1 Introduction to CBRN Protection

In this chapter we familiarize the reader with the general concepts that are most important to CBRN protection and personal protective equipment, acting as an introduction to later chapters, where we deal with these topics in more depth.

1.1 WHAT IS CBRN PPE AND WHY IS IT USED?

Personal protective equipment (PPE) is equipment worn to protect the wearer from some external hazard: in this case, chemical, biological, radiological, or nuclear hazards, all of which can be considered to be toxic. The term *CBRN*, an acronym for "chemical, biological, radiological, and nuclear," is used here to describe the particular combination of the hazard environment and the intent of use. The book is focused primarily on protection against deliberate use of CBRN agents in a terrorism or combat environment. The same PPE may be useful in a workplace setting in which CBRN agents are handled; however, as we discuss later, this results in some potentially important distinctions in the concept of use of the equipment.

CBRN PPE almost always has protective or operational requirements in addition to its CBRN protective functions. In most cases, however, the CBRN protection is deemed a primary requirement, with the other requirements superimposed once CBRN protection is provided. CBRN protective equipment may be designed to be worn by:

- Those responding to the use of CBRN agents (e.g., first or later responders)
- Those who are expected to perform their normal functions despite the fact that CBRN agents have been used (e.g., the military)
- Those who are being provided with emergency protection for escape purposes (e.g., civilians located in the vicinity)

In addition, CBRN protective equipment may be worn by those who are performing activities such as remediation, demilitarization, or laboratory investigation, where the environment is more controlled but the possibility of exposure to CBRN agents still exists. Protection against toxic materials has often been treated, conceptually, as an "all or nothing" idea—a person is either protected totally or is not protected at all.

Personal Protective Equipment for Chemical, Biological, and Radiological Hazards: Design, Evaluation, and Selection, First Edition. Eva F. Gudgin Dickson.

As we shall see, this approach is both overly simplistic and counterproductive. The degree of protection required is dependent on many factors, and protection need not be "total" to be effective; however, the protection requirements and expected performance must be well understood, and limitations and use of the equipment must be well defined.

A number of issues need to be considered to understand protection requirements. The first is the nature of the hazard for which protection must be provided.

1.2 WHAT ARE CBRN AGENTS?

CBRN agents consist of any chemical, biological, or radiological/nuclear substance that can be deliberately employed to cause harm to unprotected persons [1,2]. Chemicals may cause damage as a result of specific chemical reactions that happen when the body is exposed to them, disrupting bodily functions. Biological agents are living microorganisms that cause disease. Radiological agents (which may either result from a nuclear explosion or themselves be used) will damage living systems as a result of high-energy radiation interactions. CBRN agents may range from military agents, which have been designed or chosen to be particularly effective when used in a deliberate attack, to toxic industrial chemicals, which may be available more readily or in larger quantity.

There are a number of additional distinctions between C, B, and R/N agents: in terms of how they act on the body, their relative toxicity (Figure 1-1), and how they may be delivered, which is discussed in Chapter 2; nevertheless, it is apparent that they can all be described in general terms as materials that may be hazardous when the body is exposed to them, and there are a number of generic ways in which these hazards can be described, regardless of the class of agent. The most important aspect of these materials in the context of CBRN protection is the idea of deliberate use. Deliberate use implies the features outlined in Table 1-1 compared with those of an accidental release.

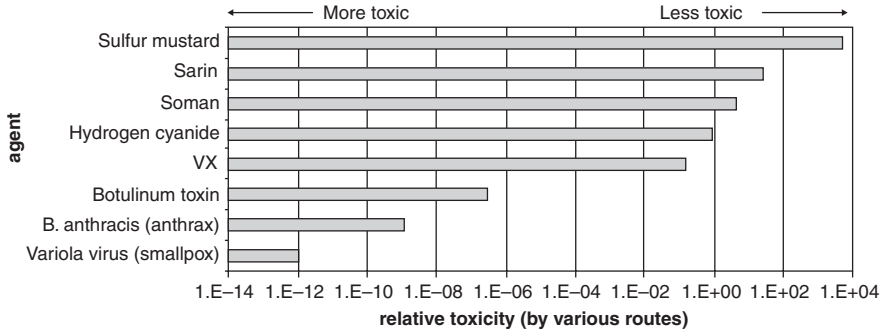

FIGURE 1-1 Approximate relative toxicity (related to mass of agent required to cause effect) of a variety of agents by various routes of entry.

TABLE 1-1 Differences Between an Accidental or Workplace Exposure to, and Deliberate Use of, a Toxic Material

	Accidental or Workplace Exposure	Deliberate Use Against Civilians	Deliberate Use Against Military
Intent	Unintentional; not a criminal event.	Criminal; needs of law enforcement may require alteration of normal response procedures.	Anticipated use will dictate complete change in operational tempo and procedures.
Location and severity of event	Not targeted, and large release events not likely to occur in a highly populated area. Most likely a small area is covered. Hazmat events: often, outdoor release with a relatively small area of effect, as dispersal is natural or passive (e.g., a leak from a tanker after a collision). Infections occur in a normal manner; epidemic events possible. Limited number of civilians involved; large-scale public panic unlikely.	Targeted location and timing, toxic material may be weaponized for efficient delivery, probably used in highly populated areas to cause maximum effect based on targeted population. Delivery designed to cause maximum disruption (e.g., covering a large area with airborne material or targeting many people). More likely to be either indoor release or covering a very large outdoor area, involving active dispersal mechanisms. Larger number of persons and casualties involved; public psychological trauma and panic likely.	Targeted location and timing; likely to cause maximum effect based on selection of optimum agent delivery conditions by a trained opponent. Delivery designed to deny territory, affect morale, change tempo of operations by requiring changes in procedures, burden medical care. Confined to theater of operations, and risk of use is usually identified prior to the event. Limited number of persons involved; training, PPE, and preparedness should limit effects.

(*continued*)

TABLE 1-1 (*Continued*)

	Accidental or Workplace Exposure	Deliberate Use Against Civilians	Deliberate Use Against Military
Nature of toxic material	Could be low-level routine workplace exposure, chemical accident, or normal biological infection; few military agents likely. Toxicity variable, usually low to moderate; amount of toxic material small except in catastrophic events.	Radiological or nuclear incidents; chemical agents as well as toxic industrial chemicals; atypical biological infections. Toxicity likely to be high; amount may be considerably more than normally encountered.	A well-armed opponent may use conventional or engineered CBRN agents; others could use more easily available industrial or commercial materials. Toxicity is likely to be high; the amount may be considerably more than normally encountered.
Measures in place to reduce risk	For releases involving industrial or commercial materials, specific emergency plan in place; containment contingencies anticipated, specific training implemented. For normal biological infections occurring on a small scale; health care system has predeveloped management strategies.	Planning must be generic; containment strategies ad hoc and broader in scope. Low likelihood of event means that training is difficult to maintain. Resources are rarely in place to deal with catastrophic or pandemic scale of events.	Planning should be effective when based on prior intelligence. Opportunity for appropriate routine user training.
Duration of event	Duration of spill or release generally short; consequence management may require hours to weeks; epidemic biological events may last months to years. May be a single or repeated workplace exposure.	Similar to accidental events, but consequence management may last for months to years. A single (lifetime) exposure.	Military approach may permit shortening of required protection time scale by sacrifice of assets or avoidance of contaminated areas. Multiple exposures possible but not expected.

Ultimately, the worst-case deliberate event is as bad as any accidental event that can be conceived. This does not mean that PPE designed for a deliberate event will then necessarily provide appropriate protection for an accidental event; many factors must be considered, and potentially traded off, to permit the optimum response to the spectrum of events that could occur.

1.3 CONTEXT OF USE AS IT RELATES TO DESIGN, SELECTION, AND PERFORMANCE

To design, select, and use the most appropriate PPE for a job, the context of use must be understood. For each potential toxic substance, user, or exposure scenario, the following questions are important:

- What might the toxic substance be?
  - How toxic is it?
  - Where and how does it enter the body?
- Who may be exposed to the substance?
  - What level of effects resulting from exposure is acceptable for this population?
  - What operations and activities will be performed by them during exposure?
- What might the conditions of exposure be?
  - How long?
  - How often?
  - How large is the potential exposure dose?
  - What is the range of possible environmental conditions?

The three main questions above can be answered once the context of use of the protective equipment is analyzed and understood. The answers to all of these questions together determine the level of protection that is required. Additional questions may affect other important design and selection considerations.

- What other external hazards may exist?
  - Does the wearer, or the equipment, need to be protected against these hazards?
- Under what conditions might the equipment be stored or worn both before and during use?
  - What type of shelf life may be desirable?
  - What type of use life may be desirable?
  - What are its requirements for durability and survivability?
- What other activities must the wearer be able to perform?
- What other requirements may affect use of the equipment?
  - How does it need to integrate with other equipment?

The answers to the questions above may be very different depending on the user; the military, for example, may require that PPE be wearable for several weeks while continuing to protect after multiple exposures or launderings, whereas a first responder may expect to wear equipment once for only an hour or two in a hazardous environment. The military or police may potentially accept a higher level of risk to the wearer to reduce risk from equally potentially lethal hazards compared with an emergency medical worker who may be exposed to more limited or different hazards. These very different contexts of use can have a significant impact on the appropriate design of equipment.

Examples of standards that follow the process as we outline it here are two CBRN PPE standards: Canadian standards for civilian responders [3] and the NATO clothing standards for military users [4], and much of the information given here is consistent with those documents.

1.4 ACQUIRING EQUIPMENT

To actually begin the acquisition of PPE, there is a significant onus on the user to perform a number of activities. Outlined in this section in brief, and throughout the book in more detail, is an approach to acquiring CBRN PPE that significantly increases the likelihood that the equipment that is procured will suit the user's requirements.

1.4.1 How Not to Do It

This is a true story—repeated hundreds, if not thousands, of times over the past decade.

You work for an organization that has been in existence for some time, or even a newly minted user group, and you've just been told that your group must be able to support CBRN operations. You've been given a budget and a requirement to develop an operational capability as quickly as possible to satisfy your superiors, governments, and the public that the issue is being addressed in a timely manner. The strategy is probably to throw a lot of money at the problem up front, with a very short time line for delivery. What's your first step? Of course, you buy equipment, including PPE, for there is nothing like shiny new pieces of equipment to show that money has been spent and action is being taken. But which approach should you take?

1. Browse the Internet and talk to salespeople.
2. Talk to user groups that have already procured equipment.
3. Ask your local expert what to buy.

Unfortunately for you, the answer is most likely (d): none of the above. And, after procurement, you will have spent a lot of money on equipment without ever knowing whether it satisfies your requirements completely (and it almost certainly won't), and the PPE you bought will limit your capability and your safety to the point that you might be putting lives at risk by implementing its use (Figure 1-2).

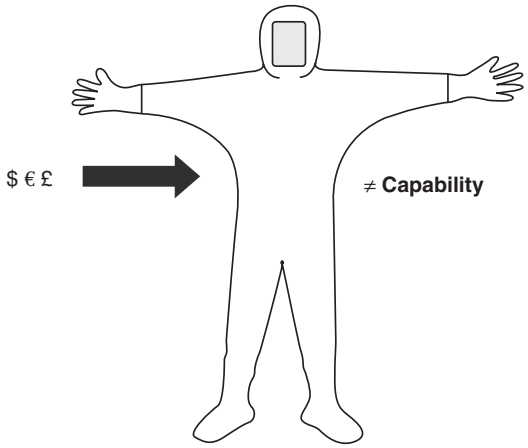

FIGURE 1-2 The usual result of urgency in acquisition.

So, at the end of this exercise, you recognize that this wasn't the best approach, but if none of these people really knew the answer to what to buy, who does? Well, here's the bad news—you (having become your local expert) are the only one that really holds the answer to what you need, and only after considerable work on your part, which will involve the engagement of many people inside and outside your organization.

It's pretty obvious, then, that as much of this work as possible should be done *before* someone arrives on your doorstep with the next parcel of money to be spent on equipment acquisition. It is important to note here that PPE is just one piece—albeit an important one—of the puzzle, and that this exercise must be performed for every type of equipment to be procured to develop an entire CBRN response capability. Nevertheless, since the focus of this book is on PPE, other aspects of the capability development are not discussed further here.

1.4.2 Stage 1: Prior to the Design and Procurement Cycle

Once the decision has been made to procure PPE, it is generally far too late to begin all the work that needs to be done. Therefore, prior to this time, the user should already have worked out a concept of operations that includes CBRN operations. In other words, equipment users should understand fully what they have to be able to do whether or not they are in a CBRN environment; and they should understand that being in a CBRN environment may limit their operational capability, so that the essential must be separated from the desirable operational capabilities to be delivered. The trade-offs that the military commander must consider have been described by NATO [5], which gives "fundamental principles for the guidance of operational level commanders and their staffs in an NBC environment."

First, the organization's non-CBRN concept of operations should be translated into:

- Specific tasks, assessing for each such factor as:
  - Work rate at which it is performed
  - Dexterity and freedom of motion required
  - Situational awareness required
- Normal hazards other than those present in a CBRN environment
- Existing non-CBRN procedures and training
- Ancillary equipment worn or used by the user that may have an impact on PPE performance, or vice versa
- User population characteristics such as:
  - Age, gender, anthropometrics, fitness
  - Education, training, and CBRN operations proficiency level expected
- Minimum and maximum duration and conditions of operations

With all of this information collated, it should be possible to summarize the organization's capabilities when operating in a non-CBRN environment. If there is an existing CBRN response capability, it should be summarized and documented. It may well be that this capability has never been explicitly analyzed despite the presence within the organization of PPE and training. The analysis should include:

- The nature of possible CBRN exposure
- Additional possible hazards other than CBRN in a CBRN environment
- Existing CBRN PPE
- Existing CBRN procedures and training
- How organizational response capabilities are altered in a CBRN environment:
  - Targeted capabilities and tasks
  - Gaps and limitations

With all of the information collated, documented, and updated on a regular basis, the process of acquisition of new PPE can proceed at the optimal pace once the decision is made to proceed.

1.4.3 Stage 2: At the Time of Decision to Procure New PPE

Sometimes when the time has come to procure new PPE, it is prompted by a change in desired operational capabilities; procurement may also occur as part of the normal process of life-cycle renewal of equipment, but in this case a desire for new capabilities will also inevitably result. The following approach will assist:

1. Reassess information from stage 1 for correctness.
2. Perform capability assessment:
   a. List targeted capabilities.

   b. Identify which are existing, which are new, and if any existing capabilities fall outside the target and can be sacrificed.
3. Compare existing standards with targeted capabilities: Is there a response or PPE standard that assists in describing these?
4. Compare available PPE with capability targets.
5. Compare the concept of use of available PPE with user capabilities.
   a. Do not neglect such factors as fitting, sizing, supply, and resupply requirements.
6. Take into account the available level of user participation in the process.
7. Either equipment must meet standards that take into account all relevant user requirements, meaning that less user involvement is required, or
8. Users must prioritize sufficient availability of an appropriate user population (10 to 30 standard users plus one or more user experts) at all stages of the development and selection program in order to address and assess:
   a. Sizing and fitting
   b. Functionality and use
   c. Putting on PPE
   d. Removing PPE
   e. Wear
   f. Range of motion
   g. Situational awareness
   h. Duration of use
   i. Equipment integration
   j. Simulated workplace protection
   k. Training program development
9. Determine time line and budget envelope for acquisition.
10. Decide whether off-the-shelf procurement (stage 3) and/or development (stage 4) is possible or required.

1.4.4 Stage 3: Off-the-Shelf Procurement

Stage 3a: Procurement Against Standards. The equipment must meet specified standards appropriate to the user group and concept of operations. User acceptance is based mainly on:

- Cost and delivery
- Integration requirements
- Interoperability requirements
- Limited operational trials
- Life-cycle management issues
- Additional features that may be provided in excess of standard requirements

Stage 3b: Procurement with a Few Additional Customized Requirements. The user must translate custom requirements into test methods and criteria. In addition to the factors listed in phase 3a, user acceptance of PPE is also based on:

- Ability to meet nonstandard test criteria.

1.4.5 Stage 4: Development Program

A development program is a major undertaking and will be considered only by large organizations and only then when off-the-shelf procurement cannot provide an adequate solution. Depending on existing limitations or capabilities within an organization, certain design options may be more desirable than others. Some considerations are obvious, such as the specific nature and magnitude of CBRN hazards to be protected against, and these will drive the design parameters required to keep the hazard out, as discussed in further detail in later chapters. Some examples of how other types of issues may have an impact on design are given below.

Logistics of PPE Availability and Issue

- Storage
  - Central depot? Carried with user or in vehicle?
  - Space available
  - Environmental conditions
- Size of stockpile? Enough for each person or enough for a subset?
- Time to resupply or recharge? (in theater or in use)
- Weight and bulk when packaged
- Time to respond? To open? To put on? To decontaminate and remove? (Just-in-time or continuous protection?)
- Sizing and fitting strategies (one size fits all, precustomized, presized, etc.)
  - Fitting capabilities: Time of issue? Time of putting on? Both?
- Mechanism of issue
- Disposability or reuse

Duration of Use

- Requirement to change PPE or to recharge air or air-purifying elements
- Weight and bulk of human-portable items
- Hydration
- Physiological burden

Extreme Environments or High Work Rates

- Microclimate control, hydration, fogging
- Durability
- Water, wind, temperature

Other Hazards—Particularly Ranked More Important Than or Incompatible with CBRN Protection

- Blast
- Ballistic
- Fire
- Electrical
- Contaminants
- Oxygen depletion

To lay the groundwork for understanding protection requirements, we focus next on the hazards from CBRN substances.