but the fire service has been slow to respond with revised respiratory protection practices.

Hazardous Materials Responses

Hazardous materials emergencies are incidents involving the release or potential release of hazardous materials into the environment that can cause loss of life, injury of personnel, or damage to property and the environment. Hazardous materials can span a wide variety of substances and hazards. NFPA defines hazardous materials as substances that present an unusual danger to persons due to properties of:

- Toxicity,
- Chemical reactivity, or decomposition,
- Corrosivity,
- Explosion or detonation,
- Etiological hazards or similar properties.

While many organizations consider chemical substances as primary form of hazardous materials, other dangerous substance including radioactive materials must also be considered.

Protective Clothing Considerations. In hazardous chemical environments the need for personal protective clothing and equipment may not be obvious. Many chemicals pose unseen hazards and offer no warning. For example, the very smallest dusts and droplets of chemicals that can reach the deepest part of the lungs, possibly doing the greatest damage. Many local, state, or federal regulations require some form of protective equipment for emergency responders for protection against hazardous chemicals. Additionally, it is in the responder's best interests to use adequate protection in order to limit personal liability for claims due to chemical exposure and to support any efforts to gain workers' compensation benefits.

Unfortunately, fire fighters and other emergency responders are faced with a myriad of choices for protective clothing and equipment. In many cases, fire fighters rely on their normal exposure. Structural fire fighting clothing and equipment should not be used for hazardous material incidents. Even when certified to the appropriate National Fire Protection Association (NFPA) standards, structural fire fighting clothing provides little or no protection against hazardous chemicals. Structural fire fighter clothing materials are likely easily permeated or penetrated by most hazardous chemicals and may actually absorb chemical liquids or vapors, increasing the likelihood of serious exposure. Only chemical protective clothing which provides appropriate designs and acceptable performance for the fire service missions should be used.

Chemical protective clothing is available to fire fighters in several types and materials. Different ways exist to classify this clothing:

- By design,
- By performance, and
- By service life.

Categorizing clothing design is mainly a means for describing what areas of the body, the clothing items is intended to protect. Fire fighters in chemical emergency response typically require full body ensembles consisting of suits, gloves, boots, and self contained breathing apparatus. Classification by performance differentiates the type of protection provided by the garment. Based on the states of matter, there are 3 levels of performance classes defined – vapor, liquid (splash), and solid (particulate) protection. This represents a hierarchy in protection since vapor protective clothing also provides liquid and solid (particulate) protection. Most hazardous material response teams use vapor and liquid protective suit ensembles, although there is a growing need for particulate protective garments in may remedial applications. Clothing item service life is in practice a decision made by the end user depending on the costs and risks associated with clothing decontamination and reuse. Fire service use is split between disposable (limited use) and reusable protective clothing. Generally those departments more concerned about clothing contamination use disposable protective suits. Every article of clothing can be classified using this system.

Ensemble Selection and Use. Chemical protective clothing must be worn whenever the emergency response personnel faces potential hazards arising from chemical exposure. The applicable Federal regulations (OSHA 29 CFR 1910.120) specify that selection of clothing material and suit type (vapor protective of splash protective) is based on the hazards identified. The specific cited system is known as the EPA levels of protection. The four established levels shown in Table 21 define the specific ensemble, but do not qualify the performance of the ensemble elements, particularly clothing items.

Most hazardous materials response teams select full body protection which is resistant to a broad range of chemicals. In many cases, totally encapsulating or vapor protective suits are initially used. As more information becomes available, teams downgrade to lower levels of protection. Also, the level of work to be done often affects the type of protective clothing and equipment necessary. This includes a variety of situations:

- Site Survey – the initial investigation of a hazardous materials incident. These situations are usually characterized by a large degree of uncertainty and mandate the highest levels of protection.

- Rescue – entering a hazardous materials area for the purpose of removing an exposure victim. Special considerations must be given as to how the selected chemical protective clothing may affect the ability of the wearer to carry out rescue and how it may increase contamination of the victim. The protection of the responder should not be compromised, so it may be necessary to modify rescue tactics.

- Hazard Control – entering a hazardous materials area to prevent a potential spill or leak or to reduce the dangers from an existing hazard. Protective clothing and equipment must accommodate the required tasks without sacrificing adequate protection.

- Emergency Monitoring – outfitting personnel in chemical protective clothing for the primary purpose of observing a hazardous materials incident without entry into the spill site. This may be applied to monitoring contract activity for spill clean up.

- Decontamination – applying decontamination procedures to personnel or equipment leaving the site. Decontamination personnel should wear the same level of protective clothing as entry team members or, in some cases, one level lower.

Table 21. Levels of Protection Specified in OSHA 29 CFR 1910.120

Level	Equipment	Protection Provided	Should Be Used When	Limiting Criteria
A	RECOMMENDED: • Pressure-demand, full-facepiece SCBA or pressure-demand SAR with escape SCBA. • Fully-encapsulating, chemical resistant suit. • Inner chemical-resistant gloves. • Chemical-resistant safety boot/shoes. • Two-way radio communications. OPTIONAL: • Cooling unit. • Coveralls. • Long cotton underwear. • Hard hat. • Disposable gloves and boot covers.	The highest available level of respiratory, skin, and eye protection.	• The chemical substance has been identified and requires the highest level of protection for skin, eyes, and the respiratory system based on either: – measured (or potential for) high concentration of atmo-spheric vapors, gases, or particulates; or – site operations and work functions involving a high potential for splash, immersion, or exposure to unexpected vapors, gases, or particulates of materials that are harmful to skin or capable of being absorbed through intact skin. • Substances with a high degree of hazard to the skin are known or suspected to be present, and skin contact is possible. • Operations must be conducted in confined, poorly ventilated areas until the absence of conditions requiring Level A protection is determined.	Fully-encapsulating suit material must be compatible with the substances involved.

Table 21. EPA Levels of Protection Specified in OSHA 29 CFR 1910.120 *(continued)*

Level	Equipment	Protection Provided	Should Be Used When	Limiting Criteria
B	RECOMMENDED: • Pressure-demand, full-facepiece SCBA or pressure-demand SAR with escape SCBA. • Chemical resistant clothing (overalls and long-sleeved jacket; hooded, one- or two-piece chemical splash suit; disposable chemical-resistant one-piece suit). • Inner and outer chemical-resistant gloves. • Chemical-resistant safety boot/shoes. • Hard hat. • Two-way radio communications. OPTIONAL: • Coveralls. • Disposable boot covers. • Face shield. • Long cotton underwear.	The same level of respiratory protection but less skin protection than Level A. It is the minimum level recommended for initial site entries until the hazards have been further identified.	• The type and atmospheric concentration of substances have been identified and require a high level of respiratory protection, but less skin protection. This involves atmospheres: – with IDLH concentrations of specific substances that do not represent a severe skin hazard; or – that do not meet the criteria for use of air-purifying respirators. • Atmosphere contains less than 19.5 percent oxygen. • Presence of incompletely identified vapors or gases is indicated by direct-reading organic vapor detection instrument, but vapors and gases are not suspected of containing high levels of chemicals harmful to skin or capable of being absorbed through intact skin.	• Use only when the vapor or gases present are not suspected of containing high concentrations of chemical that are harmful to skin or capable of being absorbed through intact skin. • Use only when it is highly unlikely that the work being done will generate either high concentrations of vapors, gases, or particulates, or splashes material that will affect exposed skin.
C	RECOMMENDED: • Full-facepiece, air-purifying canister-equipped respirator. • Chemical resistant clothing (overalls and long-sleeved jacket;	The same level of skin protection as Level B, but a lower level of respiratory protection.	• The atmospheric contaminants, liquid splashes, or other direct contact will not adversely affect any exposed skin.	• Atmospheric concentration of chemicals must not exceed IDLH levels.

Table 21. Levels of Protection Specified in OSHA 29 CFR 1910.120 *(continued)*

Level	Equipment	Protection Provided	Should Be Used When	Limiting Criteria
C (cont.)	RECOMMENDED: • hooded, one- or two-piece chemical splash suit; disposable chemical-resistant one-piece suit). • Inner and outer chemical-resistant gloves. • Chemical-resistant safety boot/shoes. • Hard hat. • Two-way radio communications. OPTIONAL: • Coveralls. • Disposable boot covers. • Face shield. • Escape mask • Long cotton underwear.	**See above**	• The types of air contaminants have been identified, concentrations have been measured, and a canister is available that can remove the contaminant. All criteria for the use of air-purifying respirators are met.	• The atmosphere must contain at least 19.5 percent oxygen.
D	RECOMMENDED: • Coveralls. • Safety boots/shoes. • Safety glasses or chemical splash goggles. • Hard hat. OPTIONAL: • Gloves. • Escape mask. • Face shield.	No respiratory protection. Minimal skin protection.	• The atmosphere contains no known hazard. • Work functions preclude splashes, immersion, or the potential for unexpected inhalation of or contact with hazardous levels of any chemicals.	• This level should not be worn in the Exclusion Zone. • The atmosphere must contain at least 19.5 percent oxygen.

Other Factors. In addition to chemical hazards, fire fighter protective clothing must protect against a number of other hazards found in hazardous chemical operations. Among these are:

- Physical hazards posed by the incident environment (resistance to cuts, tears, punctures, etc)
- Reductions in mobility, dexterity, or tactility making response tasks difficult to perform; and
- Heat stress from the physiological effect of wearing chemical protective clothing.

Since the nature of providing chemical protection is complex, comprehensive performance standards help to ease protective clothing selection decisions. Nevertheless, despite their existence for the past 12 years, compliance with industry standards, especially for lower levels of clothing, remains low. Some of the issues affecting the level of compliance include the available of cheap, but ergonomically deficient products, concerns about decontamination effectiveness, and the tendency for emphasizing barrier performance over human factors.

Urban Search and Rescue

While ancient in its application, urban search and rescue is a relatively new title for a field of specialization within the fire service. It is sometimes known as heavy or technical rescue, and is principally undertaken by municipal or county fire departments, although several private organizations exist. Urban search and rescue typically applies to events where people have been trapped or are in perilous situations other than through fire or chemical exposure.

NFPA defines technical rescue as "The application of special knowledge, skills, and equipment to safely resolve unique and/or complex rescue situations."[3] The NFPA further distinguishes "urban search and rescue incidents" as complex rescue incidents requiring specially trained personnel and special equipment to complete the mission involving the activities of victim search, rescue, body recovery, and site stabilization during operations, including but not limited to building/structural collapse, vehicle/person extrication, confined space entry, trench/cave-in rescue, and rope rescue. Technical rescue incidents in a non-urban or wilderness environment under normal conditions would not be included in this definition.

Types of Hazards. As with other emergency response activities, urban search and rescue entails its own set of different threats to the emergency responder including:

- Physical hazards (metal and masonry debris, working around heavy equipment, floating and submerged debris);
- Thermal hazards (exposure to cold water, heat stress);
- Flame and heat hazards (fire, chemical flash fire, electrical shock);
- Chemical hazards (broken gas lines, open containers of solvents);
- Biological hazards (direct exposure to bacteria contaminated water, involvement in emergency medical services; contact with victims having infectious diseases).

The degree of hazard varies with the mission and the type of activity to be performed.

[3] from NFPA 1670, *Standard on Operations and Training for Technical Rescue Incidents*, 1999 edition.

Types of Missions. Examples of urban search and rescue missions are:

- Building/structural collapse
- Vehicle/person extraction
- Confined space entry
- Trench/cave-in rescue
- Search operations (air, water, torrential)
- High angle rescue
- Swift or still water rescue
- Contaminated water diving

The first five missions entail what is generally known as technical rescue. Each of these missions potentially entails rugged physical environments and numerous hazards to the emergency responder. Typically, the emergency responder requires a high level of mobility and only limited protection against flame, heat, chemicals, or biological contaminants.

Structural or ***building collapse,*** often associated with earthquakes or bombings, can happen due to a variety of causes or during construction. The environment present during these situations contains assorted debris. Primary hazards to the responder are physical in nature and include abrasions, cuts, tears, and punctures. Nevertheless, in some incidents possible rupture of gas lines or exposure to chemicals can pose additional hazards. And as with all rescues, emergency responder exposure to victim's blood may be possible. On a lesser scale, these represent the same hazards associated with extraction of victims from ***vehicle accidents.*** This includes accidents involving not only automobiles, but trains and aircraft as well.

Confined space entry imposes to its own unique environments. Many confined space rescues are associated with chemical incidents, and, as a consequence, may involve exposure to oxygen deficient or flammable atmospheres. The biggest constraint in these rescues is the limited space which restricts wearer movement and makes rescue operations difficult. These same conditions occur in ***high angle rescue.*** High angle rescue refers to rescues involving ladder trucks that require the fire fighter to enter a building through windows or on roof-tops. ***Trench cave-ins*** offer similar circumstances to both high angle and confined space entry, but generally do not involve chemical or fire hazards.

Search operations encompass a variety of environmental settings. Though not common in a urban setting, search can be associated with major disasters such as earthquakes, hurricanes, and floods. Many times, it can involve transport of injured persons from locations near a city, such as mountain peaks. Some of these operations involve emergency responders traveling by foot, on boats, or in air craft, particularly helicopters.

For these missions, it is imperative that the clothing be designed for long wear times and resistance to physical hazards.

Flooding imposes a unique set of circumstances on the emergency responder. The greatest hazards are associated with ***swift water rescue,*** including:

- Significant water pressure (flood forces);
- Physical hazards through contact with debris;
- Contamination from sewage or chemicals; and
- Hypothermia.

At 3 miles per hour, current exerts a pressure of about 17 pounds per square inch against the legs of a person standing in its path. Doubling the water speed increases the water pressure to 68 psi. When this water is directed through flood control channels, where there are no obstructions or eddies to aid victims caught in flooding water, the potential for drowning is significant. Flood water carries significant amounts of debris which can puncture, tear, rip, and entangle flood victims. Sediment at the bottom of flood waters can impede rescue efforts. Flood water is likely to carry chemicals and other forms of contamination, especially sewage. Lastly, cold temperature exposure can cause hypothermia in both victim or rescuer if not adequately protected.

An extremely hazardous type of urban search and rescue mission is ***contaminated water diving.*** Fire departments and other emergency groups are increasingly called upon to perform a variety of functions underwater. These tasks include body recovery, evidence recovery, and recovery of submerged vehicles. In cold weather areas, due to the phenomenon known as the "diving reflex" or "cold reflex," the potential exits for actual rescues to occur, even after the victim has been submerged for a prolonged period of time. This "diving reflex" phenomenon refers to a bodily response analogous to hibernation in which the metabolism slows to protect the heart and brain. Some victims have fully recovered after such situations.

Diving in contaminated or cold water can involve severe hazards. Many bodies of water are polluted with chemical or biological wastes. Chemicals may sink, mix, float or evaporate when released into the waterways. These chemicals can be corrosive or toxic but may not produce any outward/visible effects. Some poisons can take years to produce symptoms. While many chemicals are diluted, chemicals that sink or float may be encountered at concentrated levels. Stagnant drainage ditches may contain accumulated levels of pesticides from runoff in agricultural areas. More common are biological hazards, primarily in the form of harmful bacteria, protozoans and virus from the dumping of raw sewage. These contaminants can cause disorders ranging from swimmer's ear to diarrhea, and in the worst cases can be fatal.

The principal hazards in contaminated water diving are exposures to chemical or biological agents. But other hazards exist as well, because diving can be performed in low and high temperature water. A number of physical hazards may be involved. If dive suits tear or puncture, the wearers risk chemical/biological exposure. Divers may become entangled and trapped. Particularly when supplied air is used, the diver's air supply may be vulnerable to the same hazards as the protective clothing that he or she is wearing. Adequate buoyancy must be provided so that diver mobility is not affected. Zero visibility may exist. Effective communications and non-interruption of the air supply are essential. In no other urban search and rescue mission is the emergency responder so dependent on the performance of his or her protective clothing.

Incidents Involving Weapons of Mass Destruction

International terrorism has been a global issue and threat for many years. These events, for the most part, have occurred in other countries. Recently, two terrorist acts in the United States—the World Trade Center and Oklahoma City Federal Building bombings—have heightened awareness of this threat within our borders. Terrorist acts may be carried out by either groups or individuals but the patterns of terrorism are rapidly changing. Emerging alliances of extremist and radical elements transcend the customary national, political, religious, and ethnic boundaries that formerly marked these activities. The frequency of terrorist attacks fluctuates annually, and, for a while, the number of incidents seemed to decrease. However, even as the number of incidents in a year has dwindled, there has been an unsettling trend toward ever increasing viciousness in the nature of the attacks and the resultant loss of human life and property damage. The use of a deadly chemical agent by an extremist group in Japan has illustrated the likelihood of future attacks involving weapons of mass destruction. That particular event with its release in the Tokyo subway resulted in over 5000 casualties that included emergency responders as many of the more seriously injured.

Chemical Agents. Today, the most common chemical agents are those chemicals expressly selected and produced because of their ability to cause injury or incapacitation. Chemical warfare agents are generally classified into broad categories based on their intended use.

- Lethal agents
- Incapacitating agents
- Harassing agents

Another more recognizable categorization based on physiologic effects includes nerve agents, blister agents, blood agents, choking agents, and irritating agents.

Nerve Agents **–** Nerve agents are specific organophosphorus compounds that are considered to be the most dangerous of the chemical warfare agents. Common nerve agents include those agents that are designated GA (Tabun), GB (Sarin), GD (Soman), and VX (V-agent). Nerve agents are liquids at ambient conditions. They are clear, colorless, and tasteless. The G-agents are reported to have a slightly fruity odor; the V-agents are said to be odorless. Although GA, GB, and GD are all volatile compounds, GB is the most volatile. All of these agents present a vapor hazard under temperate conditions. VX is oily with little volatility; however, a large surface area or widely dispersed droplets can, especially under high temperature conditions, present a vapor hazard. All nerve agents penetrate the skin rapidly and well. Inhalation of vapors or aerosols is especially dangerous. Exposure to these agents causes a disruption of nerve impulse transmissions by reacting with the enzyme acetylcholinesterase. Exposure to even minute quantities may be rapidly fatal. Symptoms of exposure may occur within minutes or hours, depending on the dose and mode of entry into the body.

Blister Agents – Blister agents are heavy oily liquids. In the pure state, they are colorless and nearly odorless, but in the impure state they are dark-colored and have an odor strongly suggesting mustard, onion, or garlic. Blister agents cause severe burns to the skin, eyes, and tissue in the respiratory tract. In addition, if a large area of skin is involved, significant amounts of agent can be absorbed into the bloodstream and cause severe systemic poisoning. These agents have a very high propensity for penetration and easily penetrate layers of clothing before being quickly absorbed through the skin. Mustard, mustard derivatives, and Lewsite are the most common blister agents.

Blood Agents – Blood agents produce casualties by interfering with the blood's ability to transfer oxygen to the cells, which can lead to death by asphyxiation. Signs and symptoms of blood agent poisoning include rapid death if exposed to high concentrations. Small concentrations cause respiratory distress, vomiting, diarrhea, vertigo, and headache. Large numbers of casualties displaying these common symptoms and reports of peach blossom or bitter almond odors indicate a possible blood agent release. Blood agents are liquids under pressure. Most blood agents are derivatives of cyanide compounds, such as cyanogens chloride and hydrogen cyanide.

Choking Agents – Choking agents produce casualties by severely stressing respiratory system tissues. This distress produces copious fluids, which can result in death by asphyxiation. Signs and symptoms that choking agents were released include severe irritation of the respiratory tract and eyes, as well as coughing and choking. Reports of a strong, irritating chemical odor would be characteristic. Most people recognize chlorine, and phosgene has an odor like newly cut hay. These agents are liquid when stored under pressure.

Irritating Agents - Irritating agents are also known as riot control agents or tear gas. They cause respiratory distress and copious tearing that incapacitates a victim. These agents are generally non-lethal, but under certain conditions they can act as an asphyxiant. Another common compound that produces effects similar to tear gas is pepper spray. The active ingredient in pepper spray is capsicum, a natural organic compound extracted from hot peppers. The frequency of incidents involving these agents appears to be on the increase, as many individuals use these devices for their personal defense.

Toxic Industrial Chemicals – Many common hazardous materials used in industry pose the same threat to emergency responders as the chemicals used and classified by the military as nerve, blister, blood, and choking agents. Due to easier availability in large quantities, many consider toxic industrial chemicals to be a more likely weapon used in terrorism. Examples of toxic industrial chemicals include:

- Acrolein
- Acrylonitrile
- Ammonia
- Boron tribromide
- Chloroacetonitrile
- Dimethyl sulfate
- Ethylene dibromide
- Iron pentacarbonyl
- Methyl chlorosilanes
- Methyl hydrazine
- Methyl isocyanate
- Organophosphate insecticides

Biological Agents. Biological warfare agents are living organisms or the materials derived from living organization (biotoxins) that cause harm to or disease in humans. A biological agent can have a latency period of days to weeks between infection and onset of disease, depending on the microorganism. Toxins are an example of very quick-acting biological agents, with death resulting in minutes or hours. Biological agents that cause disease have a longer period from exposure to onset of symptoms. They typically have no characteristic signature because biological agents are usually odorless and tasteless.

Biological agents pose a significant threat because their use is even more difficult to recognize than the use of chemical agents. The presence of symptoms may well be confused with a naturally occurring case or outbreak of disease. Many of the initial symptoms may be common to several other types of disease, which further complicates recognition, identification, and treatment. The ease with which people can travel throughout the world today presents a situation in which an individual can become infected in one part of the world and then carry the infection home before becoming symptomatic. The recent outbreak of the plague in India and the Ebola Virus in Zaire are examples of opportunities for a dangerous disease to spread. Fortunately, the diseases remained confined to the local area. Potential biological agents and their incubation/latency periods include:

- Anthrax (1–5 days)
- Tularemia (1–10 days)
- Cholera (2–5 days)
- Encephalitis (2–5 days)
- Plague (1–3 days)
- Botulism (2–3 days)

Radiological Materials. The use of radioactive materials in an unconventional attack via some dispersion mechanism, commonly referred to as a radiological dispersal device (RDD) or "dirty bomb," is widely recognized to have a greater likelihood of physical and social disruption than of lethal radiological consequences. However, the psychological and economic consequences of dispersal could be high and carry varying levels of risk to public health. The consequences depend not only on the radioactive material involved (its isotopic composition and physical form), but also the dispersal mechanism (explosive or non-explosive) and the environmental conditions under which it is released (e.g., urban, rural, weather). Thus, determining the absolute consequences of any potential dispersal in advance of its occurrence is not possible. Historically, exposure limits were established for the control and use of radioactive materials based on safety-basis accidents, including inadvertent exposure.

The widespread presence of radioactive materials in commerce and the myriad of possible deployment environments and mechanisms for RDDs present many challenges to understanding which radionuclides pose the greatest hazard. Table 22 provides a list of those isotopes considered as being the most likely threats. Many of these materials pose serious hazards that include high energy gamma rays and other particles that require significant shielding, though the quantities involved in an RDD could be relatively small. The chief hazard is in the contaminated area created by the dispersal.

Table 22. Characteristics of Certain Isotopes of Greatest Concern

Isotope	Common Use	Description (size, radiological characteristics, quantity, form, storage configuration, etc.)
Am-241	Measurement instruments, including well logging instruments and gauges	Sources are typically small to moderate in physical size and radiological emission (up to 1 inch in diameter, 6-inches long, and tens of millicuries to tens of curies in strength); smoke detectors use microcurie quantities. In neutron sources, the Am-241 is typically mixed with beryllium oxide, which is a toxic substance; double-encapsulated in stainless steel holders; and used for a variety of industrial assay applications. Thousands of these sources are in use.
Cs-137	Medical imaging, food/other irradiation, gauges	Found in sealed portable sources and in large irradiation facilities. The sealed sources are often found as cesium chloride, a form of particular concern for RDD use.
Pu-238	Medical devices and measurement instruments	In the past used as a heat source for pacemakers, an application that was phased out in the early 1970s. Also used as a thermal-electric generator heat source where it is contained as an oxide in stainless steel or other containers. As with the Am-241 and Pu-239, and unlike the gamma emitters, a great deal of shielding is not required in application.
Sr-90	Heat source for thermal electric generators and sealed sources	Used in large quantities in heavily shielded configurations
Po-210	Static eliminators	Typically found as metal foils.
Co-60	Food/other irradiation and radiography	Typically cast as metal rods, or pins, several to dozens of Which are combined in a holder to provide desired radiation intensity. Storage requires heavy shielding, typically in large facility.
Ir-192	Gamma source used for mobile and fixed radiography applications.	Used in many fixed and mobile irradiation applications, these sources are found in instruments used for weld inspections and other industrial applications. The mobile application of these sources and availability make them a particular concern.
Pu-239	Alpha or neutron source, typically used in research	Used in research facilities, these sources are generally small because significant quantities of Pu-239 are tightly regulated because of weapons potential.
Cm-244 or Cf-252	Neutron source used in research and measuring instruments	Sources are small, and those in instruments are shielded.

Note: Am: americium; Cs: cesium; Pu: plutonium; Sr: strontium; Po: polonium; Co: cobalt; Ir: iridium; Cm: curium; Cf: californium

Emergency Responder Protection Strategies. The primary approach for personal protection for potential incidents involving weapons of mass destruction is to use conventional protective clothing used in hazardous material response (that has been qualified to chemical agents) or model protection efforts after designs and clothing worn by the U.S. military (such as charcoal adsorbent based clothing). One of the largest problems facing emergency responders is the ability to provide sufficient clothing to first responders and to deploy that clothing in a fashion where fire fighters will be afforded sufficient protection during initial response efforts. This type of approach requires some foreknowledge or rapid assessment capabilities of the initial entry teams to an emergency scene for being able to recognize the signs and symptoms of a WMD event.

The level of preparedness of fire fighters for WMD events appears to be extremely limited given the results of the NFPA Needs Assessment and survey of equipment and response capabilities. The following additional observations can be made:

- Manufacturers have been slow to offer protective ensembles qualified to industry standards. End user buying trends have been based more on manufacturer representations of their products or the belief that certain products should provide protection.

- The development of specific chemical, biological, radiological, and nuclear (CBRN) criteria for respirators has only taken place within the last year.

- Inconsistent protection practices have been identified for biological threats. There is little understanding by the fire service as to the manner in which exposure will occur during a bioterrorism event. The difficulty in detecting the initiation of a biological attack confounds preparation efforts.

- Other than protection from particulates (alpha and beta particles) no specific equipment has been identified for protection against radiological materials.

The potential for WMD exposures during terrorism attacks, especially as fire fighters are foremost first responders to emergencies, remains one of the most difficult challenges for developing a comprehensive protective ensemble.

CHAPTER 5 - ANALYSIS OF EMERGENCY RESPONDER RISKS

An understanding of the different hazards and the missions undertaken by fire fighters and other emergency responders can be used to assess the types of risks. Using the model previously described, it is possible to determine for each hazard category and specific the relative likelihood and potential severity. When both of these factors are collectively considered, a determination of risk can be made.

For the purposes of this report, a risk assessment was performed for each of the primary fire service mission areas, excluding proximity fire fighting. The proximity fire fighting mission was excluded, because its mission is considered similar to structural fire fighting with the exception that higher levels of radiant heat exposure are presumed (there are other mission differences as well). Risk was in one of three different levels:

- Low
- Moderate
- High

For some areas, relatively no risk may exist but a rating of low was still used since the hazards at an emergency are often very unpredictable.

One basis for the risk assessment came from two NFPA committees (structural fire fighting and hazardous materials) that undertook separate hazard and risk analyses several years ago during the revision of their respective standards. A process similar to the one described in this report was followed. The audience involved in the process for both committees represented a mix of end users, manufacturers, research personnel, trade organizations, labor, and other interests. One attribute in common for these participants is their relatively higher understanding of personal protective equipment compared to the general user population. Since numerical ratings were applied in this exercise, the ranking of risks was quantitative and a system of designation of low, moderate, and high risks could be applied. By examining the output of both committees, a relative assessment of risk for the specific hazards could be provided using the same perspective for each of the mission areas.

Table 23 provides the results of the risk assessment as applied to each of the mission. It is important to point out that in this preliminary exercise that the general effects of the hazard were considered. A more detailed risk assessment would examine the specific effects of the hazard on different parts of the body or body systems, as personal protective clothing is often accordingly designed. For example, impact hazards from falling objects are typically applied to the head and feet, but not the torso, arms, legs, and hands. Likewise some hazards, such as high heat and humidity affect the entire body.

The results of the general risk assessment demonstrate that with emergency response missions, different hazards and the consequential risks exist. The relative risk significantly influences decisions about tradeoffs between protection and wearer functionality and comfort.

Table 23. Risk Assessment for Specific Hazards by Mission Area

Hazard	Mission Area					
	Structural Fire Fighting	**Wildland Fire Fighting**	**HazMat Response**	**EMS Operations**	**Technical Rescue**	**WMD or CBRNE Event**
Physical Hazards						
Falling objects	Moderate	Low	Low	Moderate	**High**	Moderate
Flying debris	Moderate	Low	Low	Low	**High**	Moderate
Projectile/ballistic	Low	Low	Low	Low	Low	**High**
Abrasive/rough surfaces	Low	Low	Moderate	Low	Moderate	Low
Sharp edges	Moderate	Low	Moderate	Moderate	Moderate	Moderate
Pointed objects	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Slippery surfaces	**High**	Moderate	**High**	Moderate	**High**	**High**
Excessive vibration	Low	Low	Low	Low	Moderate	Low
Environmental Hazards						
High heat/humidity	**High**	Moderate	**High**	Moderate	Moderate	Moderate
Ambient cold	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Wetness	Moderate	Moderate	Low	Moderate	Moderate	Moderate
High wind	Low	Moderate	Low	Low	**High**	Low
Insufficient/bright light	Moderate	Low	Low	Low	Moderate	Moderate
Excessive noise	**High**	Low	Moderate	Moderate	Moderate	Moderate
Thermal Hazards						
High Convective Heat	**High**	Moderate	Low	Low	Moderate	Low
Low radiant heat	**High**	**High**	Low	Low	Moderate	Moderate
High radiant heat	**High**	Moderate	Low	Low	Low	Low
Flame impingement	**High**	Moderate	Low	Low	Moderate	Low
Steam	**High**	Moderate	Low	Low	Moderate	Low
Hot liquids	Moderate	Moderate	Low	Low	Moderate	Low
Molten metals	Moderate	Low	Low	Low	Moderate	Low
Hot solids	Moderate	Moderate	Low	Low	Moderate	Low
Hot surfaces	Moderate	Moderate	Low	Low	Moderate	Moderate
Chemical Hazards						
Inhalation	**High**	Moderate	**High**	Low	Moderate	**High**
Skin absorption/contact	Moderate	Low	**High**	Low	Moderate	**High**
Chem. ingestion/injection	Moderate	Low	Moderate	Low	Moderate	**High**
Liquefied gas contact	Low	Low	**High**	Low	Moderate	Moderate
Chemical flashover	Moderate	Low	**High**	Low	**High**	**High**
Chemical explosions	Moderate	Low	**High**	Low	Moderate	**High**

Table 23. Risk Assessment for Specific Hazards by Mission Area *(continued)*

Hazard	Mission Area					
	Structural Fire Fighting	**Wildland Fire Fighting**	**HazMat Response**	**EMS Operations**	**Technical Rescue**	**WMD or CBRNE Event**
Biological Hazards						
Bloodborne pathogens	**High**	Low	Moderate	**High**	**High**	**High**
Airborne pathogens	Moderate	Low	Moderate	**High**	Moderate	**High**
Biological toxins	Moderate	Low	Moderate	Moderate	Moderate	**High**
Biological allergens	Moderate	Moderate	Moderate	Moderate	Moderate	**High**
Electrical Hazards						
High voltage	Moderate	Low	Moderate	Low	Moderate	Moderate
Electrical arc flashover	Moderate	Low	Low	Low	Low	Low
Static charge buildup	Low	Low	**High**	Low	**High**	**High**
Radiation Hazards						
Ionizing radiation	Moderate	Low	Moderate	Low	Moderate	**High**
Non-ionizing radiation	Low	Low	Low	Low	Moderate	Moderate
Person-Position Hazards						
Daytime visibility	Moderate	Low	Moderate	**High**	Moderate	Moderate
Nighttime visibility	**High**	**High**	Moderate	**High**	**High**	Moderate
Falling	**High**	Moderate	Moderate	Moderate	**High**	Moderate
Drowning	Moderate	Low	**High**	Low	Moderate	Low
Person-Equipment Hazards						
Mat'l biocompatibility	Low	Low	Moderate	Moderate	Low	Moderate
Ease of contamination	Moderate	Low	**High**	Moderate	Moderate	**High**
Thermal comfort	**High**	Moderate	**High**	Moderate	Moderate	**High**
Range of motion	Moderate	Moderate	**High**	Moderate	Moderate	Moderate
Hand function	Moderate	Low	**High**	Moderate	Moderate	Moderate
Ankle/back support	**High**	High	**High**	Moderate	**High**	**High**
Vision clarity	Moderate	Moderate	**High**	Low	Moderate	**High**
Communications ease	**High**	Low	Moderate	Low	Moderate	Moderate
Fit (poor)	Moderate	Low	Moderate	Low	Moderate	Moderate
Ease of donning/doffing	Moderate	Low	Moderate	Low	Moderate	Moderate

Another part of the risk assessment involved determining how the industry standards specify protection against specific hazards. In the development of standards, organizations assess the risks to the individual wearers and attempt to establish design and performance requirements that set a minimum level of protection. For fire fighters and other emergency responders, the dominant standards in industry are those created by the National Fire Protection Association (NFPA). These standards include those listed in Table 24.

Table 24. Current NFPA Standards Applying to Fire and Emergency Services Protective Clothing and Equipment

Standard	Title	Current Edition
1951	Standard on Protective Ensemble for USAR Operations	2001*
1971	Standard on Protective Ensemble for Structural Fire Fighting	2000
1976	Standard on Protective Ensemble for Proximity Fire Fighting	2000
1977	Standard on Protective Clothing and Equipment for Wildland Fire Fighting	1998*
1981	Standard on Open-Circuit, Self-Contained Breathing Apparatus (SCBA)	2002
1982	Standard on Personal Alert Safety Systems (PASS)	1998
1983	Standard on Life Safety Rope and System Components	2001
1991	Standard on Vapor-Protective Ensembles for Hazardous Chemical Emergencies	2000*
1992	Standard on Liquid Splash-Protective Ensembles for Hazardous Chemical Emergencies	2000*
1994	Standard on Protective Ensemble for Chemical/Biological Terrorism Incidents	2001
1999	Standard on Protective Clothing for Emergency Medical Operations	2003

* Current standard in revision and new edition will be approved in early 2005.

A detailed comparison and analysis of these standards will be conducted as part of future task under Project HEROES. That task will involve an examination of the various test requirements in each standard and how these requirements relate to the needed protection in each of the mission areas. Nevertheless, a preliminary analysis of how each standard applies to each of the identified hazard areas has been performed and those results are shown in Table 25. Table 25 gives an indication for which items of PPE that specific design or performance criteria are included in the respective standard. As SCBA and PASS are separate equipment used in multiple ensembles, the analysis is specific to primary clothing or ensemble standards. Shaded areas are shown for those hazard areas identified in Table 23 for which no criteria have been established.

It is recognized that the current standards are subject to several shortcomings that arise for several reasons:

Table 25. Requirements in NFPA Standards Addressing Protection from Specific Hazards

Hazard	Standard						
	NFPA 1971 (Structural Fire Fighting)	NFPA 1951 (USAR Operations)	NFPA 1977 (Wildland Fire Fighting)	NFPA 1991 (HazMat Vapor Protection	NFPA 1992 (HazMat Splash Protection)	NFPA 1999 (EMS Operations)	NFPA 1994 (Chem/biological Terrorism)
Physical Hazards							
Falling objects	Helmets, footwear	Helmets, footwear	Helmets	Footwear	Footwear	Footwear	Footwear
Flying debris	Eyewear	Eyewear					
Projectile/ballistic							
Abrasive/rough surfaces		Garments, gloves, footwear		Garments, gloves, footwear	Garments, gloves, footwear		Garments, gloves, footwear
Sharp edges	Gloves, footwear	Gloves, footwear	Gloves, footwear	Gloves, footwear	Gloves, footwear	Gloves, footwear	Gloves, footwear
Pointed objects	Gloves, footwear	Gloves, footwear	Gloves, footwear	Garments, gloves, footwear	Garments, gloves, footwear	Garments, gloves, footwear	Garments, gloves, footwear
Slippery surfaces	Gloves, footwear	Gloves, footwear		Footwear	Footwear	Footwear	Footwear
Excessive vibration							
Environmental Hazards							
High heat/humidity	Garments	Garments	Garments			Garments	
Ambient cold							
Wetness							
High wind							
Insufficient/bright light							
Excessive noise							
Thermal Hazards							
High Convective Heat	All items	All items	All items				
Low radiant heat			Garments				
High radiant heat	All items	All items	Gloves				
Flame impingement	All items	All items	All items	All items	All items as option		
Steam							
Hot liquids							
Molten metals							
Hot solids							
Hot surfaces	Garments, gloves, footwear	Gloves, footwear	Gloves				

Table 25. Requirements in NFPA Standards Addressing Protection from Specific Hazards *(continued)*

Hazard	Standard						
	NFPA 1971 (Structural Fire Fighting)	NFPA 1951 (USAR Operations)	NFPA 1977 (Wildland Fire Fighting)	NFPA 1991 (HazMat Vapor Protection	NFPA 1992 (HazMat Splash Protection)	NFPA 1999 (EMS Operations)	NFPA 1994 (Chem/biological Terrorism)
Chemical Hazards							
Inhalation	via SCBA			via SCBA	via SCBA		via SCBA
Skin absorption/contact	Garments, gloves, footwear Penetration some chemicals	Garments, gloves, footwear Penetration some chemicals		All items permeation	All items penetration		All items permeation
Chem Ingestion injection							
Liquefied gas contact				All items as option			
Chemical flashover				All items as option	All items as option		
Chemical explosions							
Biological Hazards							
Bloodborne pathogens	Garments, gloves, footwear	Garments, gloves, footwear				Garments, gloves, footwear, facewear	Class 3 items
Airborne pathogens	via SCBA			via SCBA	via SCBA		via SCBA
Biological toxins							
Biological allergens							
Electrical Hazards							
High voltage	Helmets, footwear	Helmets, footwear	Helmets, footwear				
Electrical arc flashover							
Static charge buildup				All items as option	All item as option		
Radiation Hazards							
Ionizing radiation							
Non-ionizing radiation							
Person-Position Hazards							
Daytime visibility	Garments, helmets	Garments, helmets					
Nighttime visibility	Garments, helmets	Garments, helmets					
Falling							
Drowning							

Table 25. Requirements in NFPA Standards Addressing Protection from Specific Hazards *(continued)*

Hazards	Standard						
	NFPA 1971 (Structural Fire Fighting)	NFPA 1951 (USAR Operations)	NFPA 1977 (Wildland Fire Fighting)	NFPA 1991 (HazMat Vapor Protection	NFPA 1992 (HazMat Splash Protection)	NFPA 1999 (EMS Operations)	NFPA 1994 (Chem/biological Terrorism)
Person-Equipment Hazards							
Mat'l biocompatibility							
Ease of contamination							
Thermal comfort*	Garments	Garments	Garments			Garments	
Range of motion				Ensemble	Ensemble		Ensemble
Hand function	Gloves	Gloves	Gloves	Gloves	Gloves	Gloves	Gloves
Ankle/back support							
Vision clarity	Eyewear	Eyewear		Visors	Visors		Visors
Communications ease	via SCBA			via SCBA	via SCBA		
Fit (poor)	Minimum sizing all items	Minimum sizing all items	Minimum sizing all items	Minimum sizing all items	Minimum sizing all items	Minimum sizing all items	Minimum sizing all items
Ease of donning/doffing				Ensemble	Ensemble		Ensemble

- A clear need has not been identified for protection against the specific hazard.

- The committee is still working prospective design or performance criteria to address the hazard.

- The committee has been unable to identify effective design or performance criteria to address protection from the specific hazard.

Some areas of requirement development are particularly challenging. For example, developing criteria that ensures proper footwear fit in promoting ankle support. In some cases, these types of hazards must be addressed indirectly, such as mandating an extensive series of minimum sizes.

The existence of specific requirements within the standards does not mean that adequate protection against the respective hazard is provided. As previously, indicated the level of protection is often a tradeoff between other factors, particularly where ergonomic issues are involved. In some cases, protection to one form of the hazard is no guarantee that related hazards under different conditions are addressed. For example, the high radiant heat hazards addressed in structural fire fighting clothing requirements do not account for lesser level, but longer term exposures under different conditions.

Lastly, many precedents have been established through the existing evolution of standards. These precedents may be limiting of some new technologies or fail to address other different technologies altogether. Clearly, a detailed comparison and analysis of the standards, current design features, and test methods is needed to understand the limitations and gaps of current standards as it applies to the risk assessment for the broader hazards faced by fire fighters.

CHAPTER 6 – SUMMARY

This report has provided an overview of changes in the fire service where fire fighters and other emergency responders are facing a larger variety of different hazards as their responsibilities broaden for dealing with different kinds of emergencies:

- A review of fire service demographics shows that the fire departments serving the larger communities protect a proportionately larger amount of the population.

- The portion of fire service calls is increasing for emergency medical services and other types of emergencies as compared to structural fire fighting.

- Much of the personal protective equipment in use today is relatively old and lacks modern capabilities. Only a relatively small proportion of departments are equipped and trained to handle extensive or diverse emergencies.

- Fire fighter injuries and fatalities are declining overall but strains and sprains, and stress-related injuries are still very common.

- Fire fighters face a vast array of different hazards during the different types of emergency responses. The types of stressors range in severity depending on the mission.

- Each type of mission presents a different series of low to high risks for the fire fighter. These differences in risk lead to different approaches to personal protection. These approaches to personal protection are generally not compatible to the requirements of different missions.

- An initial general analysis of risks versus current personal protection standards shows gaps in providing protection against some hazards. Protection of some hazards may not be possible because effective criteria has not been developed or is difficult to develop.

The next steps in moving forward for Project HEROES will require a systematic approach for assessing fire service needs and risks and how protection needs are met by current clothing in addition to how alternative technologies can be applied. The work of this first task will consequently be expanded through future tasks. The specific future tasks to be followed include:

1. Define of the operational capabilities, applicable design and performance requirements, and testing approaches for existing firefighter personal protective equipment

    - Identify all pieces of the current firefighter protective ensemble
    - Identify existing standards associated with components of the current firefighter protective ensemble
    - Define design requirements for each piece of equipment
    - Define performance criterion for each piece of equipment
    - Identify testing approaches available in industry for the evaluation of firefighter protective ensembles and if they are currently applied in existing standards

- o Define performance capabilities and user expectations for this equipment (what should this equipment be able to do?)
- o Identify vulnerabilities and limitations of existing equipment
- o Identify intended use for existing equipment

2. Conduct a Gaps Analysis between needed operational capabilities and performance standards

    - o Compare task and environmental requirements defined in the current report with current equipment operational capabilities and requirements defined in Task 1.
    - o Determine areas where capabilities do not exist or where specific criteria are not available to address performance areas of concern
    - o Identify incidences where approved equipment did not perform correctly or meet the expectations of end users

3. Develop specific technology and capability goals for new future fire fighter protective ensembles

    - o Based on information from Task 2, identify priority areas where additional technology, criteria, and test methods are needed.
    - o Develop a system of specific criteria that can be used to assess the practicality, maturity and economy of personal protective technology, materials and designs

4. Conduct an assessment of existing, emerging and future protective clothing and equipment technology, materials, and design concepts based upon criteria that assesses the practicality, maturity and economy of technology, materials, and designs

This overall approach is intended to provide the basis for decided the appropriate mix of mission elements and requirements to ensure the broadest protection to fire fighters and other emergency responders over the largest range of hazardous environments. The process will include the involvement of end users and other stakeholders to help refine the risk assessment approach described in this report. The output of this process can then be compared with new or emerging technologies to determine the appropriateness of changes and improvements to protective ensembles and the way in which they are tested. Ultimately, the product technology that is examined and investigated as part of Project HEROES will be successively applied to the development of new ensembles, test methods, specifications, and use and care practices that afford fire fighters and first responders a modern and greater protective envelope to face challenges of less predictable response environment.

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