When the RAND research team asked fire service representatives what primary occupational hazards and health and safety challenges their ranks faced in the line of duty, we received a wide range of responses. Despite the fact that calls for fires constitute less than 10 percent of service calls, they account for about half of firefighter injuries and fatalities (see Chapter Two), and the majority of hazards and protection needs identified in the discussions centered on the fireground. The principal areas of concern identified by fire service representatives included

- performance of turnout or bunker gear
- heat stress while working in bunker gear
- respiratory protection and ways to improve the self-contained breathing apparatus (SCBA)
- communications difficulties
- personnel command and control at the fireground
- logistical questions concerning personal protective technology management
- protection from chemical and biological hazards for front-line firefighters.

This chapter presents findings from the community discussions regarding many of these issues. (The community’s concerns associated with medical calls are discussed in Chapter Four. Issues concerning PPT logistics and chemical/biological protection, which extend beyond the fire service, are discussed in

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1Firefighter protective clothing, commonly referred to as turnouts or bunker gear, consists of flame- and water-retardant pants and overcoat.
2The self-contained breathing apparatus is a form of respiratory protection in which fresh air from a cylinder worn on the user’s back is supplied via a pressure regulator and face mask.
Chapters Six through Eight, which address topics that cut across multiple areas of emergency responder protection.)

**IMPROVING STRUCTURAL FIREFIGHTING ENSEMBLES**

Current thermal protection is adequate.
We feel very well protected in what we are in.
We are pretty well protected. Period.

—Fire service representatives

One of the most consistent points raised in RAND’s discussions with professionals engaged in structural firefighting is that their existing turnout garments provide excellent flame retardance and thermal protection—in other words, the protective capability of materials per se is not a significant concern in structural firefighting. However, participants pointed to some design shortcomings that diminish the overall performance of protective ensembles. Of these design weaknesses, the two that were most commonly raised were problems with component integration and compatibility and the poor functionality of gloves. Serious concerns were also directed at the need to reduce the heat and physical stress associated with working in modern bunker gear. Difficulties with inspection and assuring the integrity of protective equipment over time were other major concerns, and are addressed in this chapter and in Chapter Eight. Other concerns that were raised include ultraviolet degradation of thermal-protective components, difficulties with proper fitting of turnout gear, and inconsistent sizing of gear among different manufacturers.

**Ensuring Component Integration and Compatibility**

Our discussions with the firefighting community frequently focused on gaps in protection resulting from problems with the integration and compatibility of individual protective equipment components. These problems are manifested in three ways:

- Equipment performance degradation due to incompatibility of components
- Inconsistent protection levels among different components
- Bodily exposure at component interfaces.

One of the integration problems most frequently cited by participants is performance degradation and subsequent safety concerns resulting from incom-
Patibilities of components. The most common examples cited were difficulties in performing certain activities while wearing firefighting gloves and being able to communicate while wearing an SCBA mask.

A second problem with component integration and compatibility cited by some participants concerns the inconsistent levels of fire protection among different components. For example, in the past, the hood was a weak link in the protective ensemble, so some firefighters used two hoods to compensate. Then, as hoods improved, the SCBA became the weak link. Now gloves apparently are, at least indirectly, the weak link.

A third integration-related problem has to do with the interfaces between components of the protective ensemble. One example of this cited by several departments is the use of gloves and turnout coats that have “wristlets” (elastic sleeves that extend beyond the end of the glove body or coat sleeve). Wristlets add protection by providing a tight seal and several inches of overlap between the glove and coat sleeve. However, due to incompatible designs, it can be difficult for the wearer to pull one wristlet over another. Therefore, when two wristlets are used, they can potentially bunch up such that neither is positioned properly. The result is a poor interface between glove and coat that may lead to skin exposure and the potential for burns or abrasions. This mismatch can occur because coats and gloves are often purchased from different manufacturers who do not necessarily integrate their designs. Other interface problems with turnout gear that were mentioned by participants include:

- Hood and SCBA: Mismatches may create gaps between the face opening in the hood and the SCBA mask
- SCBA and helmet: The SCBA tank can interfere with the rear brim of the helmet and can either restrict head motion or knock the helmet off; SCBA strap buckles can also interfere with proper helmet fit.

Both fire departments and equipment manufacturers mentioned problems with bodily exposures at component interfaces. Both groups noted, however, that many compatible interface options are available, and the problem can be addressed by careful selection of compatible components. However, the potential still exists for selecting components with incompatible interfaces. Departments may make this error if they are unaware of incompatibilities between particular components or if they do not fully understand the functional

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3 It was observed by the community that the ongoing process of consolidation of PPT suppliers, whereby some manufacturers now produce entire protective ensembles, was leading to a reduction in the frequency of incompatibilities.
requirements of individual components in the context of the entire protective ensemble.

It would be nice if manufacturers would standardize the connections outside of the [respirator] face piece.

—Fire service representative

To address these issues, some departments advocated what one participant referred to as “configuration control.” The goal of configuration control would be to reduce the potential for incompatible interfaces and modifications by requiring components to meet configuration standards (for instance, dimension, thread size, and fastener standards) in addition to performance standards. Configuration control would also make it easier for a department to upgrade equipment by ensuring compatibility over different generations of equipment. With configuration control, a department would be less likely to find itself in the position of not being able to upgrade to, for example, a new glove design because that design was incompatible with the turnout coats currently in service. Similarly, many participants expressed the desire for standardized configurations of radio component interfaces (e.g., batteries, harnesses, jacks), especially for different generations of devices made by the same manufacturer. Configuration control would also enhance equipment interoperability among agencies, which could have enormous value—both in terms of enhanced safety and cost savings in mutual aid situations. (See Chapter Eight for further discussion of equipment interoperability.)

Concerns about component compatibility are beginning to be addressed through the introduction of standards. The National Fire Protection Association (NFPA) develops and maintains standards and certification procedures for a variety of firefighting and fire prevention equipment and protocols. For instance, the association maintains a standard for firefighter protective clothing, NFPA 1971 (National Fire Protection Association, 2000). Prior to 1997, this standard covered coats, pants, and hoods only. In an effort to establish a “systems approach” to the entire protective ensemble, this standard has been expanded to cover helmets, gloves, and footwear as well (which were previously covered under separate standards). While this standard still focuses primarily on the individual components and does not specify component interfaces, it is intended to lead to greater integration in design and more testing of firefighter protective clothing.

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4A mutual aid response is one in which more than one department participates.
A related problem raised by some departments is the loss of equipment function as a result of adding accessories. To help differentiate their products, suppliers offer a range of turnout gear designs. Departments often request custom specifications on protective equipment for a number of different reasons—to address local working conditions, to promote organizational identity, and to adhere to tradition. In some cases, such customization may degrade the performance of the equipment. The following examples were cited:

- excessive knee padding that can limit the wearer’s agility
- extra pockets, reflective trim, or lettering that can reduce heat loss and vapor transmission
- extra clasps and fasteners and excessively wide Velcro closures or storm flaps than can obstruct movement and have an increased risk of becoming entangled.

The firefighter protective clothing standard NFPA 1971 dictates that modifications influencing garment form or function require recertification to ensure that the component complies with the standard. Thus, customer-specified modifications should not result in equipment that fails to meet the standard. However, manufacturers are currently producing garments with materials that significantly exceed NFPA standards. Therefore, customization may degrade overall equipment performance while still meeting the standard. A problem associated with such customization is that purchasers are generally unaware of the degree of performance that is lost as a result of customization.

A systems approach hasn’t been applied very much to clothing. There has been a lot of dependence on the standard.

—Fire service representative

One way to improve total ensemble performance, several participants noted, is by implementing full-body testing as part of a new certification process for garments, testing that would be akin to the current NIOSH respirator certification process. Current garment certification testing focuses primarily on the material properties of the individual components. Full-body/full-garment testing is complex and expensive, impediments that have thus far delayed its introduction. At a minimum, testing standards and protocols would need to be developed. However, one of the difficulties of full-body testing is the difficulty in being able to certify the innumerable permutations of separate components. Configuration control, the development of interoperability standards for uniform components, or the more extreme case of a standardized uniform would simplify the situation by limiting the number of ensemble component options.
that would require separate full-body testing. This discussion highlights the trade-off between ensuring ensemble performance on the one hand and promoting the innovations and alternative options provided by independent designs on the other.

**Improving Gloves and Footwear**

Gloves are a huge issue.
It seems like our gloves are ancient.
It would be nice to have a decent pair of gloves. Maybe [firefighters] would wear them more often.
If you can’t do your work, you tend not to put them on.

—Fire service representatives

During their discussions with RAND researchers, participants raised many concerns about hand protection in the fire service. Many firefighters claimed that their gloves severely hindered or prevented them from performing important tasks such as manipulating radio switches, operating saws and other tools, or grasping SCBA mask straps. These problems stem from two principal concerns. The first concern was poor fit. Participants complained that glove fingers were too long, most notably the pinkie finger, which reduces dexterity, and that sizes and proportions varied greatly by manufacturer.

A second concern was glove materials. The thickness of the materials severely reduces dexterity. A technical expert familiar with glove construction and performance emphasized that currently available materials for gloves demand a trade-off between heat protection and dexterity. One consequence of this problem is the continuing use of non–NFPA-compliant gloves. For reasons having to do with habit, tradition, and improved dexterity, leather gloves are popular with many firefighters. But leather gloves do not provide levels of thermal protection commensurate with the rest of the firefighter ensemble. Additionally, firefighters mentioned that leather glove liners have a tendency to pull out or slip, especially when one is climbing a ladder. And when the leather dries, it becomes stiff.

Participants noted that because of severely degraded dexterity while wearing gloves, firefighters often must remove their gloves and sometimes suffer burns on their hands as a result. “I won’t wear gloves for anything,” said one fire service representative. Noting that most of the time firefighters do not require great dexterity, one participant advocated developing a two-layer glove system consisting of a medium-weight glove and a quick-to-remove-and-replace
“overmitten.” The mitten would provide maximum fire protection and sufficient dexterity for most operations and could be temporarily removed to allow for greater dexterity for certain tasks.

Since 1983, NFPA has published standards that cover gloves for structural firefighting. These standards address glove sizing and have resulted in improved fit and dexterity. The latest edition of these standards was published in 2000 (National Fire Protection Association, 2000). The 2000 NFPA glove standards include more-rigorous glove construction specifications and, for the first time, dexterity testing. Because this is a recent update, the firefighter community may not yet have had the opportunity to evaluate its effectiveness.

Footwear was also cited by many participants as an area needing significant improvement. For example, participants called for better traction and stability. Having consistent sizing of both foot length and width among different models and manufacturers was a need cited by one participant, who said, “It’s amazing, you would think a size is a size, but it isn’t so.” Many fire service representatives reported the increased use of leather “ranger” boots: Several reasons were cited for wearing these boots, including better fit, greater comfort, and increased stability. The greater comfort of the leather boot was seen as an important benefit in lengthier responses.

Because standard-issue gloves and footwear are regarded as being so problematic, many fire departments reported that they allowed their personnel to buy and use their own gear under certain conditions.

Improving Gear Integrity and Maintainability

The performance characteristics of bunker gear degrade over time due to exposure to high temperatures, chemical exposure, repeated cleaning, exposure to light, and normal wear and tear. The participants in the firefighting community expressed concern with the lack of an objective means of determining when their gear required replacement. For example, many departments store their bunker gear in dark closets to minimize ultraviolet light exposure. But gear is exposed to sunlight on each fire call, and monitoring light exposure of equipment is not done. And even if light-exposure information were available, the rate at which exposure to light affects bunker gear performance is unclear. Participants raised similar concerns about repeated cleaning of gear, even though the cleaning conformed to the vendor’s recommendations.

Exposing gear to very high temperatures results in an easily detectable loss of integrity; therefore, this is not a serious concern. What is more problematic is exposure to intermediate temperatures or to other impacts when damage can-
not be visibly detected. Likewise, continuous use may result in compression be­
tween layers in the equipment or damage that is not visually perceptible.

These concerns were validated during our discussions with technical experts
familiar with firefighter bunker gear. They expressed their concern with the lack
of test data on equipment integrity over time as a function of use, light expo­
sure, and cleaning methods. Potential improvements in this area include ad­
vanced materials that are resistant to photo degradation and imbedded sensors
to detect equipment wear and/or failure. In an effort to address some of these
concerns, NFPA recently introduced a standard for the periodic cleaning, main­
tenance, and inspection of firefighter protective clothing (National Fire
Protection Association, 2001a). In addition to promoting routine maintenance
and inspection procedures, one of the objectives of this standard is the imple­
mentation of a monitoring system to record cumulative exposures to various
environments and cleaning cycles. Such records may provide valuable data for
calibrating the impact of these various exposures on protective clothing per­
formance. (For further discussion of maintenance and reliability of turnout gear
and other protective equipment, see Chapter Eight.)

REDUCING PHYSICAL STRESS

Many firefighters with whom RAND spoke noted that physical stress is a serious
hazard that arises, in part, as a consequence of the high level of performance of
the modern protective ensemble. In addition to the weight of the SCBA pack,
turnout garments are heavy, hot, and do not “breathe” well (i.e., do not allow
body moisture to escape), which increases the stress on a firefighter. These
problems may lead to, among other negative outcomes, heat stress, fatigue,
scalding and steam burns, and shortened work cycles, especially during pro­
longed events. The firefighters’ concerns about physical stress are backed up by
injury data. As was shown in Chapter Two, one-quarter of fireground injuries
and nearly one-half of firefighter deaths are reported to be caused by physical
stress.

The discussion that follows centers on hardware solutions, although it should
be noted that several fire department representatives also stressed the impor­tance of procedural solutions, such as maintaining appropriate work cycles and
improving training and adherence to conventional rehabilitation practices.
Improving Heat and Moisture Dissipation of Turnout Gear

We want better heat stress relief.
Anything you can do to make firefighters lighter and cooler . . . They are totally encapsulated and insulated.

—Fire service representatives

One of the principal concerns voiced by firefighters in the RAND study was the risk of heat stress induced by increased body temperatures while fighting fires. The basic requirement that firefighters’ clothing protect them from heat and flame necessitates designs that minimize heat transmission. This creates a trade-off between keeping firefighters cool and protecting them from burns. The NFPA protective clothing standard specifies minimum heat loss requirements, but most respondents agreed that improvements beyond the current standard were a high priority. One fire service leader noted that when his service adopted a more protective ensemble in the late 1980s, the number of burns decreased significantly, whereas incidents of heat stress increased. This challenge is especially acute in the Sunbelt states—the fastest-growing region of the country.

Several ways to address this trade-off problem were suggested to RAND researchers. Some departments have tried to alleviate heat stress by outfitting firefighters in shorts and T-shirts under their turnouts rather than traditional station uniforms. Some departments also reported trying different fabric materials for station gear. While these tactics appear to help, they can introduce new problems, the most significant of which is that a firefighter’s arms and legs will be directly exposed to abrasions or cuts, body fluids, and other types of exposure during calls in which turnouts are not worn or are taken off, as is commonly done during emergency medical responses.

Another solution that was suggested is the use of active cooling technologies, such as ice packs and refrigeration systems. None of the departments participating in this study reported using active cooling for any tasks other than hazmat responses, although several expressed interest in the concept. The major hurdles to using cooling technologies that were cited include the added bulk and loss of mobility, the short useful life of ice packs (approximately 15 minutes), the burden of dealing with an additional piece of equipment, and cost.

A substantial portion of bodily heat loss occurs through sweat, and there was a strong desire for improved vapor transmission (breathability) of turnouts. Accordingly, the firefighting community put forth several potential directions for innovation, including the following:
• **Increasing the vapor transmission of turnout textiles.** Modern turnouts include a moisture barrier that repels liquid but allows sweat vapor to escape, facilitating heat dissipation. While significant progress in moisture barrier technology has been made in recent years, firefighters expressed a strong desire for continued improvement.

• **Improving turnout gear fit.** Many participants noted that turnout gear often is not well fitted to individual firefighters, even though manufacturers offer varied dimensions and fitting services. Participants called for improving the exactness of measurement services and for fully customized turnout construction.

• **Minimizing fabric layering.** Pockets, knee reinforcements, back supports, and other garment features all entail adding extra layers of fabric, which reduce breathability. And many fire services specify extra pocket space in response to demands for more storage areas. Improved garment engineering may be able to reduce fabric layering.

• **Reducing thermal protection in less-exposed areas.** Participants recommended reducing thermal protection in less-exposed areas, such as the armpit, the side of the torso, and along the back where the firefighter is protected by the SCBA frame. Textiles that provide variable levels of performance over different body areas are currently used in the construction of athletic gear.

### Reducing Personal Protective Technology Weight

Firefighters repeatedly called for lighter, less-bulky garments. The weight of turnouts, in conjunction with that of other personal gear (SCBA, helmet, radio), amounts to a substantial weight burden on the firefighter. One participant pointed out that a fully equipped firefighter might be carrying personal protective equipment in addition to hoses, ladders, or power tools that total more than 50 percent of his or her body weight. Many participants felt that the bulkiness of turnout gear restricts their range of motion and therefore interferes with their firefighting ability. They noted that tasks such as climbing, crawling, and swinging tools were hindered.

Weight savings, it was argued, could be accomplished through several approaches, including

• more-customized fitting of turnout gear to eliminate unnecessary bulk

• integrating more functions into fewer pieces of equipment, such as an SCBA frame with an integrated antifall harness
• equipment design changes that minimize mass and weight
• use of lighter-weight materials.

The weight of firefighting helmets was a specific concern and is a good illustration of the potential for improvements from design changes and lighter-weight materials. One department noted that helmets were a leading source of chronic neck strain, and that it was becoming increasingly common for doctors to prescribe lighter helmets. Traditional leather helmets favored by many firefighters are heavier than more modern designs made with synthetic materials. Some participants raised questions about the appropriateness of the existing stringent impact-resistance standards for all helmets. Several departments felt that the high-energy impacts that helmets are required to sustain under current certification standards would result in catastrophic injury to the wearer’s neck and spine. Relaxing these standards, they claimed, could allow lighter helmets to be certified for service with little or no decrease in safety.

Does Encapsulation Increase the Risk of Injury?

I think we are going to a protective environment that is far beyond what the firefighter can deal with.

—Fire service leader

Another debate that surfaced in the RAND discussions was over the costs and benefits of encapsulation. Over time, personal protection for structural firefighters has evolved toward a state in which the firefighter is nearly completely encapsulated by highly insulating turnout coats and pants, gloves, boots, and protective hoods worn over the head and neck. While providing maximum burn protection, some participants (particularly senior members of the community) noted that this high level of protection has enabled firefighters to go deeper into a burning building, thereby increasing their likelihood of getting trapped. Ambient temperature, typically sensed on the ears, is one indicator used by firefighters to gauge hazards such as the proximity of a fire or potential flashover conditions. In fact, participants noted that it was not uncommon for firefighters to suffer burns on an ear as a result of exposing the ear to gauge ambient temperature. Encapsulation, some fire service representatives claimed,

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5 The standard specifies that a helmet should withstand a test in which an eight-pound anvil is dropped from a height of five feet, imparting a maximum force of 850 pounds (National Fire Protection Association, 2000).

6 Flashover is the near-instantaneous ignition of an entire room and its contents. Flashover is usually caused by the buildup of heat from a fire burning in one part of a room, which gradually heats the rest of the room to its ignition temperature.
has limited firefighters’ ability to sense hazardous conditions. “We are sending our firefighters in too far,” concluded one fire department leader.

Some participants countered that this situation was only the latest manifestation of continuing trade-offs between the intended protection and the unintentional drawbacks that emerge from protection innovations. Such trade-offs could be resolved, it was said, through the development and implementation of appropriate operational doctrine, training, and standards enforcement mechanisms. Others pointed to the development of turnouts with integrated temperature sensors and alarms as a potentially useful innovation. Most agreed, however, that existing technology solutions of this sort fall short in that they can be unreliable, for instance, should the sensor come into contact with hot surfaces. Interestingly, another concern is that the use of such technology would require the firefighting community to address several new questions, such as what the threshold temperature should be, what the minimum duration at that temperature should be, and what action a firefighter should take when an alarm is triggered.

Along these same lines, some participants went further to suggest adopting systems to perform in situ physiological monitoring of a firefighter’s condition (e.g., temperature, pulse, respiration rate). Such systems would give firefighters a real-time, objective indication of their physiological status. If these data were then transmitted remotely via a radio system, safety officers or incident commanders could monitor their personnel and recognize when they were approaching the point of overexertion.

**IMPROVING RESPIRATORY PROTECTION**

Firefighters are exposed to a wide variety of gases, particulates, and other respiratory hazards in their activities. Respiratory protection, therefore, was a focus of attention during RAND’s discussions with representatives from the firefighting community.

The SCBA is the standard respiratory protection technology used in the fire service. We did not hear of any use of air-purifying respirators (APRs) in the fire service. While participants generally spoke very highly of the performance of SCBAs currently on the market, they did note some ways in which the technology could be improved to better meet their needs. A separate concern was that under current U.S. structural firefighting standards, the SCBA is the only means

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7 An air-purifying respirator comprises a half- or full-face mask with chemical-cartridge air filters. Ambient air is drawn through the filters, in some cases with the assistance of a fan (in powered air-purifying respirators), and is supplied to the user.
of respiratory protection that firefighters have available to them, but they questioned its appropriateness for all situations.

**Improving SCBA Air Supply and Monitoring**

A common desire expressed by participants was for a continuation of the trend toward lighter, more-compact SCBA tanks with higher capacities and longer air supplies. Many agencies reported acquiring latest-generation bottles with extended air supplies. This is of particularly great importance in extended emergency response campaigns, such as after the September 11 Pentagon and World Trade Center attacks, where SCBA air supplies lasted far shorter than the duration of the response (Jackson et al., 2002).

Participants also called for better air supply monitoring and low-volume warning systems to get more effective use of the air supplies they have available. Some respondents stressed the importance of providing continuous monitoring of remaining breathing time rather than a sudden warning at low tank pressure. Continuous monitoring allows responders to plan their actions accordingly and avoid getting caught in a situation in which it may be inconvenient or dangerous to exit an area immediately. A low-pressure alarm is also inexact because the relationship between pressure and remaining breathing time depends on the user’s rate of respiration, which varies from person to person as well as by the level of activity in which the user is engaged. Thus, the remaining air supply duration for a firefighter engaged in a very strenuous activity may be substantially shorter than that for a firefighter engaged in a less physically demanding one. A better approach, participants claimed, would also monitor the rate of pressure change to more accurately calculate remaining breathing time. Participants also expressed the importance of a visual low-air-supply alarm, because audible alarms are sometimes difficult to hear amid the background noise at a fire scene.

To these points, many participants applauded the recent improvements in the NFPA SCBA standard, which have begun to address these concerns. The new standard (National Fire Protection Association, 2002b) requires in-mask visual display systems that indicate remaining air pressure in multiple increments of total rated tank pressure, providing firefighters with a gradual warning of their remaining air supply rather than just a single low-air alarm.

**Expanding Options for Respiratory Protection**

Many departments noted that while SCBAs provide a very high level of protection against airborne hazards, they are not always appropriate for the varied tasks and levels of risk firefighters face in the line of duty. Some participants
stated that there are situations in which they would like to have alternative respiratory protection options.

The most commonly cited situation in which alternative options would be useful was the overhaul stage of fire suppression. Participants indicated that while department policies typically mandated that SCBAs be used during overhaul, compliance is low. This lack of compliance stems from the view that an SCBA is often overkill during this stage and from problems with ensuring that enough air remains at the end of an event. Accordingly, many participants expressed a desire to use an APR with the appropriate filtration capability. Because an APR presents less physical inconvenience than an SCBA, firefighters would be more inclined to use it. One variant that several departments mentioned in a favorable light is a currently available dual-purpose mask in which the SCBA regulator and hose can be disconnected and replaced by an air-purifying cartridge. Several participants questioned this recommendation. They noted that while a convertible mask allows the user to shed the SCBA tank, it does nothing to alleviate the restricted vision and comfort problems associated with the mask. Manufacturers noted that there are also some technical difficulties in designing a mask that can be used for both positive pressure (SCBA) and negative pressure (APR) applications. One department reported having conducted a study in this area and found that the currently available air-purifying respirators do not provide adequate protection from the hazards encountered during overhaul, such as toxic gasses emitted by building interiors and furniture. "Our greatest exposure occurs after the fire," said a department representative.

Thus, while the present strategy of SCBA use during overhaul suffers from a lack of compliance, the appropriate solution for maximizing their health and safety was not obvious to participants. (For a further discussion on protective equipment tailored to specific hazards, see Chapter Eight.)

Another situation in which APRs were viewed as a superior respiratory protection option is during search-and-rescue campaigns after structural collapses. Findings from emergency response to the World Trade Center attacks show that SCBAs are too cumbersome and their air supplies are too limited for such operations. APRs, on the other hand, were widely distributed at the attack site and were viewed as an essential protective measure (Jackson et al., 2002).

**IMPROVING COMMUNICATIONS CAPABILITIES**

Participants repeatedly pointed out that firefighters have great difficulty communicating while wearing an SCBA face mask. Firefighters noted that sound travels poorly in smoky air, and that there is substantial background noise at fire scenes (from engines, sirens, alarms, pumps, hoses, power tools, and other sources). Department after department relayed how firefighters typically have
to yell and repeat themselves to be heard by a person standing right nearby. Efforts to mitigate this problem through retrofitting masks with mechanical or battery-powered voice amplifiers were seen as providing only marginal improvements. With these systems, the user’s voice is reflected inside the mask, such that a firefighter’s speech still sounds muffled, only louder, observed one participant. When communicating with each other, firefighters often have to remove their face masks or resort to hand signals.

Moreover, poor radio communication between firefighters and incident commanders is also considered to be a serious problem by most of the community. Technical advances to address this problem include improved radio microphones, the positioning of these microphones directly on the side of the face mask, and specialized earphones, although departments reportedly are not entirely satisfied with these solutions—both in terms of improved communications and functionality. As one participant put it, they are “not as good as you’d think. They involve extra wires, extra cost, and communication is not that clear.” Departments reported difficulties with the microphone cables getting snagged on debris, tools, and various other items. One department abandoned the use of integrated respirator and communications systems in part because firefighters grew tired of having to connect the cables each time they donned their gear. Two solutions that participants cited were using a wireless link from the mask to the radio unit, which would be mounted on the body or SCBA frame, or setting up a wireless local area network to support sitewide communications and data transfer.

Numerous fire department representatives also expressed dissatisfaction with the radio units themselves. The representatives voiced a wide range of complaints, including

- small controls that require personnel to take off their gloves, increasing their risk of getting burned
- controls that are susceptible to being inadvertently switched when the unit is bumped or swiped
- incompatibility of jacks and other components among models made by the same manufacturer and different manufacturers
- insufficient battery life
- inadequate water and thermal resistance.

Many of these of these problems, the participants noted, could be remedied relatively easily without substantial research and development costs. Several participants expressed the view that these problems persisted because radios used in the fire service are not necessarily designed with the firefighting mission
uppermost in mind. A communications solution optimized for firefighters may not be easy to obtain, they claimed, because firefighting represents a small share of the market for radios.

Another communications issue that was raised is the desire for a dedicated transceiver for responder emergencies, such as mayday and evacuation calls. Participants were concerned that mayday calls can get lost in radio “chatter.” The existing system for mayday calls includes a button on the radio unit that opens a channel to the dispatch center and identifies the unit to which the sending radio was assigned. The dispatch center then contacts the appropriate scene commander based on unit assignments. The evacuation call system is essentially the reverse of the mayday call process: An incident commander issues an order, which is then relayed by the dispatch center to the individual firefighter. An improved system would comprise a dedicated device that would enable a responder who is in trouble to send mayday calls and receive evacuation calls directly to and from incident or unit commanders. Advocates for such a device stressed that for this technology to have maximum effectiveness, it would need to be physically separate from the voice radio, would always have to be on, and would use reserved radio frequencies and distinct warning tones.

Finally, the issue of the cost of improved communications was raised by many participants. Although, in law enforcement, each individual patrol officer typically is assigned a radio, this is not the case in firefighting or medical response: On average, fire departments have only enough portable radios to equip about half of the emergency responders on a shift (U.S. Fire Administration and National Fire Protection Association, 2002). Thus, for many fire departments, their priority is in increasing the number of responders having radios (necessitating a focus on lower unit costs) as opposed to increasing radio capabilities (likely resulting in higher unit cost).

**IMPROVING PERSONNEL ACCOUNTABILITY**

Another top-priority issue that participants raised about firefighter safety concerns on-scene personnel management. Many firefighters are injured or do not receive prompt treatment for injuries, participants claimed, because of confusion about the location and activities of individuals at an incident. Even when all responders are in radio communication contact, it is often difficult to know where individuals are relative to one another. This problem becomes more serious in situations in which injury or signal loss prevents communication. For these reasons, participants expressed a desire for the ability to monitor and manage the precise location of personnel, independent of reliance on voice communications. During the RAND discussions, participants cited several po-
A less technically demanding way to track firefighters at an incident is with fireground personnel accountability systems. These systems are designed to keep track of whoever has been deployed to a scene and what tasks each individual is doing. Nearly every fire department raised fireground accountability as an area in need of improvement. Present systems typically involve personal identification tags and status boards. Individuals transfer these tags, which are typically attached to either their helmets, bunker coats, or radios, to one or more status boards as they arrive on a scene and engage in a particular task. Participants noted that this system, while simple, is susceptible to errors. Also, even when used properly, the system provides only limited information on an individual’s location, which is inferred from the task they are assumed to be performing. A firefighter from one department described the accountability tags as being archaic and highly ineffective. In addition, many departments use accountability tags only for “special hazard” responses, such as confined-space rescues and attacks on fires in high-rise buildings, and not on a routine basis.

Several participants suggested improvements to the existing personnel accountability system, and noted that promising new approaches are under development and may soon become available. These new approaches include card-swipe or bar-code systems, in which portable magnetic card readers or bar-code readers are positioned at specified points around an incident scene. Also suggested were identification-tag reader systems, analogous to antitheft tags used in retail stores, which would passively register when a responder passes a specified point. An advantage of these systems is the potential for setting up as many registry stations as needed. This capability would allow commanders to define specialized task and location categories as needed for a particular incident and would also provide higher-resolution information on the location of individual responders. Another advantage to such a system is that it would update information automatically—for instance, when a responder registers at a second station, he would be unlisted from the first station—thereby minimizing accounting errors. These systems could also support remote data access, allowing commanders at major incidents to monitor and control operations a greater distance away.

Such technologies would greatly improve fireground safety, although there are serious barriers to their implementation. In addition to the investment costs and maintenance concerns, the systems must have the capability to be set up quickly and operate reliably in harsh environments. In addition, they should be designed to operate as “open” systems, allowing responders from multiple departments and services to utilize a single system at an incident.