

10. Decontamination

Contents

Introduction	10-1
Decontamination Plan	10-1
Prevention of Contamination	10-1
Types of Contamination	10-2
Decontamination Methods	10-2
Physical Removal	10-2
Chemical Removal	10-3
Testing for the Effectiveness of Decontamination	10-4
Visual Observation	10-4
Wipe Sampling	10-4
Cleaning Solution Analysis	10-4
Testing for Permeation	10-4
Health and Safety Hazards	10-4
Decontamination Facility Design	10-4
Decontamination Equipment Selection	10-6
Disposal Methods	10-6
Personal Protection	10-6
Emergency Decontamination	10-7
References	10-7

Introduction

Decontamination—the process of removing or neutralizing contaminants that have accumulated on personnel and equipment—is critical to health and safety at hazardous waste sites. Decontamination protects workers from hazardous substances that may contaminate and eventually permeate the protective clothing, respiratory equipment, tools, vehicles, and other equipment used on site; it protects all site personnel by minimizing the transfer of harmful materials into clean areas; it helps prevent mixing of incompatible chemicals; and it protects the community by preventing uncontrolled transportation of contaminants from the site.

This chapter describes the types of contamination that workers may encounter at a waste site, the factors that influence the extent of contamination, and methods for preventing or reducing contamination. In addition, this chapter provides general guidelines for designing and selecting decontamination procedures at a site, and it presents a decision aid for evaluating the health and safety aspects of decontamination methods. The chapter does not cover decontamination of radioactively contaminated personnel or equipment. A health physicist should be consulted if this situation arises.

Decontamination Plan

A decontamination plan should be developed (as part of the Site Safety Plan) and set up before any personnel or equipment may enter areas where the potential for exposure to hazardous substances exists. The decontamination plan should:

- Determine the number and layout of decontamination stations.
- Determine the decontamination equipment needed.
- Determine appropriate decontamination methods.
- Establish procedures to prevent contamination of clean areas.
- Establish methods and procedures to minimize worker contact with contaminants during removal of personal protective clothing and equipment (PPE).
- Establish methods for disposing of clothing and equipment that are not completely decontaminated.

The plan should be revised whenever the type of personal protective clothing or equipment changes, the site conditions change, or the site hazards are reassessed based on new information.

Prevention of Contamination

The first step in decontamination is to establish Standard Operating Procedures that minimize contact with waste and thus the potential for contamination. For example:

- Stress work practices that minimize contact with hazardous substances (e.g., do *not* walk through areas of obvious contamination, do *not* directly touch potentially hazardous substances).
- Use remote sampling, handling, and container-opening techniques (e.g., drum grapplers, pneumatic impact wrenches).
- Protect monitoring and sampling instruments by bagging. Make openings in the bags for sample ports and sensors that must contact site materials.
- Wear disposable outer garments and use disposable equipment where appropriate.
- Cover equipment and tools with a strippable coating which can be removed during decontamination.
- Encase the source of contaminants, e.g., with plastic sheeting or overpacks.

In addition, Standard Operating Procedures should be established that maximize worker protection. For example, proper procedures for dressing prior to entering the Exclusion Zone will minimize the potential for contaminants to bypass the protective clothing and escape decontamination. In general, all fasteners should be used (i.e., zippers fully closed, all buttons used, all snaps closed, etc.). Gloves and boots should be tucked under the sleeves and legs of outer clothing, and hoods (if not attached) should be worn outside the collar. Another pair of tough outer gloves is often worn over the sleeves. All junctures should be taped to prevent contaminants from running inside the gloves, boots, and jackets (or suits, if one-piece construction).

Prior to each use, the personal protective equipment (PPE) should be checked to ensure that it contains no cuts or punctures that could expose workers to wastes. Similarly, any injuries to the skin surface, such as cuts and scratches, may enhance the potential for chemicals or infectious agents that directly contact the worker's skin to penetrate into the body. Particular care should be taken to protect these areas. Workers with large areas of

damaged skin should be kept from working on site until the skin heals.

All personnel should be trained in the Standard Operating Procedures for minimizing contact and maximizing worker protection, and these procedures should be enforced throughout site operations.

Types of Contamination

Contaminants can be located either on the surface of personal protective equipment or permeated into the PPE material. Surface contaminants may be easy to detect and remove; however, contaminants that have permeated a material are difficult or impossible to detect and remove. If contaminants that have permeated a material are not removed by decontamination, they may continue to permeate to either surface of the material where they can cause an unexpected exposure.

Five major factors affect the extent of permeation:

- **Contact time.** The longer a contaminant is in contact with an object, the greater the probability and extent of permeation. For this reason, minimizing contact time is one of the most important objectives of a decontamination program.
- **Concentration.** Molecules flow from areas of high concentration to areas of low concentration. As concentrations of wastes increase, the potential for permeation of personal protective clothing increases.
- **Temperature.** An increase in temperature generally increases the permeation rate of contaminants.
- **Size of contaminant molecules and pore space.** Permeation increases as the contaminant molecule becomes smaller, and as the pore space of the material to be permeated increases.
- **Physical state of wastes.** As a rule, gases, vapors, and low-viscosity liquids tend to permeate more readily than high-viscosity liquids or solids.

Decontamination Methods

All personnel, clothing, equipment, and samples leaving the contaminated area of a site (generally referred to as the Exclusion Zone) must be decontaminated to remove any harmful chemicals or infectious organisms that may have adhered to them. Decontamination methods either (1) physically remove contaminants, (2) inactivate contaminants by chemical detoxification or disinfection/sterilization, or (3) remove contaminants by a combination of both physical and chemical means. Various decontamination methods are listed in Table 10-1.

Physical Removal

In many cases, gross contamination can be removed by physical means involving dislodging/displacement, rinsing, wiping off, and evaporation. Physical methods involving high pressure and/or heat should be used only as necessary and with caution since they can spread contamination and cause burns. Contaminants that can be removed by physical means can be categorized as follows:

- **Loose contaminants.** Dusts and vapors that cling to equipment and workers or become trapped in small openings, such as the weave of the clothing fabrics, can be removed with water or a liquid rinse (see photograph). Removal of electrostatically attached materials can be enhanced by coating the clothing or equipment with anti-static solutions. These are available commercially as wash additives or anti-static sprays.
- **Adhering contaminants.** Some contaminants adhere by forces other than electrostatic attraction. Adhesive qualities vary greatly with the specific contaminants and the temperature. For example, contaminants such as glues, cements, resins, and muds have much greater adhesive properties than elemental mercury and, consequently, are difficult to remove by physical means. Physical removal methods for gross contaminants include scraping, brushing, and wiping. Removal of adhesive contaminants can be enhanced through certain methods such as solidifying, freezing (e.g., using dry ice or ice water), adsorption or absorption (e.g., with powdered lime or kitty litter), or melting.
- **Volatile liquids.** Volatile liquid contaminants can be removed from protective clothing or equipment by evaporation followed by a water rinse. Evaporation of volatile liquids can be enhanced by using steam jets. With any evaporation or vaporization process, care must be taken to prevent worker inhalation of the vaporized chemicals.

Table 10-1. Some Decontamination Methods

REMOVAL

Contaminant Removal

- Water rinse, using pressurized or gravity flow.
- Chemical leaching and extraction
- Evaporation/vaporization.
- Pressurized air jets
- Scrubbing/scraping. Commonly done using brushes, scrapers, or sponges and water-compatible solvent cleaning solutions
- Steam jets.

Removal of Contaminated Surfaces

- Disposal of deeply permeated materials, e.g., clothing, floor mats, and seats
- Disposal of protective coverings/coatings.

INACTIVATION

Chemical Detoxification

- Halogen stripping
- Neutralization.
- Oxidation/reduction
- Thermal degradation

Disinfection/Sterilization

- Chemical disinfection
- Dry heat sterilization
- Gas/vapor sterilization
- Irradiation.
- Steam sterilization.



Gross contaminants can be removed with water or a liquid rinse. Here, a member of the decontamination team rinses and scrubs the boots of a worker with a soft-bristled brush. Both individuals are wearing Level C personal protective equipment.

Chemical Removal

Physical removal of gross contamination should be followed by a wash/rinse process using cleaning solutions. These cleaning solutions normally utilize one or more of the following methods:

- **Dissolving contaminants.** Chemical removal of surface contaminants can be accomplished by dissolving them in a solvent. The solvent must be chemically compatible with the equipment being cleaned. This is particularly important when decontaminating personal protective clothing constructed of organic materials that could be damaged or dissolved by organic solvents. In addition, care must be taken in selecting, using, and disposing of any organic solvents that may be flammable or potentially toxic. Organic solvents include alcohols, ethers, ketones, aromatics, straight-chain alkanes, and common petroleum products.

Halogenated solvents generally are incompatible with personal protective equipment and are toxic. They should only be used for decontamination in extreme cases where other cleaning agents will not remove the contaminant.

Table 10-2 provides a general guide to the solubility of several contaminant categories in four types of solvents: water, dilute acids, dilute bases, and organic solvents. Because of the potential hazards, decontamination using chemicals should be done only if recommended by an industrial hygienist or other qualified health professional.

- **Surfactants.** Surfactants augment physical cleaning methods by reducing adhesion forces between contaminants and the surface being cleaned, and by preventing redeposit of the contaminants. Household detergents are among the most common surfactants. Some detergents can be used with organic solvents to improve the dissolving and dispersal of contaminants into the solvent [1].
- **Solidification.** Solidifying liquid or gel contaminants can enhance their physical removal. The mechanisms of solidification are: (1) moisture removal through the use of absorbents such as grounded clay or powdered lime; (2) chemical reactions via polymerization catalysts and chemical reagents; and (3) freezing using ice water.

Table 10-2. General Guide to Solubility of Contaminants in Four Solvent Types

SOLVENT	SOLUBLE CONTAMINANTS
Water	Low-chain hydrocarbons Inorganic compounds Salts Some organic acids and other polar compounds
Dilute Acids	Basic (caustic) compounds Amines Hydrazines
Dilute Bases For example: — detergent — soap	Acidic compounds Phenols Thiols Some nitro and sulfonic compounds.
Organic Solvents^a For example: — alcohols — ethers — ketones — aromatics — straight-chain alkanes (e.g., hexane) — common petroleum products (e.g., fuel oil, kerosene)	Nonpolar compounds (e.g., some organic compounds).

^aWARNING: Some organic solvents can permeate and/or degrade the protective clothing.

- **Rinsing.** Rinsing removes contaminants through dilution, physical attraction, and solubilization. Multiple rinses with clean solutions remove more contaminants than a single rinse with the same volume of solution. Continuous rinsing with large volumes will remove even more contaminants than multiple rinsings with a lesser total volume.
- **Disinfection/Sterilization.** Chemical disinfectants are a practical means of inactivating infectious agents. Unfortunately, standard sterilization techniques are generally impractical for large equipment and for personal protective clothing and equipment. For this reason, disposable PPE is recommended for use with infectious agents.

Many factors, such as cost, availability, and ease of implementation, influence the selection of a decontamina-

tion method. From a health and safety standpoint, two key questions must be addressed:

- Is the decontamination method effective for the specific substances present?
- Does the method itself pose any health or safety hazards?

Testing for the Effectiveness of Decontamination

Decontamination methods vary in their effectiveness for removing different substances. The effectiveness of any decontamination method should be assessed at the beginning of a program and periodically throughout the lifetime of the program. If contaminated materials are not being removed or are penetrating protective clothing, the decontamination program must be revised. The following methods may be useful in assessing the effectiveness of decontamination.

Visual Observation

There is no reliable test to immediately determine how effective decontamination is. In some cases, effectiveness can be estimated by visual observation.

- **Natural light.** Discolorations, stains, corrosive effects, visible dirt, or alterations in clothing fabric may indicate that contaminants have not been removed. However, not all contaminants leave visible traces; many contaminants can permeate clothing and are not easily observed.
- **Ultraviolet light.** Certain contaminants, such as polycyclic aromatic hydrocarbons, which are common in many refined oils and solvent wastes, fluoresce and can be visually detected when exposed to ultraviolet light. Ultraviolet light can be used to observe contamination of skin, clothing, and equipment; however, certain areas of the skin may fluoresce naturally, thereby introducing an uncertainty into the test [2,3,4]. In addition, use of ultraviolet light can increase the risk of skin cancer and eye damage; therefore, a qualified health professional should assess the benefits and risks associated with ultraviolet light prior to its use at a waste site.

Wipe Sampling

Wipe testing provides after-the-fact information on the effectiveness of decontamination. In this procedure, a dry or wet cloth, glass fiber filter paper, or swab is wiped over the surface of the potentially contaminated object and then analyzed in a laboratory. Both the inner and outer surfaces of protective clothing should be tested. Skin may also be tested using wipe samples.

Cleaning Solution Analysis

Another way to test the effectiveness of decontamination procedures is to analyze for contaminants left in the cleaning solutions. Elevated levels of contaminants in the final rinse solution may suggest that additional cleaning and rinsing are needed.

Testing for Permeation

Testing for the presence of permeated chemical contaminants requires that pieces of the protective garments be sent to a laboratory for analysis.

Health and Safety Hazards

While decontamination is performed to protect health and safety, it can pose hazards under certain circumstances. Decontamination methods may:

- Be incompatible with the hazardous substances being removed (i.e., a decontamination method may react with contaminants to produce an explosion, heat, or toxic products).
- Be incompatible with the clothing or equipment being decontaminated (e.g., some organic solvents can permeate and/or degrade protective clothing).
- Pose a direct health hazard to workers (e.g., vapors from chemical decontamination solutions may be hazardous if inhaled, or they may be flammable).

The chemical and physical compatibility of the decontamination solutions or other decontamination materials must be determined before they are used. Any decontamination method that permeates, degrades, damages, or otherwise impairs the safe functioning of the PPE is incompatible with such PPE and should not be used. If a decontamination method does pose a direct health hazard, measures must be taken to protect both decontamination personnel and the workers being decontaminated. Figure 10-1 presents a decision aid for evaluating the health and safety aspects of decontamination methods.

Decontamination Facility Design

At a hazardous waste site, decontamination facilities should be located in the Contamination Reduction Zone (CRZ), i.e., the area between the Exclusion Zone (the contaminated area) and the Support Zone (the clean area) as shown in Figure 9-1 in Chapter 9.

The level and types of decontamination procedures required depend on several site-specific factors including:

- The chemical, physical, and toxicological properties of the wastes.
- The pathogenicity of infectious wastes.
- The amount, location, and containment of contaminants.
- The potential for, and location of, exposure based on assigned worker duties, activities, and functions.
- The potential for wastes to permeate, degrade, or penetrate materials used for personal protective clothing and equipment, vehicles, tools, buildings, and structures.
- The proximity of incompatible wastes.
- The movement of personnel and/or equipment among different zones.
- Emergencies.
- The methods available for protecting workers during decontamination.

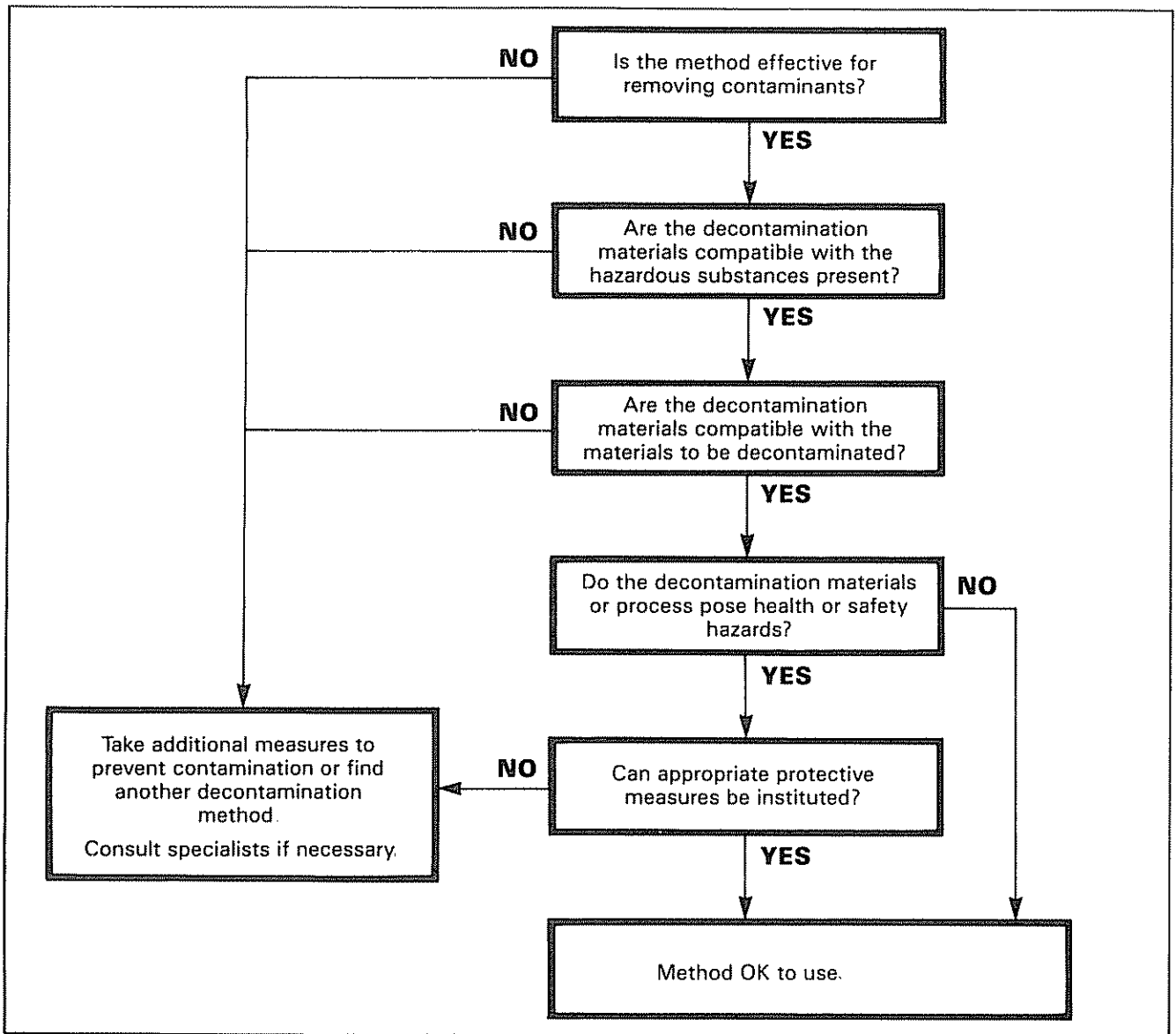


Figure 10-1. Decision Aid for Evaluating Health and Safety Aspects of Decontamination Methods.

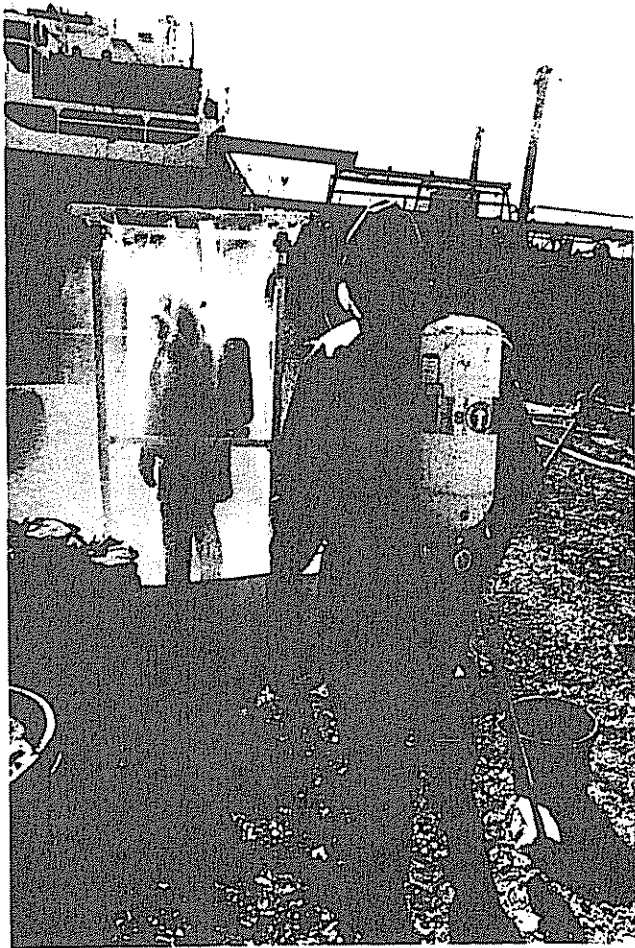
- The impact of the decontamination process and compounds on worker safety and health.

Decontamination procedures must provide an organized process by which levels of contamination are reduced. The decontamination process should consist of a series of procedures performed in a specific sequence. For example, outer, more heavily contaminated items (e.g., outer boots and gloves) should be decontaminated and removed first, followed by decontamination and removal of inner, less contaminated items (e.g., jackets and pants). Each procedure should be performed at a separate station in order to prevent cross contamination. The sequence of stations is called the decontamination line.

Stations should be separated physically to prevent cross contamination and should be arranged in order of

decreasing contamination, preferably in a straight line. Separate flow patterns and stations should be provided to isolate workers from different contamination zones containing incompatible wastes. Entry and exit points should be conspicuously marked, and the entry to the Contamination Reduction Zone (CRZ) from the Exclusion Zone should be separate from the entry to the Exclusion Zone from the CRZ. Dressing stations for entry to the CRZ should be separate from redressing areas for exit from the CRZ. Personnel who wish to enter clean areas of the decontamination facility, such as locker rooms, should be completely decontaminated.

Examples of decontamination lines and procedures for personnel wearing various levels of protection are provided in Appendix D.



A member of the decontamination team suited in Level B personal protective equipment stands by to scrub down a worker after an initial rinse down in the decontamination shower.

Decontamination Equipment Selection

Table 10-3 lists recommended equipment for decontamination of personnel, personal protective clothing, and equipment. In selecting decontamination equipment, consider whether the equipment itself can be decontaminated for reuse or can be easily disposed of. Table 10-4 lists recommended equipment for decontamination of large equipment and vehicles. Note that other types of equipment not listed in Tables 10-3 and 10-4 may be appropriate in certain situations.

Disposal Methods

All equipment used for decontamination must be decontaminated and/or disposed of properly. Buckets, brushes, clothing, tools, and other contaminated equipment should be collected, placed in containers, and labeled. Also, all spent solutions and wash water should be collected and disposed of properly. Clothing that is not completely decontaminated should be placed in plastic bags, pending further decontamination and/or disposal.

Table 10-3. Some Recommended Equipment for Decontamination of Personnel and Personal Protective Clothing and Equipment

- Drop cloths of plastic or other suitable materials on which heavily contaminated equipment and outer protective clothing may be deposited.
- Collection containers, such as drums or suitably lined trash cans, for storing disposable clothing and heavily contaminated personal protective clothing or equipment that must be discarded.
- Lined box with absorbents for wiping or rinsing off gross contaminants and liquid contaminants
- Large galvanized tubs, stock tanks, or children's wading pools to hold wash and rinse solutions. These should be at least large enough for a worker to place a booted foot in, and should have either no drain or a drain connected to a collection tank or appropriate treatment system.
- Wash solutions selected to wash off and reduce the hazards associated with the contaminants
- Rinse solutions selected to remove contaminants and contaminated wash solutions
- Long-handled, soft-bristled brushes to help wash and rinse off contaminants
- Paper or cloth towels for drying protective clothing and equipment.
- Lockers and cabinets for storage of decontaminated clothing and equipment
- Metal or plastic cans or drums for contaminated wash and rinse solutions
- Plastic sheeting, sealed pads with drains, or other appropriate methods for containing and collecting contaminated wash and rinse solutions spilled during decontamination.
- Shower facilities for full body wash or, at a minimum, personal wash sinks (with drains connected to a collection tank or appropriate treatment system).
- Soap or wash solution, wash cloths, and towels for personnel.
- Lockers or closets for clean clothing and personal item storage

Personal Protection

Decontamination workers who initially come in contact with personnel and equipment leaving the Exclusion Zone will require more protection from contaminants than decontamination workers who are assigned to the last station in the decontamination line. In some cases, decontamination personnel should wear the same levels of PPE as workers in the Exclusion Zone. In other cases, decontamination personnel may be sufficiently protected by wearing one level lower protection (e.g., wearing Level C protection while decontaminating workers who are wearing Level B).

The level of protection required will vary with the type of decontamination equipment used. For example, workers using a steam jet may need a different type of respiratory protection than other decontamination personnel because of the high moisture levels produced by steam jets. In some situations, the cleaning solutions used and wastes removed during decontamination may generate harmful vapors. Appropriate equipment and clothing for protecting decontamination personnel should be selected by a qualified health and safety expert.

Table 10-4. Some Recommended Equipment for Heavy Equipment and Vehicle Decontamination

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- Storage tanks of appropriate treatment systems for temporary storage and/or treatment of contaminated wash and rinse solutions.
 - Drains or pumps for collection of contaminated wash and rinse solutions.
 - Long-handled brushes for general exterior cleaning.
 - Wash solutions selected to remove and reduce the hazards associated with the contamination.
 - Rinse solutions selected to remove contaminants and contaminated wash solutions.
 - Pressurized sprayers for washing and rinsing, particularly hard-to-reach areas.
 - Curtains, enclosures, or spray booths to contain splashes from pressurized sprays.
 - Long-handled brushes, rods, and shovels for dislodging contaminants and contaminated soil caught in tires and the undersides of vehicles and equipment.
 - Containers to hold contaminants and contaminated soil removed from tires and the undersides of vehicles and equipment.
 - Wash and rinse buckets for use in the decontamination of operator areas inside vehicles and equipment.
 - Brooms and brushes for cleaning operator areas inside vehicles and equipment.
 - Containers for storage and disposal of contaminated wash and rinse solutions, damaged or heavily contaminated parts, and equipment to be discarded.
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All decontamination workers are in a contaminated area and must themselves be decontaminated before entering the clean Support Zone. The extent of their decontamination should be determined by the types of contaminants they may have contacted and the type of work they performed.

Emergency Decontamination

In addition to routine decontamination procedures, emergency decontamination procedures must be established. In an emergency, the primary concern is to prevent the loss of life or severe injury to site personnel. If immediate medical treatment is required to save a life, decontamination should be delayed until the victim is stabilized. If decontamination can be performed without interfering with essential life-saving techniques or first aid, or if a worker has been contaminated with an extremely toxic or corrosive material that could cause severe injury or loss of life, decontamination must be performed immediately. If an emergency due to a heat-related illness develops, protective clothing should be removed from the victim as soon as possible to reduce the heat stress. During an emergency, provisions must also be made for protecting medical personnel and disposing of contaminated clothing and equipment. See Chapter 12 for further information on decontamination during emergencies.

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