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15 August 2003

ENGINEERING AND DESIGN

Safety and Health Aspects of HTRW Remediation Technologies

ENGINEER MANUAL

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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314-1000

CEMP-RA

Manual
No. 1110-1-4007

15 August 2003

Engineering and Design
SAFETY AND HEALTH ASPECTS OF HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE REMEDIATION TECHNOLOGIES

1. **Purpose.** This manual identifies and analyzes generic safety and health hazards for 25 remediation technologies used in clean-up operations at Hazardous, Toxic, and Radioactive Waste (HTRW) sites throughout the country. This EM is intended for use by U.S. Army Corps of Engineers (USACE) project managers, technical design personnel, and safety and health professionals at all levels, and technical USACE contractor personnel responsible for worker safety and health during all phases of remediation.

2. **Applicability.** This EM applies to all HQUSACE elements and USACE commands responsible for HTRW remediation projects.

3. **Distribution.** Approved for public release, distribution is unlimited.

4. **References.** References are listed in Appendix A

5. **Discussion.** This manual updates guidance for identifying unique or significant safety and health hazards associated with each of the 25 technologies addressed, first published on 30 September 1999. Each chapter includes a brief technology description, hazard analysis, and a control point list, designating groups affected by and responsible for the hazards.

Users of this manual are cautioned to utilize the information provided with clear knowledge of specific project requirements and professional judgment. While every attempt has been made to identify hazards of special concern, the manual is not intended to be an all encompassing analysis, identifying each and every physical, chemical, radiological, or biological hazard associated with the 25 remediation technologies treated. It is critical for the user, especially those with less professional safety and health training or knowledge, to recognize that the hazard analyses presented in this EM are starting points rather than end points in evaluating the remediation technologies addressed. Each hazard analysis presented must be considered generic and not specific to actual site conditions.

This manual supersedes EM 1110-1-4007, dated 30 September 1999.

The user of this EM in the end must use all the resources available in identifying project-specific hazards.

FOR THE COMMANDER:

1 Appendix
(See Table of Contents)

MICHAEL J. WALSH
Colonel, Corps of Engineers
Chief of Staff

DEPARTMENT OF THE ARMY **EM 1110-1-4007**
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Chapter 1
Landfill Covers and Liners

1-1. General

The technology of landfill liners and covers is discussed briefly in the chapter's first section. The second portion of the chapter contains a hazard analysis with controls and control points listed.

1-2. Technology Description

Landfills are constructed to contain newly generated wastes or to convert existing waste management units to a permanent disposal facility. Landfills are constructed using liners and covers to minimize exposure of the landfill contents to the environment. Liners and covers are described in this section.

a. Liners.

Types of liners, components of a liner system, and installation methods are described below.

Landfills are lined on the bottom and sides with natural and synthetic barriers to prevent liquids and waste from escaping into underlying soils. An example of a natural liner material is compacted clay; synthetic liners include high-density polyethylene (HDPE), geosynthetic clay (GCL), and polyvinyl chloride (PVC). The synthetic and natural liners are components of an integrated system to contain and collect liquids (leachate) that leach from the landfilled materials.

An example of a typical Resource Conservation and Recovery Act (RCRA) landfill liner includes two liners and a leachate recovery/detection system at the bottom of the waste management unit. A double liner system consists of the following components from top to bottom:

- Leachate collection system (sand or gravel, or both).
- Geomembrane.
- Secondary leachate collection/leak detection layer constructed of sand/gravel.
- Secondary synthetic liner.
- Low permeability compacted clay liner.

Monitoring the drainage layer between the liners confirms the integrity of the upper liner.

Clay liners are installed as lifts of a low permeability clay at the appropriate moisture content and density to give the strength and permeability needed for the liner. The lifts are placed until the correct total thickness of the liner is achieved. Nuclear density gauges (with radioactive sources) are often used to estimate the moisture content and density of the clay lifts.

Synthetic liners, such as HDPE, are unrolled from spools and installed as long sheets. They are usually thermal-fusion welded together at the seams. PVC, which can also be used as a liner material, is installed as sheets and is typically seamed by chemical or thermal fusion methods.

As the liner system is installed, leachate collection systems are installed to collect and treat leachate generated by the landfill waste. Leachate is often treated in simple biological or other treatment processes at the site, or is trucked or piped to a local POTW (Publicly Owned Treatment Works) or industrial treatment plant.

b. Covers.

Cover purpose, system components, and installation steps are discussed in this section.

Once the lined landfill is full, an engineered cover is installed. The purpose of the cover is to keep water from infiltrating into the waste materials and generating leachate that could be released from the landfill, while maintaining a protective vegetative cover on top of the landfill to secure the landfilled materials in place. An engineered cover can consist of natural or synthetic materials, or a combination of the two.

The cover system consists of the following components from bottom to top:

- Low permeability liner to prevent water infiltration.
- Sand or geonet to provide a drainage layer.
- Protective soil cover.
- Top soil.
- Vegetative cover.

Typical cover installation steps include the following:

- Prior to installing an engineered cover, the surface of the landfill is contoured to enhance water runoff. This may involve regrading refuse in the landfill to minimize waste volumes and to ensure positive drainage.
- The low permeability liner is installed on top of the waste materials.
- A layer of coarse sand or a geonet drainage layer is then placed over the liner to collect and transport the water off the surface of the landfill cover.
- A protective soil layer is added to protect the underlying cover components and support vegetative growth.
- As the landfill cover is installed, gas collection and venting systems are installed to manage the gas (methane, hydrogen sulfide, etc.) often produced in landfills. Figure 1-1 illustrates the landfill cover and liner structure.

If the gas is not collected, it can cause heaving and damage the cover, change drainage patterns, or it can escape the landfill and migrate to basements and buildings where it may be toxic, explosive, or asphyxiating. Gas migration is controlled by providing migration pathways and cover vents.

Off-gases can be treated in several ways. If permitted, the most common treatment is simple venting, either passive (by gas pressure generated in the landfill) or active (by vacuum blower assistance to pull gas from the landfill). If simple venting is not acceptable, the gas may be passively or actively vented to a flare. In some cases, the gas is burned in engines or turbines, which may (in turn) drive generators for local power use or feed into the local electrical utility grids.

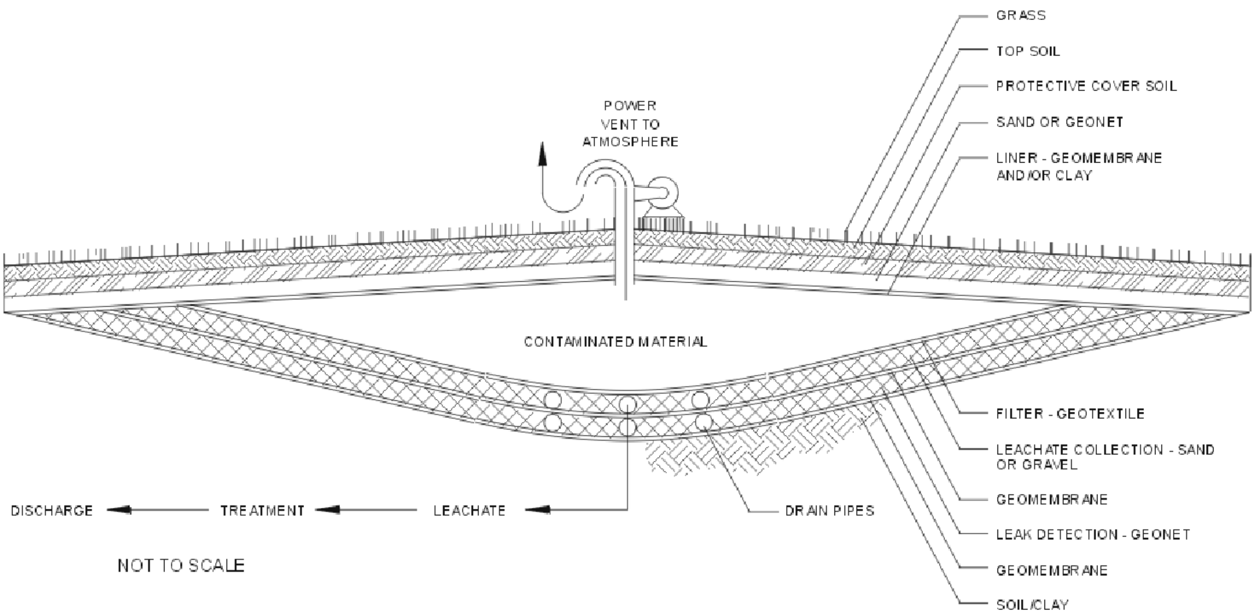

FIGURE 1-1. LANDFILL COVERS/LINERS

1-3. Hazard Analysis

Principal unique hazards associated with landfill covers and liners, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Wind/Liner Handling.*
Description. Landfill covers/liners must be handled using heavy equipment to control the roll to prevent crushing workers on the down hill side of the rollout, and must not be installed during periods of high winds, which may pose trip hazards or throw or knock down workers holding or standing on or near unsecured liners.

Control. Controls for wind hazards include:

- Select an appropriate liner material.
- Control the rollout of the liners using heavy equipment operated by trained and authorized workers only. Never place workers on the downhill side of the rollout operation.
- Install liners on calm days.
- Place soil or sand bags onto the unrolled portion of the liner. The liner installer should determine the temporary anchoring needs at the time of installation and ensure that anchoring specifications are met or exceeded.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) *Slip Hazards*.
Description. Geomembrane and wet clay liners can be very slippery, especially when placed on the slopes or used for footing while a worker carries equipment or materials.

Control. Controls for slip hazards include:

- Consider controls for slip hazards during design (see EM 385-1-1, Section 21.A).
- Use rope ladders for ascending/descending lined slopes.
- Select appropriate shoe soles for maximum traction.
- Lay high-traction walkways over the liners.
- Carry light loads or use more workers to carry larger single loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) *Sharp Liner Edges*.
Description. Synthetic liners are made in varying thicknesses and rigidities. Some liner edges are sharp and stiff after being cut to shape and can inflict cuts and abrasions.

Control. Controls for sharp liners include:

- Wear long-sleeved shirts, full-length pants, and appropriate work gloves (e.g., leather or leather-palmed) for better grip and protection.
- Wear safety glasses or goggles to help prevent eye injuries and cut resistant glove liners.

CONTROL POINT: Construction, Operations, Maintenance

(4) *Heat Stress*.
Description. Heat stress may affect workers during operations. Because most synthetic cover/liner materials are dark or black to enhance ultraviolet (UV) resistance, they absorb radiant energy and emit considerable heat. The surfaces of cover/liner materials can also reflect considerable angled radiant energy, amplifying the energy absorbed by the worker even when wearing a hat. Hot and humid conditions, combined with such operations as liner welding or other heat-

producing activities, may also increase the potential for a heat-related illness, including heat exhaustion and heat stroke.

Control. Controls for heat stress include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts or close to operating equipment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.
- Use the Buddy System.
- Additional measures include working nights, working early and late in the day, and scheduling jobs for cooler times of the year.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Design, Construction, Operations

(5) *Muscle Injuries*.
Description. Manual lifting and moving heavy materials used for anchoring may expose workers to muscle strain/sprain to the lower back or shoulder.

Control. Controls for muscle strain include:

- Use mechanical lifting equipment, such as cranes, backhoes with cables, and spreaders to lift and move liner material.
- Train workers in proper material handling procedures.

CONTROL POINT: Construction, Operations

(6) *Burn Hazards*.
Description. Equipment, including hot-shoe welders and extrusion welders, can expose workers to burn hazards. Flare systems for the discharge of off-gas from the landfill and generators may also pose burn hazards.

Control. Controls for burn hazards include:

- Make sure all personnel using welding equipment are trained and experienced in the proper use of hot-shoe welding equipment.
- Inform those using or exposed to hot operating equipment about equipment hazards at the start of the project and during daily health and safety meetings.
- Guard all exposed, heated surfaces when practical to prevent accidental contact.
- Use insulated gloves with gauntlets, coveralls, and face protection.

- Request manufacturer's and installer's procedures for the safe operation, repair, and maintenance of this equipment and include it in health and safety and installation work plans.

CONTROL POINT: Construction, Operations

(7) *Fire and Explosion Hazards*.
Description. Fire and explosion hazards may exist if the off-gas flare systems are improperly designed, installed, or maintained. Also, volatile organic compounds (VOCs) may be generated as off-gas products from wastes in the landfill and accumulate. These gases are explosive and may be ignited as off-gas products by sparks, open flame, or heated surfaces.

Control. Controls for fire and explosion hazards include:
- Train workers in the hazards of working in the vicinity of the off-gas flare systems and in the nature of the explosive landfill gases being collected by the systems.
- Train the operators in emergency procedures in case of a catastrophic event; in life saving first aid procedures for burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency off-gas flare isolation procedures.
- Design and install an off-gas management system using the guidance provided in EPA/625/4-89/022, "Requirements of Hazardous Waste Landfill Design, Construction and Closure."
- Install gas collection and vent systems in the cover. Unless properly vented, the lateral migration of gas should be anticipated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(8) *Elevated Gas Levels*.
Description. Off-gas drive engines may generate carbon monoxide and carbon dioxide during operation. Also, VOCs generated as off-gas products by landfill wastes may accumulate. If the gases are not properly vented, they may accumulate to hazardous levels in areas such as buildings and sheds. Exposure to elevated levels of these gases may cause headaches, dizziness, nausea, or possibly even death.

Control. Controls for elevated gas levels include:
- Specify (landfill designer) the ventilation/flaring requirements necessary to ensure adequate venting of off-gases from beneath landfill covers and prevent the potential migration of accumulating gases into nearby buildings or other structures on or off site.
- Ventilate buildings or other enclosed-space and test to prevent accumulations of carbon monoxide, carbon dioxide, methane, hydrogen sulfide, and other dangerous gases.

CONTROL POINT: Design, Construction, Operations, Maintenance

(9) *Electric Shock Hazards*.
Description. Electric shock hazards may exist from on-site generators and infrastructure. Generators may be present during construction, operations (off-gas dependent generation), or maintenance.

Control. Controls for electric shock hazards include:

- Verify that the hazardous area classifications, as defined in National Fire Protection Association (NFPA) 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Verify that all controls, wiring, and equipment, including the on-site generators/infrastructure, conform to the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Make sure that equipment is grounded or provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70.
- Permit only trained and experienced workers to work on the systems.
- Include appropriate lock-out/tag-out procedures in the construction and O&M of the system.
- Make fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(10) *Noise Hazards*.
Description. Heavy equipment and portable electric generators may create noise hazards to operators or workers in the immediate vicinity.

Control. Controls for noise hazards include:

- Implement a noise protection program (see 29 CGR1926.52).
- Wear hearing protection if exposed to noise at or above 85 decibels (steady-state) or to impulse noise of 140 decibels such as that generated by heavy construction equipment or generators.

CONTROL POINT: Construction, Operations, Maintenance

(11) *Equipment Hazards*.
Description. Any equipment (small and large) used to move soil and liner materials on steep slopes may roll over, crushing the operator.

Control. Controls for equipment hazards include:

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe slopes during construction (construction contractor).
- Use equipment with roll-over protective devices (ROPS).
- Do not operate equipment on excessively steep slopes.

- Wear seat belts during operation.
- Train workers in the potential operational hazards associated with and the safety features of the heavy equipment.

CONTROL POINT: Design, Construction, Operations

(12) *Traffic Hazards—Worker*.
Description. During construction, heavy vehicular traffic may also pose a danger to site workers. The movement of heavy equipment in high traffic areas or on public roads may further pose a danger to site workers or to the public.

Control. Controls for traffic hazards include:
- Address haul road considerations in the design stage (see EM 385-1-1, Section 21, for control measures).
- Use warning devices where equipment must cross over active roads according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."

CONTROL POINT: Design, Construction, Operations, Maintenance

(13) *Trench Hazards*.
Description. During installation of the liner, trenches may be excavated to secure the liner edges. Open excavations may pose a trip hazard to workers crossing the excavation or a collapse hazard to workers working near trench edges.

Control. Controls for trench hazards include:
- Provide protection to prevent personnel, vehicles, and equipment from falling into excavations.
- Inform all workers of on-site hazards and allowable access to the landfill.
- See EM 385-1-1, Section 25, for additional control measures and requirements.

CONTROL POINT: Construction, Operations, Maintenance

(14) *Heavy Equipment Hazards*.
Description. Workers may be seriously injured or killed by the operation of heavy equipment moving liners and other materials. As liners are unrolled, workers may be injured if the liner is allowed to unroll down a working slope of a landfill.

Control. Controls for heavy equipment include:
- Use earth-moving equipment and trucks equipped with a backup alarm that alerts workers.
- Approach operating equipment from the front and always within view of the operator.

- Develop an alarm communication system to warn workers during liner unrolling activities, as necessary.
- Train workers in the potential operational hazards and safety features of the heavy equipment.

CONTROL POINT: Construction, Operations, Maintenance

(15) *Steam Pressure Washing Hazards*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep body parts away from steam pressure ejection nozzle.
- Use safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from decontamination operations into a tank or pit. Drain walking surfaces and keep free of standing liquids or mud.
- Allow only trained and authorized workers to operate the steam pressure equipment.

CONTROL POINT: Construction, Operations, Maintenance

(16) *Respirable Quartz Hazard*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet soil periodically with water to minimize worker exposure. Wetting of soil may require additional controls to deal with resulting water, ice, mud, etc. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air purifying respirator equipped with N, R or P100 particulate air filters.
- Train workers in the potential inhalation hazards of crystalline silica dust exposures.

CONTROL POINT: Design, Construction, Operations, Maintenance

(17) *Ultraviolet (UV) Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and the corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage.

Control. Controls for UV radiation include:
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas if possible.

CONTROL POINT: Construction, Operations

(18) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

(19) *Traffic Hazards*.
Description. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil from borrow pits to the landfill.

Control. A control for traffic hazards to the general public includes:
- Develop a traffic management plan before excavation commences to help prevent accidents involving dump trucks and automobiles. EM 385-1-1, Section 21, provides plan details.

CONTROL POINT: Design, Construction, Operations

(20) *Utility Contact Hazards*.
Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for utility contact hazards include:
- Locate overhead power lines, either existing or proposed, in the pre-design phase.

- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from a power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.

CONTROL POINT: Design, Construction, Operations

(21) *Explosion Hazards*.
Description. During excavation activities, workers may be exposed to explosion hazards associated with unexploded ordnance or buried flammable materials at military bases.

Control. Controls for explosion hazards include:

- Do a thorough pre-design records search of the landfill to identify the possible presence of unexploded ordnance in the areas to be excavated.
- Train the operators in the hazards of excavating in areas with potential ordnance.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for severe trauma that would be expected in the event of an explosion, in burns, and extracting, extinguishing, and stabilizing victims, and in emergency excavation isolation procedures.
- Use metal detectors or ground-penetrating radar prior to excavation to clear the excavation area of such hazards. Hand probes may also be used.
- Excavate soil suspected of containing an underground hazard slowly and with caution.

CONTROL POINT: Design, Construction, Operations

b. Chemical Hazards.

(1) *Solvents*.
Description. The heating or solvent welding of the cover/liner materials may generate vapors from adhesives, thermal decomposition, or outgassing of liner material components such as plasticizers (e.g., phthalate esters, adipate esters), or from any solvents contained in the adhesive (e.g., methyl ethyl ketone, methylene chloride). A dermal hazard may also exist from skin contact with the cementing chemicals or waste materials generated during installation.

Control. Controls for solvents include:

- Ventilate the area or use appropriate respirators to control exposures during installation. Select respirator cartridges based on consultations with the liner manufacturer and the potential compounds that may be emitted.
- Use personal protective equipment (PPE) such as chemically resistant gloves (e.g., nitrile) to help control dermal exposure.

- Perform an analysis of possible chemical exposures prior to issuing gloves and other PPE. The analysis should include obtaining specific chemical hazard information on the liner constituents.

CONTROL POINT: Construction, Operations, Maintenance

(2) *Waste Chemicals*.
Description. Workers may be exposed to waste chemicals such as airborne dusts and particulates and VOC emissions resulting from redistribution of wastes associated with liner installation, landfill off-gassing, or leachate collected by leachate collection and treatment systems. Leachate may contain both organic and inorganic constituents.

Control. Controls for waste chemicals include:
- Apply water or an amended water solution to control airborne dust, particulate, and VOCs generation.
- Use respiratory protection including air-purifying respirators equipped with approved filters/cartridges such as N, R or P100 or N, R or P95 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Use PPE to control leachate exposure.
- Conduct an analysis of work tasks and potential chemical exposure, including a chemical waste profile, to determine correct PPE and respirator cartridges if necessary.

CONTROL POINT: Construction, Operations, Maintenance

(3) *Hazardous Landfill Gases*.
Description. Methane generated by existing landfills is highly flammable and is an asphyxiant. The off-gas generated from an existing landfill may also contain concentrations of vinyl chloride and hydrogen sulfide. Vinyl chloride is a human carcinogen, and hydrogen sulfide damages lungs and circulation. The hazards from exposure to landfill gas must be considered during pre-design, design, construction, operations, and maintenance.

Control. Controls for landfill gases include:
- Perform soil gas surveys during pre-design to determine the levels of methane, hydrogen sulfide, and vinyl chloride in soil. The methods for collecting landfill off-gas samples (barhole probe, permanent gas monitoring, and gas extraction wells) are discussed in EPA-450/3-90-011a, “Air Emissions From Municipal Solid Waste Landfills.”
- Periodically monitor landfill off-gas during construction, especially in enclosed areas such as excavations and other low, undisturbed areas.
- Ventilate an area if methane levels reach 10 percent of the Lower Explosive Limit (LEL).
- Train workers in the potential hazards of landfill off-gassing.

CONTROL POINT: Design, Construction, Operations

c. Radiological Hazards.

(1) *Nuclear Gauge Hazards*.
Description. Use of a nuclear gauge to determine the moisture content and density of the clay liner and cover may pose a radiation hazard.

Control. Controls for nuclear gauges include:

- Use personnel with the proper training and experience in the use and maintenance of the neutron density gauge.
- Comply with Nuclear Regulatory Commission (NRC) Standards for Protection Against Radiation (10 CFR 20), NRC Rules of General Applicability to Domestic Licensing of Byproduct Material (10 CFR 30), licensing requirements for the particular source (10 CFR 31, 32, or 39), all license conditions, and OSHA 29 CFR 1910.1096 or 29 CFR 1926.53.

CONTROL POINT: Construction, Maintenance

(2) *Radioactive Materials*.
Description. Although an uncommon hazard, radioactive materials may pose a hazard by exposure to radiation or inhalation/ingestion of radioactive particles during the installation of covers/liners. A variety of radiation sources may have ended up in landfills, including Naturally Occurring Radioactive Materials (NORM) from oil and gas exploration and production, medical wastes, low-level research wastes, and disposed of instruments and their sources.

Some radioactive materials are pyrophoric. Machine filings or turnings of uranium or thorium may spontaneously ignite, and pose fire and airborne radioactivity hazards. Turnings or filings buried in existing landfills may combust upon excavation when the material is exposed to air. Other radioactive materials may present an external exposure hazard.

Control. Controls for radioactive materials include:

- Test the contents of the landfill prior to construction or maintenance operations.
- Consult a qualified health physicist to determine the exposure potential, the nature and extent of the radiation or radioactive materials, necessary controls, and the appropriate PPE to prevent exposure.
- Provide decontamination facilities if required, using guidance such as *The Health Physics and Radiological Health Handbook* (Bernard, Schleien, Scinta, Inc. 1992).

CONTROL POINT: Design, Construction, Operations, Maintenance

d. Biological Hazards.

(1) *Biological Contaminants*.
Description. At those sites having medical wastes or sewage sludge, biological hazards may result through inhalation/ingestion and dermal contact with microbes in the waste and pathogens, such as *Coccidioides sp.*, *Histoplasma sp.*, and *Mycobacterium sp.* Exposure to biological hazards may result in eye and skin bacterial and fungal infections.

Control. Controls for biological contaminants include:

- Test the contents of the landfill to assess the potential risk and prevent exposure to dangerous biological materials during construction. If such materials are present, follow the next step.
- Determine the nature and extent of biological hazards and the appropriate PPE to prevent exposure such as respiratory protection equipped with N, R, or P100 or N, R, or P95 particulate air filters approved for microbial inhalation hazards and provide decontamination.
- Prevent inhalation/ingestion of biological materials through dust suppression techniques using water or amended water treatments. Use dust suppression techniques only when adequate runoff controls are in place and a slip hazard is not generated from the wetting of the material.
- Control eye infections by using portable eyewashes to remove dust or other objects from the eyes.
- Use germicidal soap prior to eating or drinking.

CONTROL POINT: Design, Construction

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit West Nile Virus.

Control. Controls for pests include:

- Periodically inspect the site to identify bee hives and wasp nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as an active ingredient, for exposure control. Workers should check their skin and clothing for ticks periodically throughout the workday. Clothing may be treated with permethrin clothing repellent BEFORE donning it, for added protection.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 2
Extraction/Monitoring Wells (Vertical/Horizontal Wells) and Soil Flushing

2-1. General

In the chapter's first section, extraction/monitoring well components and how they function, along with well development techniques, are briefly described. Soil flushing methods are also discussed. The second portion of the chapter is a hazard analysis with controls and control points listed.

2-2. Technology Description

a. Extraction/Monitoring Well Components and Methods.

Extraction/monitoring wells are typically vertical or horizontal PVC, steel, or stainless steel pipes with screened sections to allow groundwater or soil gas to enter the pipe interior. The wells are typically installed into a vadose (unsaturated) zone or an aquifer at strategic locations to extract or monitor groundwater or soil gas. The pipe is installed into a slightly oversized borehole, typically created by using a hollow stem auger-drilling rig. Air and mud rotary methods may be used to install deeper wells. The annular space between pipe and boreholes, where the pipe is screened, is typically surrounded with porous sand or other packing to filter out larger particles as water/air enters the well. The boring outside the well pipe, above the filter pack (above the screened well section), is typically sealed with cement or bentonite slurry to prevent mixing of groundwater/air from above the screened zone with water or air entering the well down the boring and above the filter pack.

A down-hole pump (electrical or air driven) is typically used for water extraction wells to move the contaminated water to the surface. A surface vacuum pump (positive displacement, centrifugal, or regenerative depending on air flow, soil formations, and other factors) is used for air extraction. Water is usually extracted from monitoring wells using manual bailers, peristaltic, or similar pumps that may or may not be dedicated to each well.

Small "alpha" type air pumps feeding tedlar bags are typically used for air monitoring wells to extract samples through a well cap nipple, or through a small tube inserted through the well cap and down the barrel of the well. The extracted water/air may then be analyzed (monitoring wells) or treated (extraction wells) with above-ground treatment technologies. A schematic of a typical vertical extraction/monitoring well is presented in Figure 2-1. Once installed, the wells are developed by surging water along the well, jetting, pumping, bailing or air sparging (on and off) to remove drilling mud, silt, and cutting materials. The procedure allows free flowing water/air into the well.

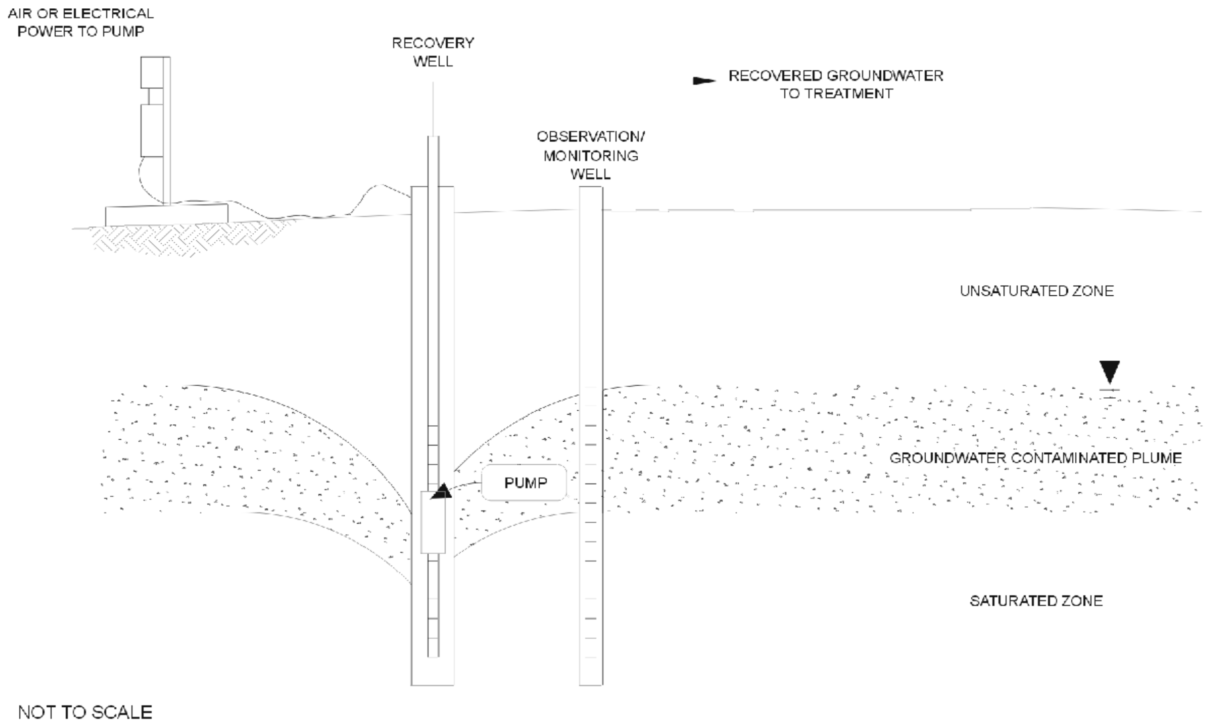

FIGURE 2-1. VERTICAL EXTRACTION WELL

An alternative to vertical extraction wells is horizontal extraction of water/air through wells installed using either a drill rig designed to slant or curve the boring or temporary trenches to install the well pipe at a horizontal orientation. Horizontal wells offer a greatly enhanced capture zone as a long horizontal length of the well can be screened and filter packed, while vertical wells' screened lengths are limited by the depth of the aquifer. Figure 2-2 shows a schematic of a horizontal well.

Extraction wells are the most common water/air recovery technology used for groundwater/soil cleanup in "pump-and-treat" systems and in soil vapor extraction (SVE) systems. The effectiveness of pump-and-treat systems, and hence extraction wells, depends strongly on hydrogeologic properties (e.g., porosity, permeability) and contaminant properties (e.g., volatility, partitioning coefficients).

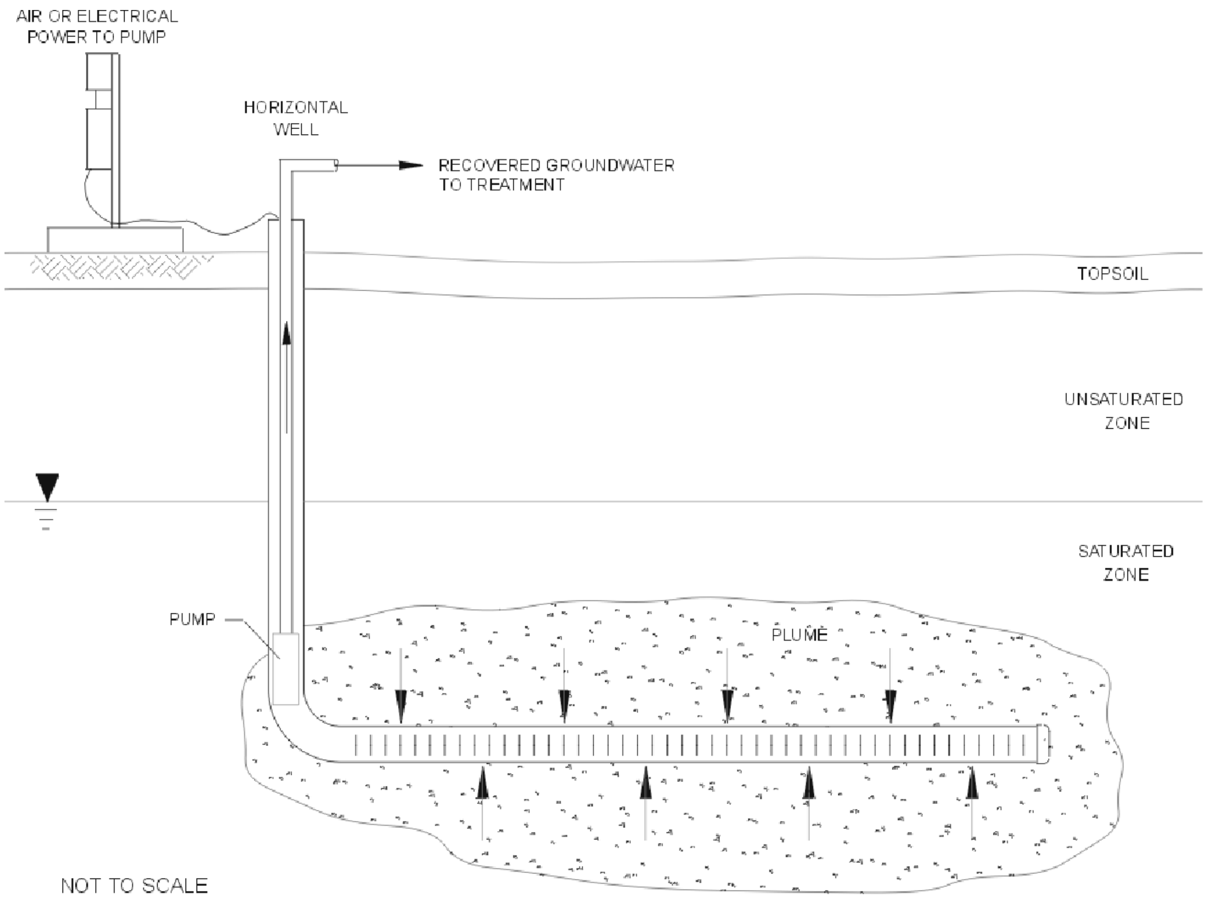

FIGURE 2-2. HORIZONTAL EXTRACTION WELL

b. Well Development Techniques.

When the performance of wells declines, they are often cleaned and redeveloped using some of the well development processes discussed below under Soil Flushing Methods, but they may also be rehabilitated via additional processes. The additional processes may include:

- Acidification (e.g., hydrofluoric, sulfamic, or hydrochloric acids) to chemically react with and remove acid-soluble scales and hydrolyze biofouling.
- Hypochlorite or peroxidation to kill and hydrolyze biofouling.
- Mechanical scrubbing or swabbing to clean scale and biofouling.

Wells may also be redeveloped using standard development techniques, such as surging, to remove accumulated fines and sediments and rejuvenate well performance.

c. Soil Flushing Methods.

Soil flushing is a technology also linked to pump-and-treat methods (Figure 2-3). Water, with or without additives (such as surfactants) to enhance the removal of contaminants, is pumped through or infiltrated through contaminated soils to flush (in-situ wash) contaminants into the groundwater for collection by groundwater extraction wells and treatment. If enhancers are added, typical additives are surfactants that act as detergents, change interfacial tensions between the soil/water/contaminants, and form micelles, thus enclosing contaminants and enhancing the rate of contaminant removal and recovery. To flush material from soils into the groundwater requires that groundwater be captured, extracted and treated, or that the groundwater be treated in-situ to prevent further spread of contamination. Soil flushing is a remediation enhancement that is infrequently employed.

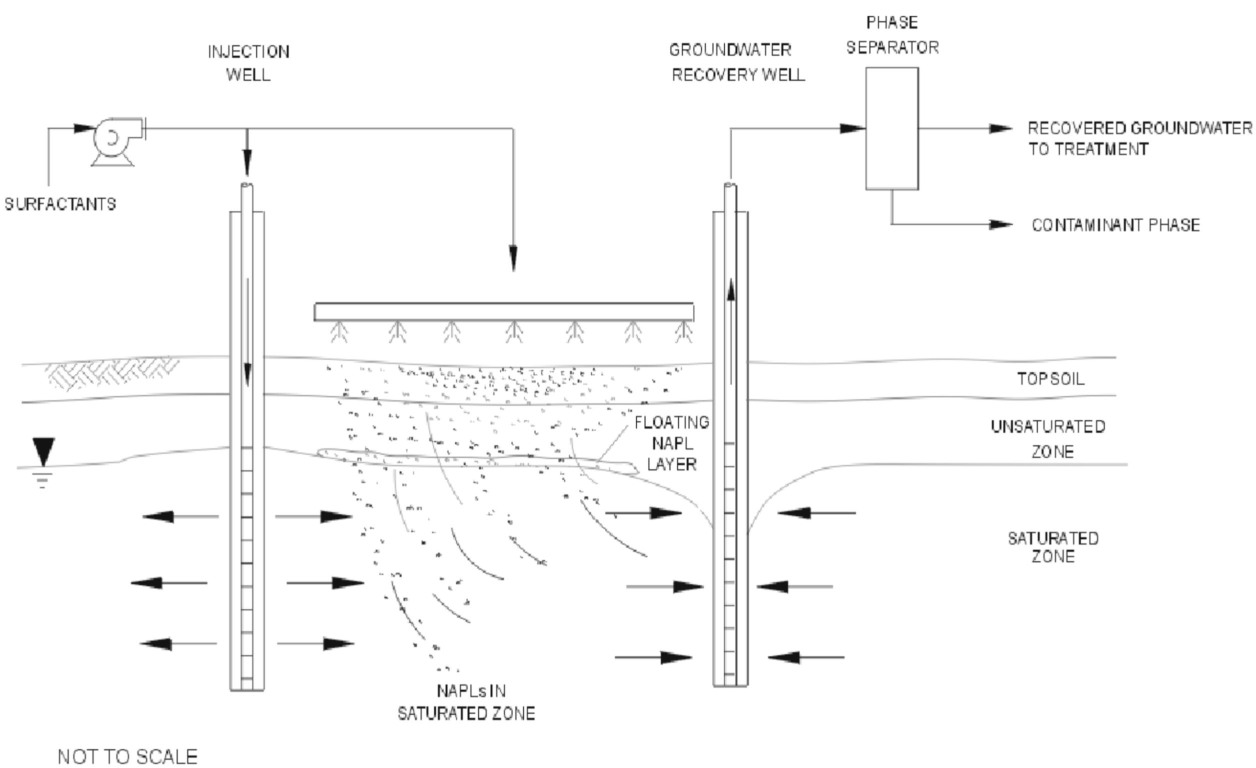

FIGURE 2-3. SOIL FLUSHING

2-3. Hazard Analysis

Principal unique hazards associated with extraction/monitoring wells (vertical/horizontal wells) and soil flushing, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Equipment Hazards*.
Description. During drilling operations, heavy equipment, such as augers, cables, buckets, and pipes, is periodically raised overhead and placed into or above the well. Thus, workers may be exposed to swinging equipment during lifting, or may be exposed to crushing hazards if equipment falls or is carelessly lowered. Loose clothing may become entangled in cables used to raise and lower equipment or on the equipment itself. Lowered augers, buckets, or direct push drilling methods (using hydraulic pressure to advance a soil boring) may further pose a crushing hazard to hands or feet. Rough edges or spaces on cables, auger flights, buckets, and pipe may cause cuts and abrasions.

Control. Controls for equipment hazards include:

- Establish a work zone around the drilling rig and permit only those personnel and equipment required for the task within the zone.
- Inspect lifting equipment regularly and operate it safely.
- Raise equipment only as high as needed.
- Maintain contact with the raised equipment to help minimize swinging.
- Wear appropriate clothing and equipment (site workers). (Avoid wearing loose clothing.)
- Avoid contact with auger edges, running cables, and pipe; wear work gloves to prevent cuts and abrasions from exposed spurs, wires, and edges. No jewelry should be worn (operators).
- Train workers in the equipment and operational hazards associated with drilling operations, including safety features built into the equipment.

CONTROL POINT: Construction, Maintenance

(2) *Rotating Equipment*.
Description. The rotating auger and other rotating or moving parts, such as "cat heads" and winches, pose a potential hazard to workers if loose clothing becomes entangled with the revolving equipment.

Control. Controls for rotating equipment include:

- Secure all loose clothing and remove jewelry.
- Use low-profile auger pins and long-handled shovels to remove soil cuttings from the borehole.
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may become entangled in loose clothing.
- Use drilling equipment equipped with a cut-off switch accessible to all drill crew members.
- Train operators on safe drilling practices, including hazard recognition in moving parts, entanglement, and pinch points of equipment.

CONTROL POINT: Construction, Maintenance

(3) *Utility Contact Hazards*.
Description. Fire, explosion, or electrocution hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling mast or auger comes in contact with overhead electric lines, or ruptures underground utilities or tank/piping systems.

Control. Controls for utility contact hazards include:
- Train the operators in the hazards of drilling in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill isolation procedures.
- Identify the location of all below- and above-ground utilities prior to drilling by contacting local utilities and public works personnel.
- Use a metal detector to help detect buried metal piping. When there is any doubt or uncertainty, probe with a metal rod prior to excavation or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Have an observer to the side to guide when raising a drill mast.
- Operate the mast at its lowest height; different drill rigs will have different mast elevations and may be operated at different heights.
- Do not move the drilling rig with the mast raised.
- Locate overhead hazards and design so that installations using erect equipment are not necessary in that area, if possible.

CONTROL POINT: Design, Construction

(4) *Flammable or Combustible Material*.
Description. Soil boring using hollow-stemmed augers or other drilling methods may cause a fire or explosion in soils saturated with flammable or combustible materials under unusual or extraordinary conditions. Sparks generated when an auger contacts rocks, metal, or other underground objects may ignite a flammable atmosphere inside the borehole. Examples of materials particularly subject to ignition in this manner are carbon disulfide (CS_2), methane, natural gas, ethane, propane, ethylene, benzene, or hydrogen sulfide, a decomposition product.

Control. Controls for flammable/combustible materials include:
- Use methods such as mud or water rotary drilling in areas suspected to contain soils saturated with flammable or combustible materials. These methods add moisture to the cutting area unlike hollow-stem augers.

CONTROL POINT: Design, Construction

(5) *Electrical Fires or Explosions*.
Description. Electricity in a wet environment and in the presence of flammable, floating layers of explosive NAPL may cause a fire or explosion.

Control. Controls for electrical fires include:

- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Verify that all controls, wiring, and equipment conforms to the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use equipment that is grounded or provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.
- Permit only trained, experienced, and authorized workers to work on the systems.
- Include appropriate lockout/tag-out equipment and procedures in the construction and O&M of the system.
- Have fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) *Extraction of Flammable Liquids*.
Description. Extraction of flammable liquids may cause a fire if the material is ignited via extraction, transfer, or storage, or if gases vented from the storage tank come in contact with a spark or other source of ignition. Fires may also occur if extraction pumps are not selected and installed in accordance with the appropriate EM 385-1-1, Section 11, and NFPA 70 requirements.

Control. Controls for extraction of flammable liquids include:

- Use equipment that is grounded or provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.
- Direct tank vents to prevent contact with sources of ignition.
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, 500.1 through 500.10, are indicated on the drawings.
- Verify that all controls, wiring, and equipment, including the piping system, conforms to the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Permit only trained, experienced, and authorized workers to work on the systems.
- Include appropriate lockout/tag-out equipment and procedures in the construction and O&M of the system.

- Have fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) to prevent thermal burns and keep all body parts away from the ejecting point of the steam pressure nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Equip with deadman or kill switch if not provided.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.
- Allow only trained and authorized workers to operate the steam pressure equipment.

CONTROL POINT: Construction, Operations, Maintenance

(8) *Drill Rigs*.
Description. Drill rigs can seriously injure workers during positioning for drilling.

Control. Controls for drill rigs include:

- Equip drill rigs and other vehicles with a backup alarm that alerts workers to moving vehicles.
- Drill rigs shall be leveled and stabilized. Appropriate blocking must be used when soil conditions dictate.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Allow only trained and authorized workers familiar with drilling operation hazards to work near the equipment.

CONTROL POINT: Construction, Maintenance

(9) *UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and other dermal damage. Exposure to hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(10) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle strain include:

- Use mechanical lifting equipment to lift heavy loads.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385 1-1, Section 14). Use two people if necessary for manual lifting.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(12) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Contamination Hazards*.
Description. Exposure to airborne dusts, VOCs, and metals in contaminated soils or groundwater brought to the surface during drilling, soil and groundwater sampling, and infiltration system installation can be hazardous to on-site personnel. During well installation, site workers may be exposed to gasoline, diesel fuel, or other organic materials, as well as heavy metals such as lead and chromium. These hazards can be contacted through dermal exposure, ingestion, or vapor inhalation. Workers may also be exposed to reactive, caustic, or acidic materials from cuttings and groundwater.

Control. Controls for chemical contamination hazards include:
- Use personal protective equipment (PPE) selected by a qualified health and safety professional (e.g., air-purifying respirators, chemically resistant disposable coveralls, water/chemical impervious gloves [e.g., nitrile], and rubber or steel-toed leather boots).
- Have frequent health and safety meetings.
- Use experienced workers, decontamination stations, or other standard procedures.
- Test soils for reactive, highly flammable, or corrosive materials.
- Design all installation methods appropriately.
- Use non-sparking tools and intrinsically safe equipment in extreme conditions (e.g., carbon disulfide, CS_2) if emissions are expected to be high.
- Conduct personnel and general area monitoring for airborne chemicals when exposures may potentially exceed half of the threshold limit value (TLV) or permissible exposure limit (PEL). Also conduct area monitoring when airborne combustible chemical concentrations exceed 1/10 of the lower explosive limit (LEL).
- Use proper respiratory protection (e.g., air-purifying respirator with filters or organic vapor cartridge, or both) if ventilation or other engineering, work

practice, or administrative controls are insufficient to maintain exposures less than the TLV or PEL.

- Select respiratory protective equipment in accordance with the OSHA regulation 29 CFR 1910.134 and the National Institute for Occupational Safety and Health (NIOSH) guidelines.

CONTROL POINT: Construction, Maintenance

(2) *Additive Hazards*.
Description. Additives (usually surfactants used in flushing) enhance exposure to contaminants by increasing dermal absorption and holding contaminants on skin. For example, linear alkyl benzene sulfonate or ethoxylate surfactants could be used to enhance recovery of contaminants as part of a pump-and-treat groundwater extraction program. This could also enhance concentrations of contaminants in the recovered water, increasing the risk and hazard of contact with that water. In addition, additives can increase the solubility of contaminants, raising concentrations to which personnel are exposed.

Control. Controls for additive hazards includes:

- Select additives (system designer) with the lowest health and safety impact that can still do the job (e.g., avoid use of materials such as dimethyl sulfoxide (DMSO) which enhances dermal absorption, when other solvents are available and practical).
- Allow only trained and authorized workers to handle the chemicals and equipment.

CONTROL POINT: Design, Operations

(3) *Chemical Fire or Explosion*.
Description. Fire or explosion or chemical release hazards (inhalation/ingestion/asphyxiation) may exist when using hollow-stem auger, direct push, or other drilling methods if drilling ruptures underground utilities or tanks/overhead piping systems that contain hazardous chemicals.

Control. Controls for chemical fire or explosion include:

- Perform a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of underground lines prior to drilling.
- Develop actions/procedures to locate overhead hazards during design.
- Allow only trained, experienced, and authorized workers near and on the drilling operation.

CONTROL POINT: Construction

(4) *Acids*.
Description. Acids used in well flushing or rehabilitation may pose skin, eye, or inhalation hazards upon contact.

Control. Controls for acids include

- Use closed acid injection systems to minimize worker exposure to acids.
- Wear PPE, such as neoprene gloves, chemically resistant coveralls, safety goggles, and a face shield.
- Allow only trained and authorized workers to handle and work in areas with acids and bases.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) *Equipment*.
Description. Use of a neutron or gamma source in down-hole logging systems to log wells may pose a radiation hazard if improperly used or if damaged in such a way as to expose the sources.

Control. Controls for equipment hazards include:

- Use personnel with the proper training and experience in the use of neutron density gauges and proper maintenance of the instrument.
- Comply with the Nuclear Regulatory Commission (NRC) Standards for Protection Against Radiation (10 CFR 20), NRC Rules of General Applicability to Domestic Licensing of Byproduct Material (10 CFR 30).
- Note the license type required for the particular source (10 CFR 31, 32, or 39) as well as license conditions and OSHA 1910.1096 or 29 CFR 1926.53 criteria.

CONTROL POINT: Design, Construction, Maintenance

(2) *Contaminants*.
Description. Contaminants in the groundwater and soil may pose a rare radiation hazard to personnel through inhalation or ingestion of radioactive materials during installation, sampling, and maintenance of wells or well-related systems. Buildup of radioactive scale in the well and associated piping may present an external exposure hazard. Contaminants may include naturally occurring radioactive material (NORM), radium, thorium, and uranium, or radioactive wastes that have been buried in previous disposal activities.

Control. Controls for radioactive contaminants include:

- Test the soil and groundwater to determine if elevated levels of radioactive materials are present.
- Consult a qualified health physicist if elevated levels occur to determine the exposure potential and any necessary engineered controls or PPE.

CONTROL POINT: Design, Construction, Maintenance

d. Biological Hazards.

(1) *Biological Contaminants*.
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the groundwater and soil may cause exposure hazards during the installation, sampling, and maintenance of the wells or well-related systems. Workers may be exposed to inhalation/ingestion or dermal contact with pathogens, such as *Coccidioides sp.*, *Histoplasma sp.*, and *Mycobacterium sp.* The resulting exposure may result in an occupational illness.

Control. Controls for biological contaminants include:

- Test microorganisms in the groundwater and soil and determine the appropriate PPE to prevent exposure. The appropriate PPE typically includes an air-purifying respirator equipped with N, R, or P100 or N, R or P95 particulate air filters approved for microbial inhalation hazards.
- Enforce (strictly) eating, drinking, and smoking restrictions prior to washing/decontamination. Decontamination with water and or disinfectant soaps may be used to control exposure.
- Wear chemically resistant protective overalls to prevent clothes from becoming grossly contaminated with wastes, soils, or contaminated water. If contaminated clothing is laundered, use a commercial laundry familiar with cleaning procedures for industrial clothing. These procedures include employee hazard warnings and cleaning solution disposal requirements.

CONTROL POINT: Design, Construction

(2) *Dangerous Insects or Animals*.
Description. Well vaults or enclosures may have snakes, spiders, scorpions or other potentially dangerous insects and animals sheltering or trapped in them that could bite or sting workers during operations or maintenance. Other biological hazards include bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for dangerous insects or animals include:

- Design well vaults with tight covers where practical to prevent entry of insects and animals.
- Remove well vault covers with a hook or other tools to prevent possible bites or stings.
- Inspect vaults after opening and prior to entry to determine if snakes, spiders, scorpions, or other potentially dangerous insects and animals are present. If present, the animals should be removed in a safe manner by a qualified health and safety professional.
- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies for removal.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically throughout the workday.

CONTROL POINT: Design, Operations, Maintenance

(3) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit West Nile Virus.

Control. Controls for pests include:
- Periodically inspect the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies for removal.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing periodically throughout the work day.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 3
Excavation, Removal, and Off-Site Disposal

3-1. General

The process of excavation of contaminated solids/sludges, dewatering, pretreatment, and technology applications are briefly discussed in the first section of the chapter. The second portion of the chapter is a hazard analysis with controls and control points listed.

3-2. Technology Description

a. Process.

Contaminated solids/sludges are excavated, dredged, or pumped from surface or subsurface areas, typically staged for loading (treated if required), and loaded into transport vehicles for shipment to an approved receiving facility (usually a licensed landfill). Soils can be excavated with backhoes, front loaders, continuous excavators, scrapers, or other equipment. Sludges can be removed with open-face (impeller) centrifugal pumps, backhoes, or similar equipment. Submerged sediments are often removed using a dredge.

Material may be dewatered during staging operations. Settling and decanting, filter or belt pressing, or centrifuging, if needed, can perform dewatering.

Pretreatment (stabilization, fixation, or encapsulation) of material may be required to bind free water and prevent leachate development from the excavated wastes once disposed of off site. Pretreatment processes are usually done during staging. Liquids generated during dewatering may also require treatment prior to shipment or discharge.

Loading may be direct (e.g., from the bucket excavator) but is more typically done with front-end loaders after stockpiling, classifying, and pretreating solids and sludges. Waste materials are typically disposed of in permitted treatment, storage and disposal facilities (TSDFs).

b. Applications.

Landfill disposal typically requires that no free liquid be present in the material or that the materials meet TCLP (Toxic Characteristic Leaching Procedure) leaching criteria, or both. Volatile organic compounds (VOCs) may be volatilized from the solids or sludges during excavation; consequently excavation, transport, and disposal off site are not usually appropriate for wastes high in hazardous volatiles such as BTEX (benzene, toluene, ethylbenzene, xeylene), ketones, or chlorinated solvents (e.g., methylene chloride) unless pretreated in some manner to minimize volatile loss to the environment. Semi-volatile organic materials and inorganic contaminants can also be released into the air as particulate matter.

3-3. Hazard Analysis

Principal unique hazards associated with excavation, removal, and off-site disposal, methods for control, and control points are described below

a. Physical Hazards.

(1) *Equipment*.
Description. During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. This equipment may also generate excessive noise during operation.

Control. Controls for equipment hazards include:
- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection when working around operating equipment.
- Train workers in the potential operational hazards and the safety features provided for heavy equipment operation.

CONTROL POINT: Construction, Operations, Maintenance

(2) *Fire and Explosion or Utility Hazards*.
Description. During excavation into soil contaminated with explosive, flammable, or combustible materials (e.g., carbon disulfide, hydrogen sulfide, methane) under unusual or extraordinary conditions, the bucket of a backhoe or cutting blade of a crawler may spark from rocks, buried metal, or other objects and ignite a flammable vapor. During excavation, a backhoe or other earth-moving equipment may rupture an underground utility, such as electrical or gas lines, and cause a fire, explosion, or electrocution.

Control. Controls for fire and explosion hazards include:
- Train the operators in the hazards of excavating in highly flammable or explosive material and in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in the event of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency excavation isolation procedures.
- Locate underground electrical utilities using electromagnetic surveys, inductance surveys, installation maps and drawings, locating services, interviews with utilities personnel, and hand excavation prior to machine excavating.
- Adhere to the excavation safety requirements of 29 CFR 1926.650-652.
- Equip earth-moving equipment with a non-sparking bucket or blade when highly flammable excavation environments are suspected.
- Wet or foam the active work area periodically with water or a foam fire suppressant to prevent vapor ignition. The addition of foam to control vapors

may also create a slip and fall hazard. Do not allow workers where foam has been applied.

- Conduct area monitoring when airborne combustible chemical concentrations may reach Immediately Dangerous to Life or Health (IDLH) or potentially exceed 10% of the Lower Explosive Limit (LEL).

CONTROL POINT: Design, Construction, Operations

(3) *Excavation Wall Collapse or Flooding*.
Description. Entry into an excavation may expose workers to confined-space atmospheric dangers and risk of excavated wall collapse. Flooding of an excavation may cause drowning or electrocution if electrical equipment is in use.

Control. Controls for wall collapse or flooding include:

- Wear inflation vests, use lockout procedures for wet environments, and develop a plan to evacuate workers in basins or impoundments with the potential for rapid flooding where other means of controlling the water hazards are not available.
- Slope the walls of all excavations greater than 5 feet away from the edge or properly shore in accordance with Occupational Safety and Health Administration (OSHA) guidance (29 CFR 1926.650-652).
- Do not allow workers to enter an unstable excavation.
- Provide excavation/trench emergency egress at distances not to exceed every 25 feet of the excavation/trench perimeter. See EM 385-1-1, Section 25.
- Train workers in the unique hazards of excavations, including wall collapse, and in recognized hazard controls such as sloping or shoring the sides prior to worker entry. See EM 385-1-1, Section 25.

When confined-space hazards are known or suspected, appropriate health and safety steps include:

- Ventilate the area and perform entry using confined-space procedures and supplied air (29 CFR 1926.21) for eliminating the hazard.
- Implement a confined-space atmospheric testing program using an oxygen meter, combustible gas meter, and other gas-specific meters as part of the confined-space entry program. A confined space is defined as any space with the potential to hold toxic, asphyxiant, or explosive concentrations of gas whether more dense (e.g., sump, basement, tank, or excavation) or less dense (e.g., low canopy or roofed tank) than air.
- Follow confined-space entry procedures (29 CFR 1926.21) for excavations greater than 4 feet. Regardless of the depth, a competent person must assess the excavation prior to each entry.

CONTROL POINT: Design, Construction, Operations

(4) *Skin Puncture/Cut Hazards*.

Description. Workers may also be exposed to skin puncture and cut hazards during the excavation and transport of sharp or abrasive objects contained in waste material.

Control. Controls for skin puncture/cut hazards include:

- Use personal protective equipment (PPE), including boots and gloves made of cut-resistant, puncture-resistant materials. Work boots should be equipped with steel-reinforced shanks to help prevent puncture when walking over waste materials.
- Handle materials with appropriate equipment, not hands or feet, to avoid injury.
- Carefully remove materials posing a clear potential hazard (e.g., framing lumber with nails, broken glass) to avoid later, inadvertent contact hazards.
- Train workers in the unique waste material handling hazards associated with the excavation of the materials.

CONTROL POINT: Construction, Operations, Maintenance

(5) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Equip the washer with a deadman or kill switch if not provided by the manufacturer.
- Wear slip-resistant boots.
- Drain water away from decontamination operations into a tank or pit. Drain walking surfaces and keep free of standing liquids and mud.
- Only allow trained and authorized operators to operate the steam pressure washing equipment.

CONTROL POINT: Construction, Operations

(6) *Unstable Soil Conditions*.
Description. Operating heavy equipment over unstable ground (ground that has been affected by pumping or involved in subsurface treatments) may cause the ground surface to subside or sink. The result may cause an injury to the operator of the equipment or to nearby workers.

Control. Controls for unstable soil conditions include:

- Use a qualified engineer to assess soil to ensure safe site conditions for equipment operation.
- Only allow trained and authorized operators to operate the equipment.

CONTROL POINT: Design

(7) *Respirable Quartz Hazard*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz hazards include:

- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air-purifying respirator equipped with a N, R or P100 particulate air filters.
- Train workers in the potential inhalation hazards associated with exposure to crystalline silica quartz containing dust.

CONTROL POINT: Construction, Operations

(8) *UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and the corresponding ultraviolet (UV) radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts or close to operating equipment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.
- Shade the work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.
- Use the Buddy System.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(9) *Utility Contact Hazards*.
Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for utility contact hazards include:

- Note the location of overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and dragline rigs at least 10 feet from the power line according to OSHA regulations 29 CFR 1926.550 and EM 385-1-1, Section 11.

CONTROL POINT: Design, Construction, Operations

(10) *Traffic Hazards*.
Description. During field activities, equipment and workers may come in proximity to traffic. Also, drilling rigs and other equipment may need to use public roads. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil.

Control. Controls for traffic hazards include:

- Post warning signs where equipment crosses roads according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site trucks and automobiles. EM 385-1-1, Section 21, provides plan details. Equip traffic guides with fluorescent orange or lime green safety vests.

CONTROL POINT: Design, Construction, Operations

(11) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other actions. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards that are identified.

CONTROL POINT: Design

b. Chemical Hazards.

Contamination Hazards.
Description. Workers involved with excavation activities may be exposed to VOCs and particulate matter contaminated with semi-volatile organic or inorganic contaminants, or both. Inhalation hazards are particularly evident during warm and dry periods when there is a greater chance for airborne dusts to be generated. The addition of foam to control vapors or dust may create a slip hazard. Workers may also be dermally exposed to waste materials during excavation and transport of waste materials. Workers may inadvertently ingest contaminants or waste materials that collect on hands and clothing in the form of dust during excavation. Dust may also be ingested when workers take water or meal breaks, or after they have left the work area if established hygiene procedures (e.g., washing hands) are not followed.

Control. Controls for chemical contamination hazards include:

- Use proper types of PPE as necessary. Examples of PPE include nitrile gloves for dermal exposure to petroleum distillates such as gasoline or diesel fuel, an air-purifying respirator equipped with approved N, R or P100 or N, R or P95 particulate air filters, organic vapor (OV) cartridges for vapors, or combination filter/cartridges for dual protection, and chemically resistant disposable coveralls.
- Use experienced workers, repeated health and safety awareness meetings, decontamination stations, and other standard procedures.
- Suppress dust and other emissions using water or foam suppressants if needed. Workers should not walk on areas where foam has been applied.
- Test soils for reactive, highly flammable, or corrosive materials. In extreme conditions (e.g., carbon disulfide CS_2) non-sparking tools and intrinsically safe equipment may be required if emissions are expected to be high.

CONTROL POINT: Construction, Operations

c. Radiological Hazards.

Radioactive Material.
Description. Naturally occurring radioactive material (NORM) is found in all soils, groundwater, and surface water. At typical background levels, this radioactive material poses neither an internal nor an external hazard during excavation, removal, or off-site disposal. Elevated levels of naturally occurring radioactivity, however, have been found in materials such as sewage sludge, fossil fuels, fertilizers, and evaporation ponds. Excavation, removal, or off-site disposal of radioactive material at greater than background concentrations may pose an internal hazard if radioactive particles are inhaled or ingested. Certain devices containing radioactive material may also be present in the soils or rubbish to be excavated and handled (e.g., U.S. Army and U.S. Air Force gauges painted with radium-226, compasses, and radar devices). Intact radium gauges will not yield an unacceptable extremity dose. Broken gauges may present an internal hazard if radium paint chips are inhaled or ingested.

An external hazard may also exist, depending upon the type and extent of contamination. Small particles of uranium metal and some uranium alloys are pyrophoric. They can ignite spontaneously in air as a function of surface to volume ratio. They burn rapidly at very high temperatures.

Control. Controls for radioactive materials include:

- Consult a qualified health physicist whenever significant radioactive hazards above background are suspected.
- Review site history thoroughly for evidence of concentrated NORM or for the presence of devices containing radioactive material.
- Use time, distance, and shielding to control external hazards from ionizing radiation.
- Use PPE to prevent external contamination.
- Use respiratory protection (N, R or P100 particulate air filters) and engineering controls for internal hazards.
- Use decontamination procedures/facilities as necessary to reduce radiation exposure.
- Suppress dust and other emissions as described above for chemical hazards.

CONTROL POINT: Design, Construction, Operations

d. Biological Hazards.

(1) *Biological Contaminants.*
Description. Microorganisms in the groundwater and soil may cause exposure hazards at sites containing medical wastes or sewage sludge. Workers may be exposed to inhalation/ingestion and dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.*

Control. Controls for biological contaminants include:

- Test the microorganisms in the groundwater and soil and determine the appropriate PPE to prevent exposure. The appropriate PPE may include an air-purifying respirator equipped with N, R or P100 or N, R or P95 particulate air filters approved for microbial inhalation hazards. Most rubber gloves (e.g., nitrile or PVC) provide protection against microorganisms; however, the type of glove used must also be compatible with contaminants at the site. The use of latex gloves may aggravate or cause allergic reactions in some people.
- Use dust suppression with water or amended water sprays.
- Enforce (strictly) eating, drinking, and smoking restrictions prior to washing and decontamination. Decontamination with water and or disinfectant soaps may be used to control exposure.
- Wear chemically resistant protective overalls to prevent clothes from becoming grossly contaminated with wastes, soils, and contaminated water. If contaminated clothing is to be laundered, use a commercial laundry familiar with cleaning procedures for industrial clothing. These procedures

include employee hazard warnings and cleaning solution disposal requirements.

CONTROL POINT: Design, Construction, Operations

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile virus.

Control. Controls for pests include:

- Periodically inspect the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies for removal.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as an active ingredient, for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically throughout the work day.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 4
Solidification/Stabilization (Ex Situ/In Situ)

4-1. General

The process of solidification/stabilization, ex-situ methods, in-situ methods, binding agents, and applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

4-2. Technology Description

a Process of Solidification/Stabilization.

Solidification/stabilization is the use of various chemical additives (Portland cement, kiln dust, and fly ash) to chemically bind and immobilize contaminants or to micro-encapsulate them in a matrix that physically prevents mobility. Solidification generally refers to a physical process where a semi-solid material or sludge is treated to render it more solid. Stabilization typically refers to a chemical process that actually binds the matrix of the contaminant such that its constituents are immobilized. Functionally, these processes either chemically bind or physically trap the contaminants. The terms *solidification* and *stabilization* refer to the formation of chemically as well as physically stable matrices. Solidification and stabilization can be done in-situ or ex-situ.

b Ex-situ Methods.

Field processes involve excavation and staging of the solids, screening to remove materials too large in diameter to be effectively treated (often 2 inches in diameter or greater), blending the binding agents and water with solids (typically in a pug mill), and stockpiling treated solids for testing prior to shipment off site or placement back in the excavation. Solidification/stabilization is most effective on metals and inorganic contaminants, and less effective with increasing concentrations of organic contaminants. Figure 4-1 illustrates the in-situ and ex-situ solidification/stabilization processes. Solidification/stabilization can result in monolithic-formed blocks or chunks, or in a soil-like matrix.

A significant consideration in applying the ex-situ technology is the "swell factor" in the solid volume created by the binding agent; this factor depends on the amount of reagents that must be added and can approach 50% in some cases. Not all of the treated material may fit in the same excavation from which it was removed without altering the natural grade.

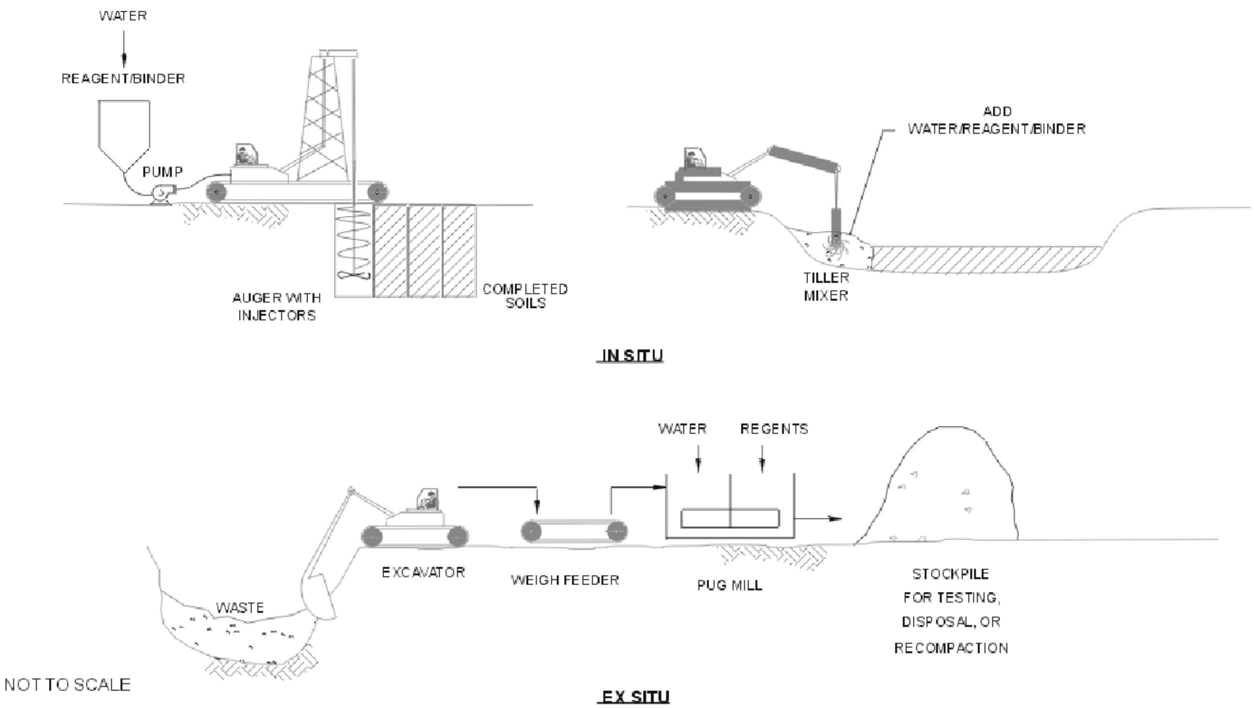

FIGURE 4-1. SOLIDIFICATION/STABILIZATION (IN SITU/EX SITU)

c. In-situ Methods.

In-situ solidification/stabilization involves the injection or mixing of stabilizing agents into subsurface soils to immobilize the soil matrix and contaminants to prevent leaching into infiltrating precipitation or groundwater. Typically, in-situ stabilization involves the addition of binding agents to an area of sludge or soils, addition of water if necessary, and then repeated in-place mixing with the bucket of a back or track hoe to thoroughly mix and stabilize the sludges or soils in place. A growing method of in-situ solidification/stabilization is the use of very large flighted rotary augers, 6–8 or more feet in diameter, capable of injecting slurry chemicals and water through the auger flights. The auger bores and mixes a large diameter “plug” of the contaminated material. During augering, stabilization chemicals and water (if needed) are injected into the soils. After thorough mixing, the auger is removed and the setting slurry is left in place. The auger is advanced to overlap the last “plug” slightly and the process is repeated until the contaminated area is completed. The solidification/stabilization additives are the same as with other in-situ or ex-situ techniques, but the process provides better in-situ mixing and distribution of additives.

d. Binding Agents.

Typical binding/stabilizing agents (in-situ or ex-situ) include Portland cement, pozzolanic binders, and various kiln dusts. Most of these materials are highly alkaline, and form a solidified matrix when mixed with the contaminated material.

Ex-situ solidification/stabilization uses the same kinds of binding/stabilizing agents as those used in-situ, but solids are excavated and treated in mixing equipment, such as pug mills or cement mixers outside the original waste locations. The material handling requirements of this approach are greater than for in-situ methods, but the degree of mixing and blending control is significantly higher than for in-situ processing. This generally yields higher confidence that the contaminants have been effectively immobilized and may require less reagent per unit volume of solids treated.

e. Applications.

The solidification/stabilization process has been successfully demonstrated and used for inorganic contaminants, primarily metals, and radionuclides in the presence of low levels of organic materials. The process is not considered routinely applicable for situations where the organic content of the wastes/soil, as measured by total petroleum hydrocarbons (TPH), is greater than 5,000–10,000 mg/kg because the organic material has leached out of the cement matrix over several years in some cases. The addition of activated carbon and other adsorbents can enhance the levels of organics practically treatable with this technology.

4-3. Hazard Analysis

Principal unique hazards associated with solidification/stabilization (ex-situ/in-situ), methods for control, and control points are described below

a. Physical Hazards.

(1) *Equipment Hazards*.
Description. During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders, tillers, scrapers, and other equipment.

Control. Controls for equipment hazards include:

- Use heavy equipment with a backup alarm to alert workers.
- Equip workers near heavy equipment with fluorescent orange or lime green traffic vests.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Train workers in the unique operational hazards and safety features of the heavy equipment.

CONTROL POINT: Construction, Operations

(2) *Auger/Caisson Hazards*.
Description. Installation of auger/caisson systems poses mechanical hazards owing to the use of large rotating augers. During the in-situ stabilization process, heavy equipment and materials, such as augers and caissons, are periodi-

cally raised overhead and placed into position. Workers may be exposed to swinging equipment or crushing hazards if the equipment falls.

Control. Controls for auger/caisson hazards include:

- Establish a work zone and allow only those personnel necessary for the task in the zone.
- Inspect lifting equipment regularly and operate safely.
- Raise equipment only as high as needed and minimize the movement of raised equipment.
- Avoid contact with auger edges, cables, and pipe and wear appropriate personal protective equipment (PPE), including hard hats, steel-toe shoes, instep guards, and appropriate clothing.
- Only allow trained and authorized workers within the swing radius and work areas around the equipment.

CONTROL POINT: Construction, Operations

(3) *Rotating Equipment Hazards*.
Description. Rotating augers or backhoes pose hazards to workers as loose clothing may become entangled with the revolving augers.

Control. Controls for rotating equipment include:

- Secure all loose clothing.
- Stay clear of rotating and moving equipment.
- Allow only trained and authorized workers near the equipment.

CONTROL POINT: Construction, Operations

(4) *Utility Contact Hazards*.
Description. Fire and explosion hazards may exist when using augers or other drilling methods if the auger contacts or ruptures underground utilities, such as electric or gas lines, or underground tanks. Also, underground obstructions, such as sewers and foundations, may cause drilling equipment to abruptly stop, resulting in unsafe drilling conditions. Electrocution hazards may also exist if large stabilization augers come in contact with overhead electrical wiring during placement or operation.

Control. Controls for utility contact hazards include:

- Train the operators in the hazards of excavating in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency excavation and auger isolation procedures.
- Identify the location of all below- and above-ground utilities prior to drilling by contacting local utilities and public works personnel. When there is any doubt or uncertainty, carefully excavate with a backhoe, probe with a metal

rod, or hand excavate to determine the exact location of utilities. Once utilities are located, careful excavation by backhoe may be allowed.

- Post an observer to the side to direct the raising of a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction, Operations

(5) *Unguarded Moving Mechanisms*.
Description. Pug mills and similar equipment used to mix soils may be equipped with unguarded drive shafts, sprockets, chains, pulleys, or other revolving/rotating mechanisms. Exposure to the unguarded equipment may result in workers becoming entangled.

Control. Controls for unguarded moving mechanism include:

- Guard all moving mechanisms to prevent accidental contact.
- Operate equipment only when guards are in place.
- Wear appropriate PPE and clothing. No loose clothing should be worn, shirt tails should be tucked in, and long sleeves should be buttoned.
- Restrain long hair under hard hats.
- Train workers in the unique hazards associated with unguarded machinery and rotating powers shaft pinch and entanglement points.

CONTROL POINT: Design, Construction, Operations

(6) *Explosive Gases*.
Description. Solidification/stabilization can sometimes cause off-gassing of dangerous substances. As an example, when quantities of magnesium are present, solidification/stabilization with cement will cause off-gassing of hydrogen from a water–magnesium reaction and present a fire and explosion hazard. This can be a problem with stabilization in drums and other containers.

Control. Controls for explosive gases include:

- Train the operators in the hazards of the chemistry of all contaminants and potential reactants involved in the soil matrix being prepared by solidification/stabilization.
- Train the operators in emergency procedures in the event of a catastrophic event, in life saving first aid procedures for burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency reactant isolation procedures.
- Evaluate during design what off-gases, if any, to expect.
- Ventilate the work areas where stabilization is taking place.
- Monitor as necessary for explosive gases.

CONTROL POINT: Design, Construction, Operations

(7) *Steam Pressure Washing*.

Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Uses insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Equip washer with deadman or kill switch if not provided by the manufacturer.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations

(8) *Respirable Quartz Hazard*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz potential, sample and analyze site soils for fines content by ASTM D422 (R2002): “Standard Test Method for Particle Size Analysis of Soils” followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air-purifying respirator equipped with an N, R or P100 particulate air filter.
- Train workers in the potential hazards associated with inhalation exposures to crystalline silica.

CONTROL POINT: Construction, Operations

(9) *UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and the corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts or close to operating equipment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.

- Shade work and break areas, if possible.
- Minimize exposure to heat stress conditions by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.
- Use the Buddy System and provide easy access to water.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(10) *Electrocution Hazards*.
Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for electrocution hazards include:

- Verify the location of overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs, at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.

CONTROL POINT: Design, Construction, Operations

(11) *Heavy Equipment Hazards*.
Description. The heavy equipment (small and large) used for site operations may roll over on steep slopes or unstable ground, crushing the operator.

Control. Controls for heavy equipment hazards include:

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction (construction contractor).
- Use heavy equipment with roll-over protective devices (ROPS) and do not operate on steep slopes or unstable ground.
- Train workers in the hazards associated with heavy equipment and the safety features built into the equipment.

CONTROL POINT: Design, Construction, Operations

(12) *Traffic Hazards*.

Description. During field activities, equipment and workers may come close to traffic. Also, drilling rigs and other equipment may need to cross or use public roads. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil.

Control. Controls for traffic hazards include:

- Post warning signs where equipment crosses roads according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site trucks and automobiles. EM 385-1-1, Section 21, provides plan details.

CONTROL POINT: Design, Construction, Operations

(13) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle strain include:

- Use mechanical lifting equipment to lift heavy loads.
- Use proper lifting techniques, including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14).

CONTROL POINT: Design, Construction, Operations, Maintenance

(14) *Noise Hazards*.
Description. Both in-situ and ex-situ solidification/stabilization systems may present a noise hazard to workers.

Control. A control for noise hazards includes:

- Wear hearing protection in accordance with 29 CFR 1910.95 and 29 CFR 1926.521 requirements as necessary around operating equipment.
- Institute a hearing conservation program for the workers.

CONTROL POINT: Construction, Operation

(15) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(16) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) *Contamination Hazards*.
Description. During excavation and mixing operations (in-situ or ex-situ), workers may be exposed to inhalation/ingestion/dermal hazards from airborne contaminated dusts, VOCs, and waste materials. These materials may include: portland cement, quicklime, hydrated lime, kiln dust, fly ash, sodium silicate, and gypsum. Stabilizers such as quicklime will induce an exothermic reaction in the presence of organic materials in the waste and water, creating a potential chemical/thermal hazard exposure. Also, the addition of cement may result in chemical release to the air from chemical reactions with waste materials. Eye exposure to airborne dusts and chemicals may occur, resulting in irritation, scratching, and scarring of eyes. High-pressure injection of stabilizing compounds can spray or splatter chemical agents that may also cause eye damage.

Control. Controls for contamination hazards include:
- Reduce airborne contaminants by applying water periodically to the active excavation and mixing areas.
- Use injection equipment with pressure-trip interlocks to prevent operation at excessive pressures.
- Select the proper types of PPE: an air-purifying respirator with approved N, R or P100 or N, R or P95 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Wear eye protection.
- Offer frequent health and safety awareness meetings.
- Use experienced workers and decontamination stations.

CONTROL POINT: Design, Construction, Operations

(2) *Chemical Exposure*.
Description. During the excavation process, accidental rupturing of underground utilities, such as sewers and pipelines containing gases and liquids, may result in worker exposure to chemicals.

Control. Controls for chemical exposure include:
- Identify underground utility location by contacting local utilities and public works personnel.
- Locate the below-ground utilities and probe with a metal rod prior to excavating to prevent underground rupture.

CONTROL POINT: Construction, Operations

(3) *VOCs Exposure*.
Description. Enhanced off-gassing of VOCs may occur as a result of the heat generated during the stabilization process. Also, ammonium compounds may release ammonia when mixed with cement. Workers may be exposed to VOCs via inhalation or dermal exposure routes.

Control. Controls for VOCs exposure include:
- Reduce airborne VOCs by the periodic application of water or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas to which foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and portable surface covers.
- Use the proper types of PPE: an air-purifying respirator equipped with approved N, R or P100 or N, R or P95 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Offer frequent health and safety awareness meetings; use experienced workers, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Operations

c. Radiological Hazards

Contaminant Hazards.
Description. Contaminants in excavated or in-situ soils, sludge, and associated water may pose a rare radiation hazard. Naturally occurring radioactive material (NORM) may be present in the soils, sludge, and groundwater. Some radioactive materials are pyrophoric. Radioactive materials of uranium or thorium may spontaneously ignite and pose a fire hazard and an airborne radioactivity hazard. Buried radioactive materials may present an external hazard. All radioactive materials may present an internal hazard through inhalation or ingestion.

Control. Controls for contaminant hazards include:

- Test soil, sludge, and water to identify and eliminate exposure potential during excavation, classification, and disposal. A qualified health physicist should determine the presence of radiation or particulate radioactive materials, and their nature and extent.
- Use appropriate engineering, PPE, and other controls to prevent exposure.
- Make decontamination facilities available to help minimize exposure.
- Suppress dust and other emissions using periodic applications of water or amended water.

CONTROL POINT: Design, Operations

d. Biological Hazards.

(1) *Biological Contaminants.*
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.*

Control. Controls for biological contaminants include:

- Test for microorganisms in the soil and determine the appropriate PPE to help control exposure.
- Reduce the generation of airborne contaminants, including microbes and particles (dust), with the periodic application of water or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Use the proper types of PPE: an air-purifying respirator equipped with approved N, R or P100 or N, R or P95 particulate air filters approved for microbial inhalation hazards, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Offer frequent health and safety awareness meetings; use experienced workers, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Construction, Operations

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for pests include:

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically throughout the workday.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 5
Slurry Walls

5-1. General

The design and function of slurry walls and specific uses of cement/bentonite walls are discussed in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

5-2. Technology Description

a. Design and Function of Slurry Walls.

A slurry wall is an in-ground physical containment device designed to isolate contaminant source zones and groundwater plumes from the surrounding environment. Contaminated soil, wastes, and groundwater can be physically isolated within surrounding low-permeability barriers by constructing a vertical trench excavated down to and keyed into a deeper confining layer, such as a low-permeability clay or shale, and filling the trench with a slurry. Slurry walls usually consist of a soil, bentonite, or cement mixture. The slurry mix hydraulically shores the trench to prevent collapse during installation and forms a permeation barrier to prevent the escape of contaminants from the contained area. As the excavation continues, additional slurry is added, and the process continues until the depth and length needed are completed. A schematic diagram of a slurry wall configuration is presented in Figure 5-1.

Slurry walls are commonly used subsurface barriers because they are a relatively inexpensive means of reducing groundwater flow in unconsolidated earth material and are also useful for sites where present technologies can not effectively or economically treat contaminant sources. Cement and bentonite construction of a wall can adsorb and retard the escape of heavy metals and larger organic molecules but can not completely stop water movement. Consequently, slurry walls are either "stop-gap" measures or are typically accompanied (as illustrated in Figure 5-1) by pump-and-treat systems. Often the enclosed area is capped or covered to prevent additional infiltration of water behind the wall.

Slurry walls are also used to direct or funnel the flow of groundwater to pump-and-treat well arrays or in-situ treatment areas, such as a reactive wall or biosparging array. Soil/bentonite walls have been used for decades for groundwater control in conjunction with large dam projects. However, the ability of these walls to withstand long-term permeation by many contaminants is unknown. Evidence indicates that soil/bentonite backfills are not able to withstand attack by strong acids and bases, strong salt solutions, and some organic chemicals.

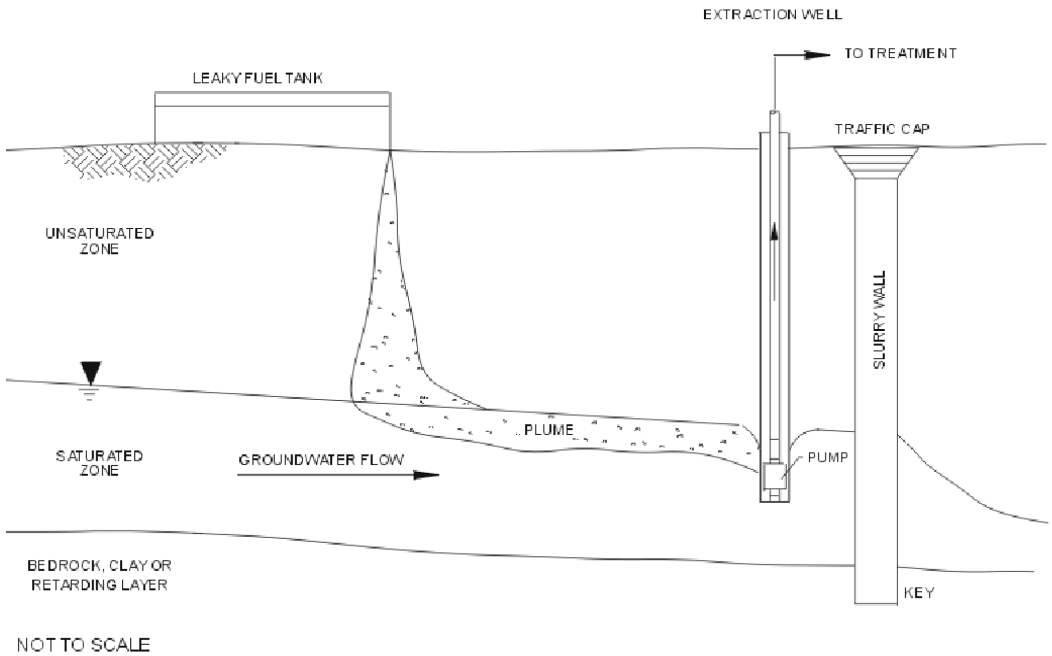

FIGURE 5-1. SLURRY WALLS

b. Cement/Bentonite Walls.

Cement/bentonite walls are more expensive than soil/bentonite walls and are generally used where: (1) there is no room to mix and place soil/bentonite backfills; (2) increased mechanical strength is required; or (3) extreme topography conditions (slopes) make it impractical to grade a site level. Cement/bentonite slurry walls are limited in their use by their higher permeability and their narrow range of chemical compatibilities (more susceptible to attack by sulfates, strong acids or acid bases, and other highly ionic substances).

5-3. Hazard Analysis

The principal unique hazards associated with the slurry walls, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Equipment Hazards*.
Description. During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders and backhoes. This equipment may also cause a noise hazard to workers.

Control. Controls for equipment hazards include:
- Use heavy equipment with a backup alarm to alert workers.

- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection around operating equipment.
- Train workers in the operational hazards and safety features associated with the heavy equipment.

CONTROL POINT: Construction

(2) *Utility or Underground Structure Hazards*.
Description. Fire, electrocution, or explosion hazards may exist during installation of the slurry wall if a backhoe ruptures an underground utility, such as sewers, pipelines, or electrical or gas lines. Abrupt equipment stoppages attributable to contact with underground structures, such as foundations, may cause a dangerous condition leading to equipment-related accidents.

Control. Controls for utility and underground structure hazards include:
- Train the personnel in the hazards of excavating in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency excavation isolation procedures. If workers are required to enter the excavation, rigorously train in protective shoring measures (see 29CFR 1926.650 - .652) and in confined space requirements (see 29CFR 1926.21).
- Identify the location of all below- and above-ground utilities prior to excavation by contacting local utilities and public works personnel. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate prior to excavation to determine the exact location of utilities. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to supervise when raising a backhoe or other equipment.

CONTROL POINT: Design, Construction

(3) *Trench Hazards*.
Description. Open excavations may pose fall hazards to personnel working near the trench. The trench wall may collapse or the worker may fall into the trench while measuring trench depth or collecting samples.

Control. Controls for trench hazards include:
- Inspect the excavation each day to ensure the stability of the walls.
- Limit worker activities near the excavation and only approach wearing fall protection, such as a safety harness or attached lanyard.
- Require all workers near or adjacent to the trench to wear life vests in the event that a worker falls into the slurry as the wall is being poured.
- Equip all personnel crossings with handrails.

- Train workers in unique hazards associated with working in trenches and in the controls required, such as shoring prior to entry.

CONTROL POINT: Construction, Operations

(4) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:
- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Equip the washer with deadman or kill switch if not provided by the manufacturer.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations

(5) *UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts or close to operating equipment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.
- Use the Buddy System.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(6) *Electrocution Hazards*.
Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for electrocution hazards include:

- Verify the location of overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(7) *Heavy Equipment Hazards*.
Description. The heavy equipment (small and large) used for site operations may roll over on steep slopes or unstable ground, seriously injuring the operator. Trucks loaded with backfill can back up too far and become stuck in the trench.

Control. Controls for heavy equipment hazards include:

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction (construction contractor).
- Provide workers and spotters in the vicinity of operating heavy equipment with fluorescent orange or lime green traffic vests.
- Use heavy equipment with roll-over protective devices (ROPS) and do not operate on steep slopes or unstable ground.
- Train workers in the potential operational hazards and safety features of the heavy equipment.

CONTROL POINT: Design, Construction, Operations

(8) *Traffic Hazards*.
Description. During field activities, equipment and workers may come close to traffic. Also, drilling rigs and other equipment may need to cross or use public roads. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil.

Control. Controls for traffic hazards include:

- Post warning signs according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."
- Provide traffic guides with fluorescent orange or lime green safety vests.
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site trucks and automobiles. EM 385-1-1, Section 21.I.10, provides plan details.

CONTROL POINT: Design, Construction, Operations

(9) *Respirable Quartz Hazard*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet soil periodically with water to minimize worker exposure. Wetting of soil may require additional controls to deal with resulting water, ice, mud, etc. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air purifying respirator equipped with N, R or P100 particulate air filters.
- Train workers in the potential inhalation hazards of crystalline silica dust exposures.

CONTROL POINT: Design, Construction, Operations, Maintenance

(10) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(11) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and

other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

Slurry/Contamination Hazards.
Description. During excavation/mixing/installation operations, workers may be exposed to inhalation/ingestion/dermal hazards from caustic irritants such as portland cement, airborne dusts, volatile organic compounds (VOCs), metals, or free silica from soil/bentonite mixtures and waste materials. Eye exposure may occur, resulting in scratching and scarring of eyes.

Control. Controls for contamination hazards include:

- Reduce airborne dusts by periodically applying water, amended water, or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas to which foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and portable surface covers.
- Use the proper types of PPE: an air-purifying respirator equipped with approved N, R or P100 or N, R or P95 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection, and eye protection.
- Use experienced workers, frequent health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Construction, Operations

c. Radiological Hazards.

Radioactive Material.
Description. Radiological materials may have been buried or naturally occurring radioactive material (NORM) may be present in the excavated soils, sludge, and groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion. Note that this may be a rare hazard to encounter using this remediation technology.

Control. Controls for radioactive materials include:

- Test excavated soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist if any radioactive material above background levels is found. Consultation should result in determination of exposure potential, any necessary engineered controls, or PPE required.

CONTROL POINT: Design, Construction, Operations

d. Biological Hazards.

(1) *Biological Contaminants.*
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during the soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens, such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.* if contaminated dusts become airborne.

Control. Controls for biological contaminants include:

- Reduce generation of airborne microbe-contaminated dust with the periodic application of water, amended water, or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect windscreens and use portable surface covers.
- Use proper types of PPE such as an air-purifying respirator with N, R or P100 or N, R or P95 particulate air filters approved for microbial inhalation hazards.
- Use experienced workers, repeated health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Operations

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents, during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for pests include:

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as an active ingredient for exposure control. Clothing may be treated

with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically throughout the workday.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 6
Soil Washing/Solvent Extraction

6-1. General

The methods of soil washing and solvent extraction, their applications, and resulting waste streams are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

6-2. Technology Description

a. Soil Washing.

(1) Process.

Soil washing typically uses water as the solvent (sometimes with wash-improving additives) to extract, desorb, and dissolve contaminants, particularly hydrophilic contaminants. It is also used to sort and separate the contaminated solids by size. Soil washing removes contaminants from soils by dissolving or suspending them in an aqueous wash solution or by concentrating them into a smaller volume of soils, typically the "fines," as this fraction has the highest specific surface area (surface area/volume or mass).

In the soil washing process (Figure 6-1), contaminated soil is screened and homogenized prior to being fed into the washing apparatus. Extraction agents (e.g., surfactants or pH modifiers such as hydrochloric acid) and makeup water are added to the soil. After sufficient mixing, remediated soils are separated from the water. Concentration of contaminants into a smaller volume of soil begins with the use of a "grizzly" to separate out large rocks and continues with various screening and controlled rate-settling processes. Oversized rejects are discarded and the remaining solids washed to separate fine (small) clay and silt particles from the coarser sand and gravel particles.

The success of this technology is based on the principle that most organic and inorganic contaminants preferentially bind, either chemically or physically, to clay, silt, and organic soil particles. The smallest particles have a higher specific surface area, thus increasing their sorbed concentrations relative to volume or weight. The silt and clay are attached to sand and gravel by physical processes such as compaction and adhesion. For heavy metal compounds (such as lead or radium oxides), gravity separation can separate low- and high-specific gravity particles. Adherent contaminant films can be removed from coarser particles by attrition scrubbing. At the end of the process, the remediated solids can be returned to the site or disposed of off site. If the soil does not meet the agreed remediation criteria after washing, the process can be followed by additional treatment of the solids.

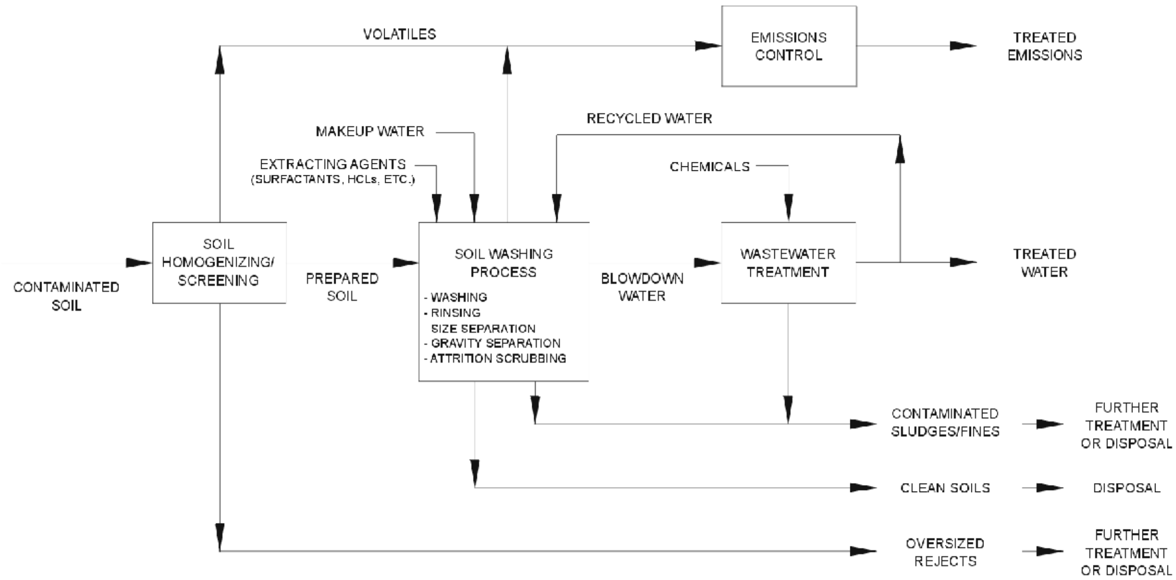

FIGURE 6-1. TYPICAL PROCESS FOR SOIL WASHING

(2) Applications.
Soil washing has been applied to the remediation of semi-volatile compounds, fuels, and inorganics, such as heavy metals and radionuclides. Under certain circumstances, the technology can be applied to volatile compounds and pesticides. Removal of fine soil particles (e.g., silts and clays) from the washing fluid may require the addition of polymeric materials such as flocculants.

(3) Resulting Waste Streams.
This process can produce up to five streams that may require additional handling or treatment:

- Volatile emissions from soil homogenization/screening (require additional treatment).
- Oversized rejects from soil preparation (require additional handling).
- Wastewater (requires additional treatment).
- Contaminated sludge/fines (require additional treatment).
- Solids (may require additional treatment).

The wash water is treated in a wastewater treatment plant and, whenever possible, treated water is recycled back into the washing apparatus.

b. Solvent Extraction.

(1) Process.
Solvent extraction uses a chemical solvent (usually organic) to extract, desorb, and dissolve contaminants. As illustrated in Figure 6-2, contaminated soil, sludge, or sediments are excavated, sized, and screened prior to the extraction process. The homogenized solids are mixed with solvents such as pentane, methyl ethyl ketone, or water-based solvents that extract much of the contaminants. The treated soil matrix is separated from the contaminated solvent and returned to the site after having met remediation cleanup criteria, including solvent concentrations. If the soil does not meet the agreed criteria, solvent extraction can be combined with other technologies to complete treatment. In the ideal version of the process, the contaminants are removed from the solvent and clean solvent is recycled to the extractor.

The solvent should be selected based on the materials to be extracted and other practical characteristics (e.g., ease of recovery and reuse). The toxicity of the solvent is an important consideration if traces of solvent remain in the treated soils. Most solvent extraction processes use hydrophobic solvents such as pentane since most of the contaminants needing to be specifically extracted are hydrophobic. Hydrophilic contaminants may not be effectively removed by the usual organic solvent extractant, and the presence of detergents and emulsifiers can reduce the effectiveness of the technology. For hydrophilic contaminants, water- or amended-water-based solvents should be used as the solvent. The organic solvent technology is generally not used for extracting inorganics (e.g., acids, bases, salts, or heavy metals), and inorganics usually do not have a detrimental effect on the extraction process.

(2) Applications.
Solvent extraction has proven effective in treating sediments, sludges, and soils containing high concentrations of primarily organic contaminants, such as polychlorinated biphenyls (PCBs), VOCs, halogenated solvents, and petroleum hydrocarbon wastes. Organically bound metals (e.g., alkyl lead or tin compounds) can be extracted along with the target organic contaminants, which may result in restricted handling of the residuals.

(3) Resulting Waste Streams.
The process can produce up to five streams that may require additional treatment or special handling:

- Emissions from waste preparation and solvent handling (requires additional treatment).
- Oversized rejects from waste preparation (requires additional treatment or handling).
- Water from moisture content of solids (requires additional handling and possible treatment).
- Concentrated contaminants (requires additional treatment).
- Solids (may require additional treatment).

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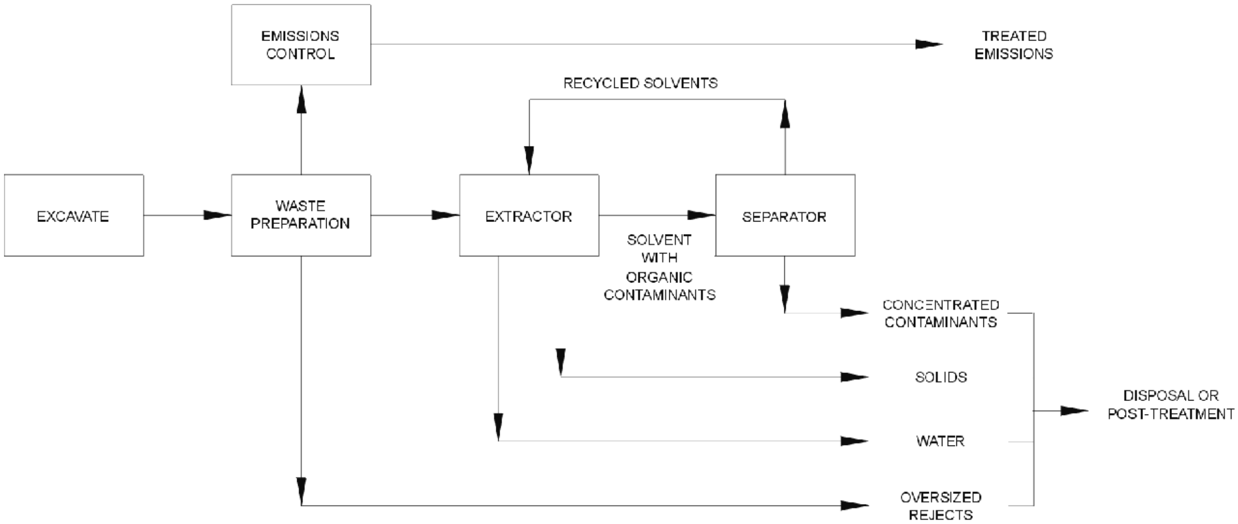


FIGURE 6-2. TYPICAL PROCESS FLOW FOR SOLVENT EXTRACTION

6-3. Hazard Analysis

Principal unique hazards associated with soil washing/solvent extraction, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Heat Stress.*
Description. Workers may be exposed to elevated temperatures, especially during the excavation phase of the treatment process owing to excessive seasonal temperature or operation of process equipment, or both. The exposure may induce heat stress.

Control. Controls for heat stress include:

- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Vigorously train workers in the signs and symptoms of heat stress.
- Use the Buddy System and provide easy access to water.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun

hats should not be worn around moving parts or close to equipment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.

- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.

CONTROL POINT: Design, Operations, Maintenance

(2) *Equipment Hazards.*
Description. During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. This equipment may also cause a noise hazard.

Control. Controls for equipment hazards include:

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection around operating equipment.

CONTROL POINT: Construction, Operations

(3) *Fire and Explosion Hazards.*
Description. During excavation into soils saturated with flammable or combustible materials, fire or explosion hazards may exist. Under unusual or extraordinary conditions, the bucket of a backhoe or the blade of a crawler may cause a spark during contact with rocks, buried metal, or other objects and ignite a flammable vapor that may be created.

Control. Controls for fire and explosion hazards include:

- Train the operators in the hazards of excavating into or through flammable liquids or materials.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency excavation isolation and equipment shutdown procedures.
- Equip the backhoe with a non-sparking bucket or blade when highly flammable excavation materials are suspected.
- Wet the active work area with water periodically.

CONTROL POINT: Design, Operations

(4) *Unguarded Moving Equipment.*
Description. The movement of soil from the excavation area to the treatment unit by a conveyor may create pinch-point hazards from unguarded rollers. Workers' clothing may become entangled with the rollers, causing injury or death.

Control. Controls for minimizing exposure to moving equipment include:

- Use guards for conveyor belts, rollers, and associated equipment to prevent accidental contact.
- Train workers in identifying potential pinch points.
- Disallow the wearing of loose-fitting clothing.

CONTROL POINT: Design

(5) *Fire and Explosion Hazards (Crushing Soils).*
Description. Fire and explosion hazards may exist as soils containing flammable materials are crushed and sized or screened for treatment. As aggregate soils are crushed, sufficient heat may be generated to ignite vapors that have volatilized from the soil. Noise and vibration may also be present during equipment operation. Workers may also be exposed to flying projectiles as a result of the crushing/grinding operation.

Control. Controls for fire and explosion hazards during soil crushing include:

- Train the operators in the hazards of excavating, crushing, and screening soils that are sufficiently contaminated or saturated with flammable liquids or materials. Incorporate in the training on ignition sources any potential for the creation of static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in soil handling/processing system isolation and equipment shutdown procedures.
- Reduce the potential for a fire or explosion with periodic application of water.
- Install equipment on vibration dampening bushings to reduce vibration and noise.
- Use baffles or sound deflecting/absorbing walls between the source and the operator to control noise, and use hearing protection.
- Wear safety glasses with side shields to help prevent eye injuries from projectiles during operation of soil sizing and screening equipment.

CONTROL POINT: Construction, Operations

(6) *Fire and Explosion Hazards (Distillation).*
Description. Fire and explosion hazards may exist during distillation of solvents used in the extraction process. Over-pressurization may result in rupture of the vessel. The resulting release of flammable solvent may pose a fire or explosion hazard.

Control. Controls to prevent over-pressurization of distillation and solvent delivery systems include:

- Train the operators in the hazards of distilling flammable solvents used for the extraction process. Incorporate in the training on ignition sources any potential for the creation of static electricity in the distillation process.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency distillation system isolation and shutdown procedures.
- Use pressure relief valves and hazard warning alarms.

CONTROL POINT: Design

(7) *Steam Pressure Washing.*
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.
- Allow only trained and authorized workers to operate the steam pressure equipment.

CONTROL POINT: Construction, Operations, Maintenance

(8) *Respirable Quartz Hazard.*
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): “Standard Test Method for Particle Size Analysis of Soils” followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air-purifying respirator equipped with N, R or P100 particulate air filters.
- Train the workers in the potential hazards of exposure to crystalline silica inhalation hazards.

CONTROL POINT: Design, Construction, Operations

(9) *Confined-Space Hazards*.
Description. Workers may be exposed to confined-space hazards during entry into mixing/reaction vessels for maintenance. Confined space may expose workers to toxic atmospheric hazards or to hazards associated with oxygen deficiency.

- *Control.* Controls for confined-space hazards include:
- Train workers in confined space hazards and on safety procedures to employ in confined space entry.
- Design the confined space to maximize natural ventilation.
- Develop a pre-entry confined space permit. Implement a confined-space entry program to assess hazards, including air testing the space interior both prior to and throughout the work planned (see 29 CFR 1910.146).
- If the space is filled with flammable vapors, eliminate all potential sources of ignition prior to and during occupancy.
- Require testing of the atmosphere prior to entry into the reaction or mixing vessels, or other confined spaces.
- Ventilate the space prior to and during entry and use supplied air and confined space monitoring techniques to eliminate the hazards (see 29 CFR 1910.146).
- Design air-handling systems to minimize or eliminate oxygen-deficient locations.

CONTROL POINT: Design, Operations, Maintenance

(10) *Electrical Hazards*.
Description. Operation of temporary and permanent electrical equipment, such as lights, generators, and soil washing/solvent extraction system components may cause electrical hazards.

Control. Controls for electrical hazards include:
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Verify that all controls, wiring, and equipment conforms to the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Use grounded equipment or equipment with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) *Emergency Wash Equipment Hazards*.

Description. Emergency shower/eyewash equipment required by 29 CFR 1910.151 is not always equipped with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. Controls for wash equipment hazards include:

- See American National Standards Institute ANSI Z 358.1 – 1998: “Emergency Eyewash and Shower Equipment” for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that may be hazardous when wet.

CONTROL POINT: Design

(12) *Design Field Activities.*
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) *Extracting Agents and Solvents.*
Description. Workers may be exposed to VOC emissions from either extracting agents (surfactants and concentrated acids), solvents used in the solvent extraction process, or to wastes in the extraction/washing process. Examples of solvents include methyl ethyl ketone, pentane, and citric acid derivatives.

Control. Controls for chemical exposure include:

- Add chemicals to the system under closed or properly ventilated conditions.
- Use respiratory protection (e.g., an air-purifying respirator with organic vapor cartridges or air-supplied respirator depending on the existence of adequate warning properties) to control inhalation exposures.
- Assess the exposure by exposure monitoring to determine the type of respirator for the particular application.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) *Chemical Release from System Malfunction.*
Description. During system failure, workers may be exposed to either solvents or extraction agents if the system experiences a release from over-pressurization or other malfunction.

Control. A control to prevent system chemical release includes:

- Use a system designed with redundant safety features, including automatic warning systems, to prevent a release of chemicals from over-pressurization or other malfunction.

CONTROL POINT: Design

(3) *Chemical Exposure from Precipitation Chemicals or Sludge.*
Description. During the process of treating water from the operation, workers may be exposed to chemical hazards from acidic or caustic precipitation chemicals or to the sludge generated from the process. Exposure may be through inhalation/dermal/ingestion routes. The sludge may contain heavy metals, including lead, or organic compounds such as fuels.

Control. Controls to prevent chemical exposure include:

- Design a closed-feed system for the addition of precipitation chemicals as well as for sludge handling and removal.
- Use less toxic precipitation agents.
- Use personal protective equipment (PPE): nitrile gloves for dermal protection from fuels and an air-purifying respirator with combination N, R, or P100 particulate air filter/organic vapor cartridges for control of inhalation hazards.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

Radioactive Material.
Description. Radiological materials may be segregated in the soil washing process, and naturally occurring radioactive material (NORM) may be present in soils, sludge, and groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion.

Control. Controls for radioactive materials include:

- Test soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist if any radioactive material above background levels is found. Consultation should result in determination of exposure potential, any necessary controls, or required PPE.

CONTROL POINT: Design, Construction, Operations

d. Biological Hazards.

Biological Contaminants.
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during the soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp*., *Histoplasma sp*., and *Mycobacterium sp*. if contaminated dusts become airborne.

Control. Controls for biological contaminants include:

- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, amended water, or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and use portable surface covers.
- Use proper types of PPE: an air-purifying respirator with N, R or P100 or N, R or P95 particulate air filter approved for microbial inhalation hazards.
- Offer frequent health and safety awareness meetings, use experienced workers, decontamination stations, and standard personal hygiene procedures.

CONTROL POINT: Design, Construction, Operations

Chapter 7
Soil Vapor Extraction (In Situ), Bioventing, Biodegradation, Thermally Enhanced Soil Vapor Extraction, Electrical Resistivity Heating

7-1. General

The process of soil vapor extraction (SVE), SVE enhancements, bioventing, and in-situ groundwater bioremediation technology applications are included in this section. The second section of the chapter is a hazard analysis, including controls and control points.

7-2. Technology Description

a. Soil Vapor Extraction Methods.

SVE is the process of extracting soil gas from the vadose zone (the vertical soil zone between the ground surface and the groundwater surface) to convey volatile organic compound vapors (VOCs) to the surface for collection or destruction. The process, illustrated in Figure 7-1, generally consists of wells screened in the unsaturated, impacted zone above the water table. The wells are manifolded and connected to a vacuum blower capable of establishing a vacuum on the subsurface soils. The process relies on the combined effects of lowered soil gas pressure (partial vacuum) and soil gas mass flow (soil gas extraction) to enhance volatilization and mass removal of volatile compounds from soil and soil water. The process is dependent on the partitioning of VOCs into the soil gas from the water films and water table (Henry’s Law) or from a separate phase on the pore space surfaces of the soils (Raoult’s Law), or both.

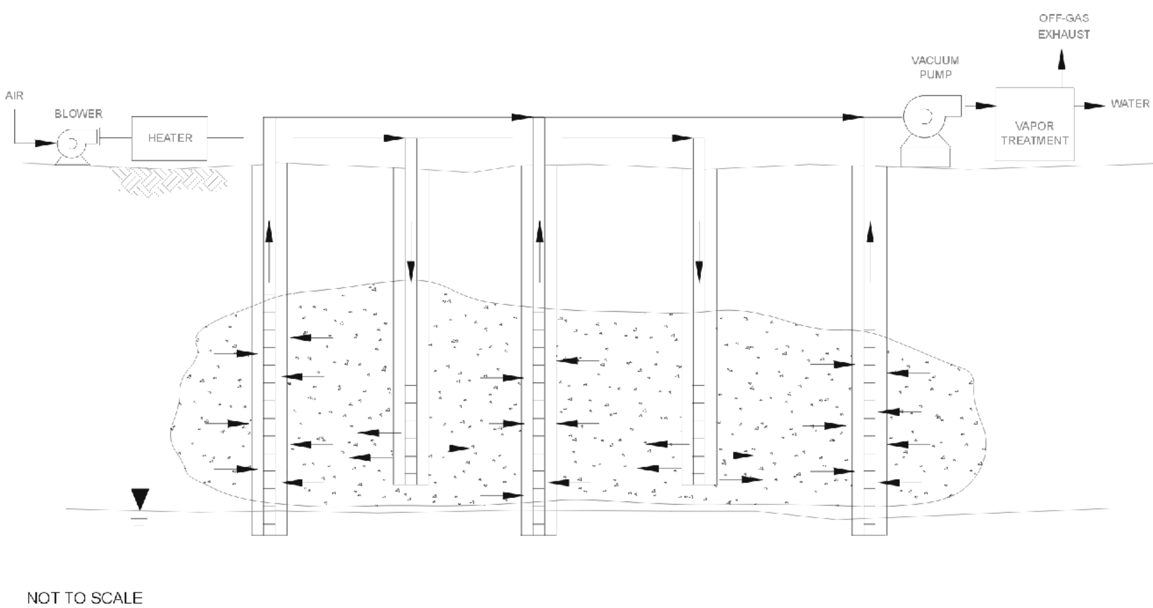


FIGURE 7-1. SVE (IN SITU)/THERMALLY ENHANCED SVE

Many VOCs of environmental concern have low water solubility and relatively high vapor pressures, so the SVE process extracts them readily. Ancillary equipment is used to protect the pump and to treat the extracted soil gas (typically using vapor phase granular activated carbon or catalytic oxidation). Fresh air can be introduced by installing infiltration, induction, or injection wells, or by general infiltration from the surface, or a combination of both.

b. SVE Thermal Enhancements.

SVE systems can be installed with accompanying sparging or air injection processes to enhance the soil gas movement. Occasionally, the processes may also be enhanced in rate and extended to many semi-volatile organic compounds (SVOCs) by applying heat to the treatment zone. Most commonly, the air is heated before its injection, the soil is conductively heated through placement of down hole heaters, the soil is heated by passage of electrical current (Electrical Resistivity Heating [ERH]) through it between electrodes, or steam is injected into the subsurface. Because air has a much lower heat capacity than the soil and water it must heat, the rate of heating using air is generally slow. Steam can heat the soil much faster, but tends to flow upward from the injection point owing to buoyancy. Steam will preferentially travel through the more porous and permeable zone and, therefore, depends on conduction to heat less permeable zones. Heating using electric current passing through the soils (electrical resistivity heating) may more evenly heat the soil, but may result in undesirable voltages at the surface. Both steam injection and electrical resistivity heating can reach temperatures slightly above 100ºC, depending on the depth. Thermal conduction heating using down hole heaters results in quite uniform heating. Such thermal conduction heating can generate significantly higher temperatures than the other methods (greater than 400ºC near the heaters). Thermal enhancements may also alter the soil chemistry and structure, redistribute water in the soils, enhance mobilization of low solubility or low volatility contaminants, and thus (undesirably) mobilize them to the groundwater. Vapors from high volatility compounds may not be adequately controlled by the SVE system and may migrate to the surface or structures. The waste streams generated by these techniques are present in piping and equipment at high temperatures (boiling or above).

c. Bioventing (In-situ Biodegradation).

In-situ biodegradation, as related to SVE, is termed *bioventing* (Figure 7-2). Bioventing is the process of enhancing in-situ bioremediation of the contaminants in the soils by enhancing the availability of oxygen to the microbes by SVE-type venting processes. The primary parameters that can be altered are oxygen content of the pore water, nutrient (nitrogen and phosphorus) content of the soil and water, and pH.

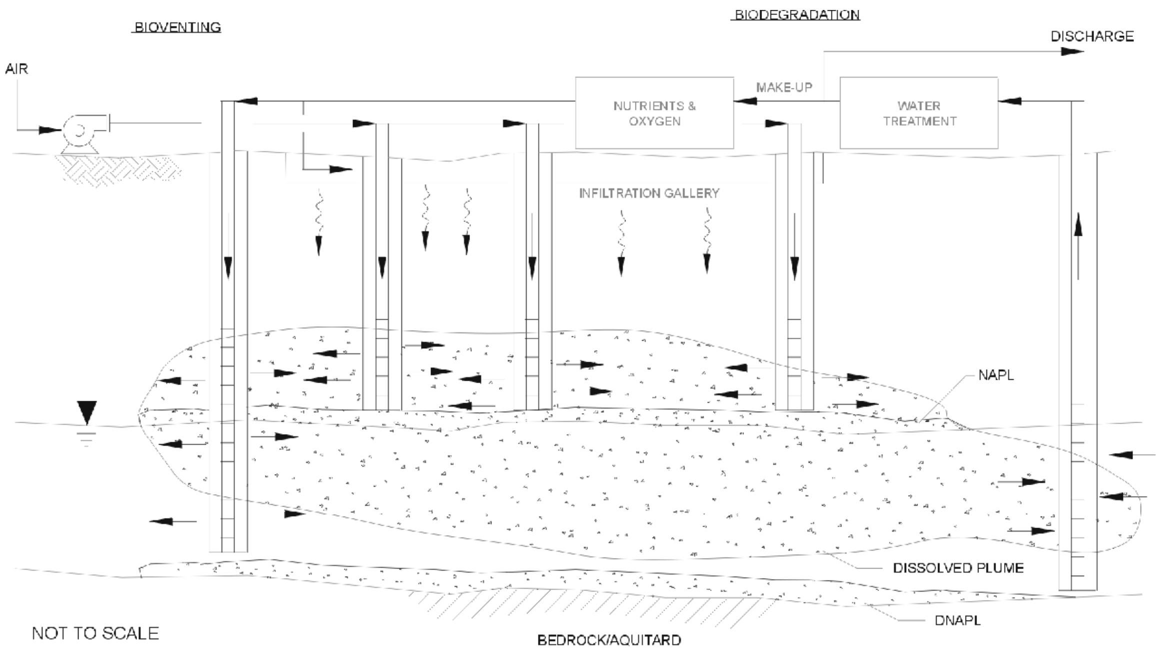


FIGURE 7-2. BIOVENTING/BIODEGRADATION

During bioventing, air drawn or injected into the subsurface provides oxygen to aerobic microorganisms that degrade the VOCs and SVOCs. Because the objective is to provide sufficient oxygen to microbes rather than to use air as a mass remover of VOCs, the rate of air flow is usually lower than with SVE; only the rate needed to sustain biological activity is required. Occasionally, nutrients and water may be added to the subsurface using infiltration galleries to optimize the biodegradation rate or in some cases these can be delivered via air into the treatment zone. The degradation process produces carbon dioxide, water, and incompletely digested organic intermediates as the reaction products with the intermediate products subject to further microbial digestion.

d. Bioventing Enhancements.

These venting processes can be enhanced by active injection of air or by induction of air during active air extraction. The latter approach provides for better control of the off-gas as active injection of air can cause contaminated soil gas to exit the soil surface, and radially flow uncontrolled through the soil.

e. In-situ Groundwater Bioremediation.

In-situ bioremediation (ISB) of groundwater usually involves injection of an organic substrate (i.e., electron donor), such as molasses, sodium lactate, or hydrogen release compound. Electron donor solutions can be introduced via injection wells or direct push injection points. Addition of electron donors can be used to stimulate reductive de-chlorination of some types of chlorinated solvents such as TCE. Biodegradation of nitrate and perchlorate can also be stimulated through electron donor injection. In some instances nutrients or buffering compounds are also injected. Examples of nutrient-containing compounds include ammonium nitrate and ammonium phosphate.

Biofouling of injection or extraction wells often occurs during ISB. Well rehabilitation procedures may involve use of acid, sodium hypochlorite, or hydrogen peroxide solutions. Incomplete degradation of contaminants during in-situ bioremediation can produce intermediates (i.e., TCE may be transformed into DCE and vinyl chloride). Electron donor injection can also produce hydrogen sulfide or methane. If the aquifer is relatively shallow, then there may be an increased risk of hydrogen sulfide or methane migrating into basements and above ground structures.

f. Applications.

The processes will remove or biologically alter the chemical structure of many VOCs and SVOCs. Because they are in-situ processes, they minimize exposure to these compounds during the remediation. However, they require longer times to implement than soil removal technologies.

SVE effectively treats fuel component VOCs and chlorinated organic VOCs as well; bioventing effectively treats fuel, VOCs, and some SVOCs. Thermal enhancements can extend the range of treatable organics to compounds with higher boiling points and viscosities and may allow treatment of volatile metals such as mercury. Chlorinated compounds treated with SVE are treated at rates commensurate with their volatilities and solubilities. The conventional bioventing process is not very effective for treating most types of chlorinated VOCs. However, a variation on the bioventing process (i.e., co-metabolic bioventing) was developed to treat of some types of chlorinated VOCs. Co-metabolic bioventing involves injection of air and a co-metabolite, such as methane or propane.

7-3. Hazard Analysis

The principal unique hazards associated with soil vapor extraction (in-situ) bioventing, biodegradation, and thermally enhanced soil vapor extraction, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Heat Stress*.
Description. Workers may be exposed to elevated temperatures while installing the wells and from excessive heating by blowers and other process equipment during operation of the extraction system. The exposure may induce heat stress.

Control. Controls for heat stress include:

- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Vigorously train workers in the signs and symptoms of heat stress.
- Use the Buddy System and provide easy access to water. Require frequent body fluid replacement and frequent work breaks in shaded locations.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Design, Operations, Maintenance

(2) *High Temperatures*.
Description. Operation of the thermal enhanced treatment systems, such as the injection of steam into the subsurface or in using ERH system electrodes and metal wells adjacent to the heat application points, can increase the subsurface temperatures to the boiling point of groundwater. Following shutdown, it may take several days or weeks for the equipment to cool down, including casings. Severe burns can result from contact with components without proper personal protection equipment (PPE).

Control. Controls for high temperatures include:

- Verify through temperature probes that the equipment, such as metal casings used in conjunction with the heat treatment, is cooled below 140ºF for safe handling.
- Provide proper PPE for burn hazards, such as insulated gloves for handling well attachments and electrodes.
- Vigorously train personnel in working around equipment heated to extreme temperatures for sampling during active heating and for several weeks following shutdown.
- Use the Buddy System for the symptoms of heat stress, and provide easy access to water. Require frequent body fluid replacement and frequent work breaks in shaded locations.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Operations, Maintenance

(2) *Equipment Hazards (Excavation).*
Description. During drilling of wells or excavation of trenches when installing horizontal piping systems, workers may be seriously injured or killed by heavy equipment such as drill rigs or front-end loaders and scrapers operating in their work areas. This equipment may also generate excessive noise during operation.

Control. Controls for equipment hazards include:

- Use heavy equipment with a backup alarm to alert workers.
- Provide workers and spotters in the vicinity of operating heavy equipment with fluorescent orange or lime green traffic vests.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection and establish a hearing conservation program.

CONTROL POINT: Construction, Operations, Maintenance

(3) *Utility Contact Hazards*.
Description. Fire or explosion hazards may exist if excavation equipment ruptures an underground utility (electrical or gas lines) during installation of the system.

Control. Controls for utility hazards include:

- Train the operators in the hazards of excavating in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency excavation isolation procedures.
- Identify the location of all below- and above-ground utilities by contacting local utilities and public works authorities. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.

CONTROL POINT: Design, Construction

(4) *Fire and Explosion Hazards (Gas Transfer).*
Description. During the transfer of flammable gas from the extraction wells or subsurface piping systems to the treatment unit, a fire or explosion hazard may exist. The gas may be ignited by improperly selected or installed equipment.

Control. Controls for fire and explosion hazards during gas transfer include:

- Train the operators in the hazards of the gas collection system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency gas recovery system isolation and shutdown procedures.
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use grounded equipment or equipment with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70.
- Monitor the atmosphere periodically around the area with a combustible-gas monitor. If the concentration of explosive gas reaches 10% of the Lower Explosive Level (LEL) or greater, inspect the system for leaks and emission points.
- Control all sources of VOC emissions to prevent the release of flammable gas.
- Install a permanent explosion level meter or alarm if necessary.

CONTROL POINT: Design, Construction

(5) *Explosion Hazards (Steam Generator).*
Description. Thermally enhanced SVE systems may incorporate steam to heat soils. Pressure caused by plugged steam lines may cause a rupture or an explosion in the system.

Control. Controls for explosion due to steam generators include:
- Train the operators in the hazards of operating the steam generators, including the operating parameters that would lead to plugged lines and catastrophic pipe failure and steam release.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including emergency burn treatment, extracting, and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.

- Operate the steam generator within its design parameters and use emergency pressure relief valves.
- Flush steam lines periodically to remove any accumulated scale or deposits.

CONTROL POINT: Design, Operations, Maintenance

(6) *Burn (Steam) and Freezing Hazards.*
Description. The surface temperature of uninsulated steam generators and piping systems may reach several hundred degrees and pose a burn hazard to workers. Steam will be generated in the subsurface during operation of the ERH system. The steam will be present throughout the treatment area, and in the vapor recovery wells in the vicinity of the treatment area as well as at the condenser and within the condenser. Steam may be generated under positive pressure. Catalytic oxidation system components can be hot, and also pose a burn hazard. Cryogenic systems, associated with O_2 delivery systems, can have very cold surfaces and pose a contact-freezing hazard.

Control. Controls for burn and freezing hazards include:

- Train the operators in the hazards of operating high temperature steam generators, including the surface operating temperatures of equipment.
- Properly insulate surfaces exposed to operators.
- Avoid exposing workers to the sources of steam.
- Provide PPE including face shields, gloves, and heat resistant rain clothing for protection against burns when opening or working around wells, piping, or system components containing steam.
- Include high temperature hazard warning signs on the equipment.
- Provide physical covers and barriers to prevent contact.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) *Noise Hazards*.
Description. High levels of noise may be generated by blowers and compressors and may result in hearing loss.

Control. Controls for noise hazards include:

- Use insulated materials, barriers, and properly lubricate and maintain equipment.
- Establish a hearing protection program (see 29 CFR 1926.52). Require personal hearing protection when working in areas of elevated noise levels.

CONTROL POINT: Design, Operations

(8) *Unguarded Moving Equipment*.
Description. Unprotected blowers and fans may entangle workers' clothing and cause injury.

Control. Controls for moving equipment include:
- Guard all moving and rotating equipment.
- Inform workers that all such equipment must be operated with guards in place.
- Train workers in the entanglement hazards.
- Disallow the wearing of loose-fitting clothing.

CONTROL POINT: Design, Operations

(9) *Equipment Hazards (Drilling).*
Description. During drilling and direct push operations, heavy equipment such as augers and pipes are periodically raised overhead and placed above or into the well. Workers may be exposed to swinging equipment during lifting or may be exposed to crushing hazards if the equipment falls. Cables used to rise and lower equipment may also become entangled in loose clothing or other equipment. Direct push drilling methods using hydraulic pressure to advance a soil boring may pose a crushing hazard to hands or feet.

Control. Controls for equipment hazards during drilling include:
- Train workers in heavy equipment lifting hazards, including properly securing the loads, establish and practice the Buddy System for all lifts, and maintain a constant line of sight between all members of the ground crew and the lift operator.
- Stabilize drill rig by leveling or blocking whenever soil conditions dictate.
- Post a spotter to the side to supervise when raising a drill mast.
- Do not move the drilling rig with the mast raised.
- Secure all loose clothing, use low-profile auger pins, and use long-handled shovels to remove soil cuttings from the borehole.
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may become entangled in loose clothing.

CONTROL POINT: Design, Maintenance

(10) *Electrocution/Fire Hazards (Overhead Lines or Piping Systems).*
Description. Electrocution or fire hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling mast contacts overhead electric lines or piping systems containing flammable chemicals.

Control. Controls for electrocution include:

- Train the operators in the hazards of drilling in the vicinity of overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Inform all workers as to the location of overhead utilities.
- Drill in an alternative location if possible.
- Keep all lifting equipment (cranes, forklifts, and drilling rigs) at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.
- Post a worker to observe and supervise when raising a drill mast.
- Operate the mast at its lowest height; different drill rigs have different mast elevations and may be operated at different heights.

CONTROL POINT: Design, Construction, Maintenance

(11) *Electrical Equipment Hazards*.
Description. Operation of temporary and permanent electrical equipment, such as lights, generators, and heated SVE system components, such as ERH electrodes, may cause electrical hazards.

Control. Controls for electrical equipment include:

- Train workers in recognizing electrical hazards and in the controls specified in NFPA 70 and EM 385-1-1.
- Verify that the hazardous area classifications as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use all controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazardous areas.
- Use grounded equipment or equipment provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.
- Startup and initial unattended operations of ERH power control units must be performed only with Site Startup Checklist completed and signed by appropriate thermal operations personnel.
- Establish an exclusion zone around the electrode field of an ERH system when voltage is initially applied to electrodes, typically with a chain link security fence, plastic fencing or barrier tape, depending on environs. Locate fencing to maintain less than or equal to step-

touch potential not to exceed 15 volts. If surface voltages are verified less than 15 volts throughout the electrode field, the exclusion zone can be reclassified to general remediation hazard area. Identify all metal objects within 100 feet of the electrodes prior to startup. If startup indicates hazardous voltages developing outside the exclusion zone, improve grounding systems by reorienting the surface grid area, or adding grounding rods, otherwise breaking the conducting path outside the exclusion zone or increasing the size of the exclusion zone.

- Maintain strict access control to the exclusion zone, electrodes, and equipment.
- Establish and maintain rigorous lock-out/tag-out procedures implemented by only authorized personnel.

CONTROL POINT: Design, Construction, Operations, Maintenance

(12) *Explosion Hazards (Gas Storage).*
Description. Improper storage and use of cylinders of compressed gases in some in-situ bioremediation systems may cause explosive or projectile hazards.

*Control***.** Controls for explosion attributable to gas storage include:

- Train the workers in the hazards of handling compressed gases in cylinders and in safe handling requirements (see 29CFR 1910.101, Compressed Gas Association Pamphlet P-1-1965, and Compressed Gas Association Pamphlets S-1.1-1963 and 1965 addenda and S-1.2-1963).
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including emergency burn treatment, toxic gas exposure treatment, extracting, and stabilizing victims, and in emergency isolation procedures.
- Store cylinders of compressed gases upright, capped, and secured to prevent movement or tipping.
- Avoid extreme temperatures.

CONTROL POINT: Design, Operations

(13) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

*Control***.** Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.

- Wear safety goggles and hearing protection.
- Equip washers with a deadman or kill switch if not provided by manufacturer.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(14) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle injuries include:

- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques, including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14). Some loads may require two people.
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(15) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Degradation Products*.
Description. Biological degradation of certain organic compounds may produce toxic intermediate products. As an example, degradation of trichloroethylene (TCE) can produce trichloroethylene (DCE) and vinyl chloride (VC). Vinyl chloride exists as a gas and may accumulate to

higher levels in boreholes or in the system. Workers may be exposed to the degradation products during operation or maintenance of the system.

Control. Controls for degradation products include:

- Install vapor extraction wells to prevent emissions from reaching basements, above-ground work areas, and enclosed structures.
- Ventilate the area to minimize exposure.
- Require air-supplied respiratory protection if supported by air monitoring results. (Note: air-purifying respirators are not recommended for vinyl chloride.)
- Remediation designers must understand and anticipate the generation and management of general and specific process products, such as carbon dioxide, hydrogen sulfide, methane, and vinyl chloride (CO, H_2S, CH_4, VC), and design for their management.

CONTROL POINT: Design, Operations, Maintenance

(2) *Waste Chemicals and VOC Exposure*.
Description. During installation of the wells and system operations and maintenance, workers may be exposed to dermal or inhalation hazards associated with waste chemicals, such as airborne dusts, particulates, and VOC emissions resulting from off gassing or leaks.

Control. Controls for waste chemicals and VOCS include:

- Apply water or surfactant amended water solution to the area during installation to help control airborne dusts, particulates, and VOCs.
- Use proper ventilation during installation and operation.
- Use personal protective equipment (PPE) that eliminates exposure hazards (e.g., an air-purifying respirator with organic vapor cartridges).
- Check closed systems, such as SVE, routinely for leaks of the off-gas treatment system with PIDs, air samples, oxygen meters, leak detection fluids, explosive gas meters, or specific gas tests with chemical-specific detector tubes.
- Repair leaks immediately.
- Make vent stack heights adequate to disperse off-gas.
- Designers must anticipate byproducts and products and be certain that technologies selected for treatment (e.g., activated carbon, condensation, catalytic oxidation) of off-gas residuals are both effective and safe.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) *VOC Migration*.
Description. Air injection may cause the migration of VOCs to low areas, such as basements and sewers. The accumulated, flammable VOCs can cause chemical exposure or an explosion to the occupants. In addi-

tion to VOCs, other types of gasses may accumulate such as hydrogen sulfide and methane.

Control. Controls for VOC migration include:

- Train workers in the hazards of accumulating dense flammable contaminants, such as VOCs generated during the extraction process, in low areas and spaces, such as basements, sewers, and manholes.
- Install vapor extraction wells to prevent emissions from reaching basements, above-ground work areas, and enclosed structures.
- Operate building heating/ventilation/air-conditioning systems under positive pressure to reduce intrusion of emissions from the subsurface.
- Train workers in emergency procedures in case of a catastrophic event, such as a gas explosion, in life saving first aid procedures including emergency burn treatment, extracting, and stabilizing victims, and in emergency SVE shutdown procedures.
- Test air periodically to ensure safe levels in basements and other areas where VOCs may migrate.

CONTROL POINT: Design, Operations, Maintenance

(4) *VOC Exposure (Vents).*
Description. Workers may be exposed to VOCs as they are discharged from the blower vent.

Control. Controls for VOC migration include:

- Install emission controls, such as activated carbon canisters, on the blower vent discharge.
- Monitor periodically for efficiency.

CONTROL POINT: Design, Operations, Maintenance

(5) *Chemical Release*.
Description. Fire or explosion or chemical release (inhalation/ingestion/asphyxiation) hazards may exist when using a hollow-stemmed auger, direct push, or other drilling methods if the drilling bit or bucket ruptures underground utilities, tanks, or piping systems (overhead chemical feed lines) containing hazardous chemicals.

Control. Controls for accidental chemical release include:

- Train workers in the hazards of drilling in the vicinity of underground utilities.
- Train workers in emergency procedures in case of a catastrophic event, such as a gas explosion or electrocution, in life saving first aid procedures including emergency burn treatment, extracting, and stabilizing victims, and in emergency SVE or drilling shutdown procedures.

- Identify location of all below ground utilities by contacting local utilities during design phase.
- Perform a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of underground lines prior to drilling.
- Locate overhead hazards and design so that installations using erect equipment are not necessary in that area, if possible.

CONTROL POINT: Design, Construction

c. Radiological Hazards.

Radon Exposure.
Description. In some geological settings, workers may be exposed to naturally occurring radon gas. The gas is drawn from the soil in the SVE stream. Radon gas and radon progeny do not present a significant external hazard. While breakdown products of radon (progeny) may present an inhalation/ingestion hazard, quantities of radon progeny normally present would not pose a significant exposure hazard.

Control. Controls for radon exposure include:

- Operate emission control technologies properly to limit exposure to acceptable levels.
- Consult a qualified health physicist if excessive levels are encountered or suspected.

CONTROL POINT: Design, Operations, Maintenance

d. Biological Hazards.

(1) *Biological Contaminants*.
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during system installation activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp.*, *Histoplasma sp.*, and *Mycobacterium sp.* if contaminated dusts become airborne.

Control. Controls for biological contaminants include:

- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, surfactant amended water, or emission-suppressing foams to the active excavation/drilling areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Erect windscreens and use portable surface covers.

- Use the proper types of PPE: an air-purifying respirator with N, R or P100 particulate air filters approved for microbial inhalation hazards and rubber gloves.
- Use experienced workers, repeated health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Construction, Maintenance

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for pests include:

- Periodically inspect the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents containing the active ingredient N,N-diethyl-m-toluamide (DEET) 25% for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 8
Free-Product Recovery

8-1. General

Chemical contaminants usually existing as free product and methods of removal are described in the first section of the chapter. The chapter's second section is a hazard analysis with controls and control points listed.

8-2. Technology Description

a. Compound Types.

Many contaminants, usually hydrophobic organics, when released in sufficient volume, will exceed the absorption capacity of the intervening soils and flow down to the groundwater surface through the soil pore spaces. If less dense than water, the materials will float on the groundwater, slightly depressing the surface tension in a potentially recoverable pool. If denser than water, the materials will continue to sink through the pore spaces (displacing water), forming discrete and connected ganglia, and later possibly reaching a lower retarding layer.

The most prevalent classes of compounds likely to exist as free product or non-aqueous phase liquids (NAPLs) are those compounds with low solubilities in water such as chlorinated solvents, reagents (e.g., trichloroethylene, tetrachloroethylene, and PCBs), and petroleum hydrocarbons (e.g., gasoline, jet fuel, fuel oils, and tars). Chlorinated solvents and tars are typically more dense than water and are called DNAPL (dense non-aqueous-phase liquids). Petroleum hydrocarbons are generally less dense than water and are called LNAPL (light non-aqueous-phase liquids). DNAPLs tend to sink vertically. They will often migrate deep underground into isolated areas where it may be impossible to remove them by conventional treatments. LNAPLs float on the water table and tend to spread laterally at the top of the capillary fringe.

b. Removal Methods.

Free product, such as oil or NAPLs, on groundwater may be removed using three methods:

- Open trenches.
- Back-filled trenches with recovery wells.
- Extraction wells.

Water table depth and gradient are the primary factors in selecting a recovery method. Schematics of one-pump and two-pump recovery well systems are presented in Figures 8-1, 8-2, and 8-3.

Making any free-phase product recovery system effective requires a good understanding of geologic conditions. Limitations on the rate of recovery include water, free-phase handling capabilities, and site-specific factors.

Recovery trenches can be used to remove LNAPL when the groundwater depth is shallow enough to reach with a trench. LNAPL recovery devices can be installed into the trench to recover free product. A groundwater pump may be used to depress the local groundwater and increase the rate of oil and water flow to the trench. An impermeable barrier or barriers (e.g., bentonite or clay slurry wall) can be installed to divert liquid flow towards the trench.

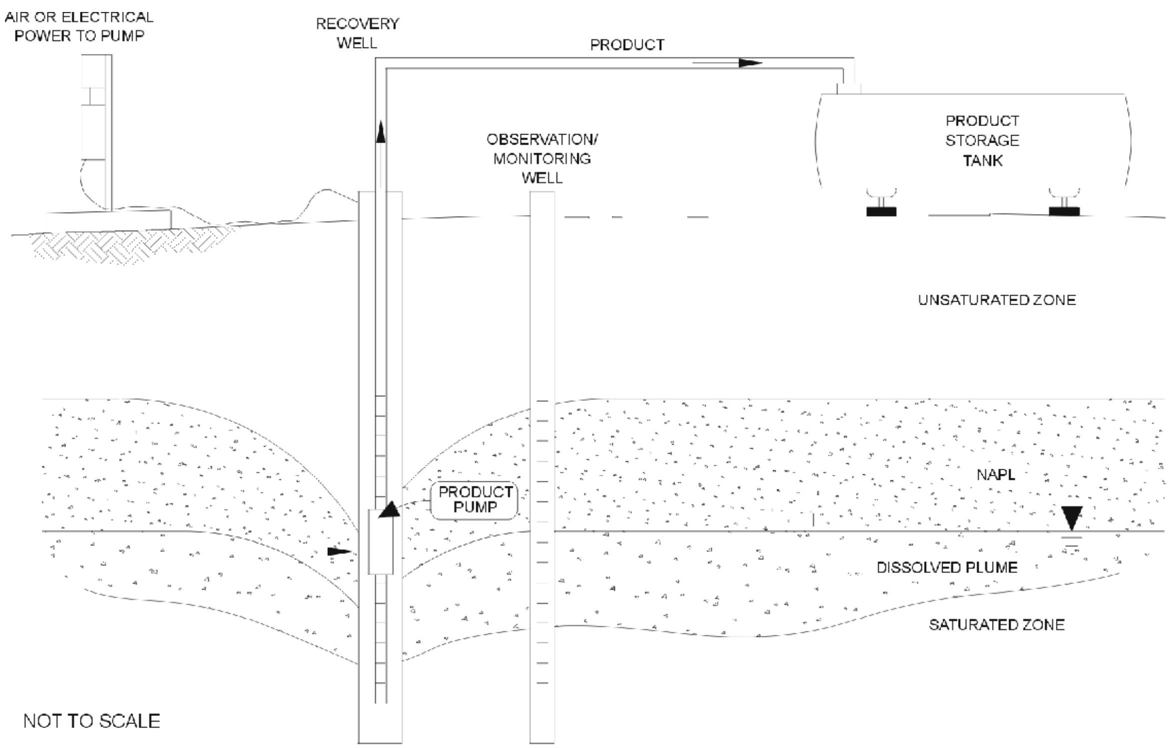


FIGURE 8-1. FREE-PRODUCT RECOVERY(ONE-PUMP SYSTEM)

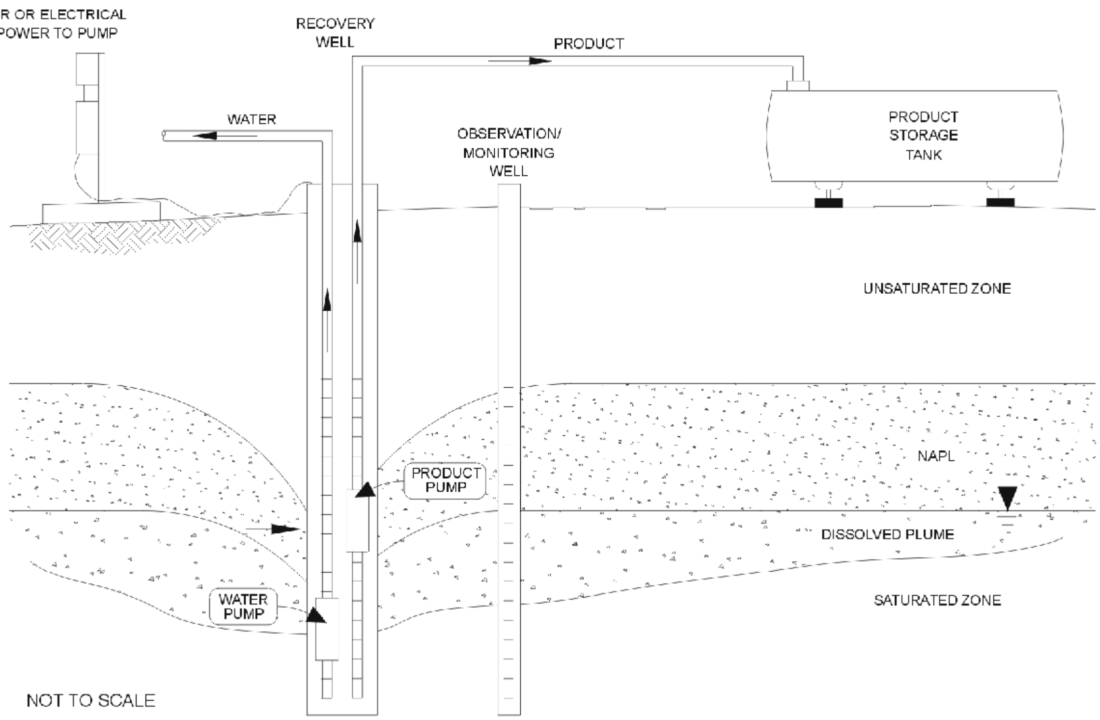


FIGURE 8-2. FREE-PRODUCT RECOVERY(TWO-PUMP SYSTEM)

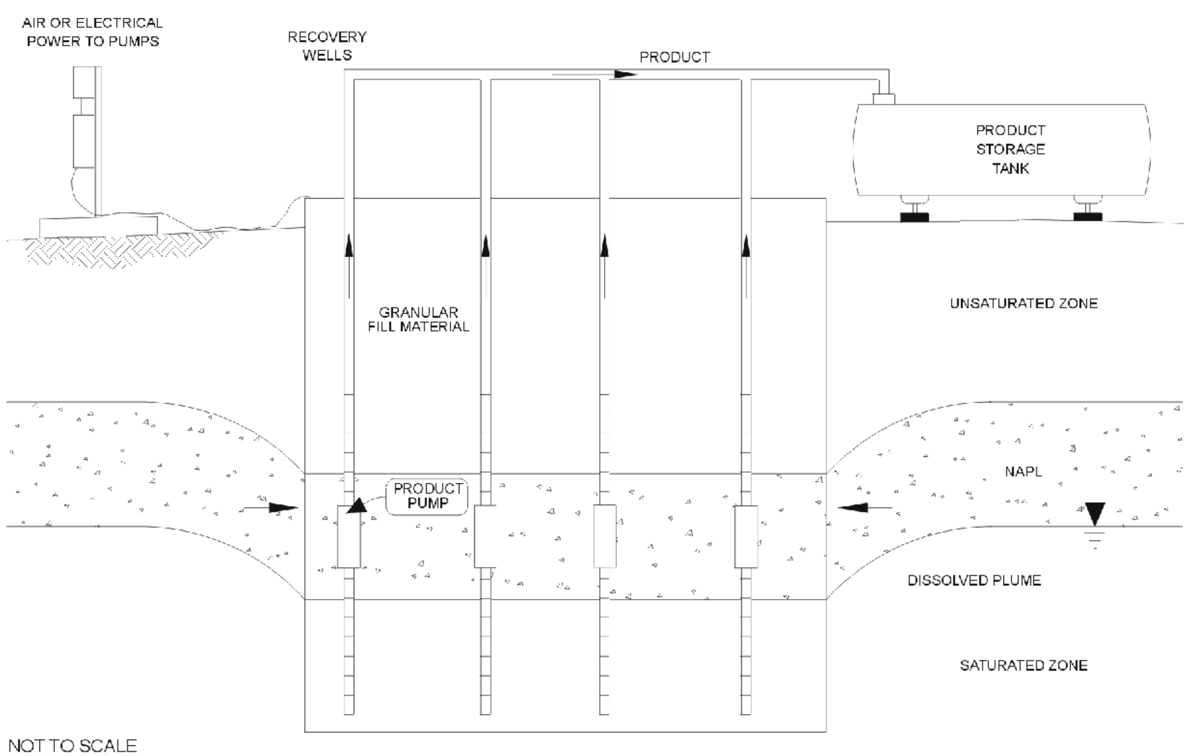


FIGURE 8-3. FREE-PRODUCT RECOVERY TRENCH

Extraction (recovery) wells also may be used. Slurry walls can be used to guide the groundwater and product flow to the well or wells. LNAPL in the well can be removed with a product skimmer pump or belt skimmer, vacuum devices (slurpers), or a groundwater recovery pump. A groundwater pump creates a cone of depression, which can increase the oil recovery rate, but can also emulsify water and LNAPLs. Recovery wells can be single pump, double pump, or double shaft. A single-pump well uses one pump to recover oil and water. Double-pump wells combine a product recovery pump with a groundwater drawdown pump into a single well. A double-shaft well uses two concentric casings in one well. Free product is recovered in the outer casing while groundwater is drawn down by another pump in the inner casing. This separation of devices allows better regulation of water level and flow within the well, and helps minimize emulsion of oil and water.

For DNAPL recovery, the pool of sinking product must be located (if present); the lower retarding strata must be delineated for low points where the DNAPL has flowed; and those low points must be penetrated by recovery wells and pumps to capture NAPL. This is usually a slow process, but may be enhanced by groundwater recovery and re-injection with or without surfactants.

8-3. Hazard Analysis

Principal unique hazards associated with free-product recovery, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire or Explosion Hazards (Drilling).*
Description. Soil boring using hollow-stemmed augers prior to well installation may cause a fire or explosion during drilling into soils saturated with flammable or combustible materials under unusual or extraordinary conditions. Sparks generated when an auger contacts rocks, metal, or other underground objects may ignite a flammable atmosphere inside the borehole. This is considered an unlikely but potential hazard.

Control. Controls for fire or explosion hazards include:

- Train operators in the hazards of drilling into or through flammable liquids or materials.
- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Use mud or water rotary drilling methods, which add moisture to the cutting area.

CONTROL POINT: Construction, Maintenance

(2) *Utility Contact Hazards*.
Description. Fire, explosion, or electrocution hazards may exist when using hollow-stemmed auger drilling methods if the rotating auger contacts or ruptures underground utilities (electrical or gas lines) or comes in contact with overhead electric lines.

Control. Controls for utility contact hazards include:
- Train the operators in the hazards of drilling in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Contact local utilities and public works authorities to determine the locations of all utilities. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful drilling may be allowed.
- Post an observer to the side to supervise when raising a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction, Maintenance

(3) *Fire and Explosion Hazards (Transfer of Flammable Liquid).*
Description. During the transfer of flammable or combustible liquids (such as jet fuel) from the recovery well, a fire or explosion hazard may exist. The liquid may be ignited by improperly selected or installed equipment. Emissions from the collection equipment may also be ignited, possibly causing a fire or explosion. Ejector pumping systems produce mixtures of flammable vapors and air, which may ignite and explode.

Control. Controls for fire and explosion hazards include:
- Train the operators in the hazards of the collection system, including the reactivity of the contaminants extracted, and the sources of ignition including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Check electrical system design and equipment installation for appropriateness to hazard areas.

- Use grounded equipment or equipment provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1 or NFPA 70.
- Do not use piping systems and ejectors that mix air with flammable vapors.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) *Equipment Hazards*.
Description. During installation of the extraction trenches, workers may be seriously injured or killed by heavy equipment such as front-end loaders and backhoes. Heavy equipment may also generate elevated noise levels, which may damage worker hearing.

Control. Controls for equipment hazards include:

- Use heavy equipment with a backup alarm to alert workers.
- Provide spotters for the equipment operators.
- Provide workers in the vicinity of operating heavy equipment with fluorescent orange or lime green traffic vests.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection.

CONTROL POINT: Construction, Maintenance

(5) *Trench Hazards*.
Description. Walls of trenches used for free-product recovery may collapse, causing workers to fall into the excavation.

Control. Controls for trench hazards include:

- Ask a competent person to determine the integrity of the excavation before workers are allowed to walk near the edge of the excavation.
- Do not approach the edge of the excavation without fall protection.
- See EM 385-1-1, Section 25, for additional control measures and requirements.

CONTROL POINT: Design, Construction, Maintenance

(6) *Confined Space Hazards*.
Description. Depending on the dimensions, trenches can create confined space conditions where workers may be overexposed to airborne chemical hazards if the atmosphere in the confined space contains a toxic chemical, such as flammable liquid vapors or chlorinated solvent vapors, or is otherwise oxygen deficient.

Control. Controls for confined space chemical hazards include:

- Train workers in confined space hazards and on safety procedures to employ in confined space entry.
- Design the confined space to maximize natural ventilation.

- Develop a pre-entry confined space permit. Implement a confined-space entry program to assess hazards, including air testing the space interior both prior to and throughout the work planned (see 29 CFR 1926.21).
- Ventilate confined spaced if a hazardous atmosphere exists.
- If the space is filled with flammable vapors, eliminate all potential sources of ignition prior to and during occupancy.

CONTROL POINT: Operations

(7) *Unguarded Moving Equipment*.
Description. Skimmer belts used for free-product removal from trenches are often equipped with unguarded pulleys, which may cause entanglement of body parts or loose clothing.

Control. Controls for moving equipment include:

- Use only guarded pulleys and guarded moving or rotating mechanical devices.
- Train workers to operate the equipment only with the machine guarding in place.
- Disallow the wearing of loose clothing near the equipment.

CONTROL POINT: Design, Construction, Operations, Maintenance

(8) *Fire or Explosion Hazards (Tanks)*.
Description. Containment tanks used for storage of recovered free product may overflow, creating the potential for fire or explosion.

Control. Controls for tanks include:

- Train the operators in the hazards of the collection tank system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Install fluid level indicators equipped with automatic shut-off switches on free-product recovery tanks to help prevent overflowing.
- Inspect the collection equipment regularly to identify and repair system leaks.

CONTROL POINT: Design, Operations, Maintenance

(9) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the stream pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Equip washers with deadman or kill switch if not provided by manufacturer.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(10) *Respirable Quartz Hazard.*
Description. Depending on soil types, exposure to respirable quartz may be a hazard during trench excavation. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet soil periodically with water to minimize worker exposure. Wetting of soil may require additional controls to deal with resulting water, ice, mud, etc. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air purifying respirator equipped with N, R or P100 particulate air filters.
- Train workers in the potential inhalation hazards of crystalline silica dust exposures.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) *Muscle Injuries.*
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle injuries include:

- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14). Utilize more than one worker to manage the lift.
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(12) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(13) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Vapor Discharge*.
Description. Vapors discharged from oil/water separators may expose workers to VOCs via inhalation.

Control. A control for vapor discharge includes:

- Vent the discharge from the oil/water separators into the ambient environment above and beyond the breathing zone of workers.

CONTROL POINT: Design

(2) *Chemical Exposure*.
Description. Process and equipment piping for the collection, transfer, treatment, and storage of recovered free product may leak and create an exposure

pathway by ingestion/inhalation/dermal contact for workers operating or maintaining the system. Workers may be exposed to waste materials, such as benzene in gasoline or other hydrocarbons in jet fuel. The exposure may cause skin, eye, and respiratory tract irritation and other symptoms.

Control. Controls for chemical experience include:

- Prevent leaks through regular system inspection and maintenance.
- Detect leaks by a regular leak detection process using O_2 meters, explosivity meter, PIDs, OVA, leak detection fluids, and other appropriate methods.
- Wear personal protective equipment (PPE) such as an air-purifying respirator with organic vapor cartridges and nitrile gloves for exposure to the free products such as jet fuel or gasoline.

CONTROL POINT: Operations, Maintenance

(3) *Contaminant Exposures (Trench/Well Installation).*
Description. During trench or well installation, workers may be exposed to contaminants, such as VOCs, dusts, and metals in soil and development water through the three exposure routes of inhalation/ingestion/dermal contact.

Control. Controls for contaminant exposures include:

- Apply water or an amended water solution to the area during well and trench installation to help control the generation of airborne dusts, particulates, and VOCs.
- Use respiratory protection including an air-purifying respirator equipped with approved filter/cartridges such as N, R or P100 particulate air filters, organic vapor (OV) cartridges for vapors, or combination filter/cartridges for dual protection.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE and respirator cartridges. The analysis should include a chemical waste profile to help ensure that PPE specified will be appropriate for the respective chemical hazards.

CONTROL POINT: Construction, Operations, Maintenance

(4) *Contaminant Exposures (Free-Product Recovery and Collection).*
Description. During operation of the free-product recovery trenches and collection equipment, workers may be exposed to chemical materials, such as jet fuel, hydrogen sulfide, VOCs, and biologically generated byproducts (e.g., vinyl chloride, methane).

Control. Controls for contaminant exposures include:

- Wear respiratory protection (e.g., an air-purifying respirator with organic vapor cartridges or supplied air, depending on adequacy of the warning properties – hydrogen sulfide and vinyl chloride exhibit poor warning properties) to control inhalation exposures to VOCs during operation of collection equipment.

- Analyze the type of respirator required before issuing PPE. Include a chemical waste profile on the waste materials to ensure that the respirator and filter/cartridge or air supply specified will be appropriate.

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

Radioactive Materials.
Description. Radioactive materials may have been buried or naturally occurring radioactive material (NORM) may be present in soils, sludge, and groundwater. Radioactive materials may become entrained with the free product and eventually build up as scale in pipes and handling systems. Some radioactive materials may present an external exposure hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion. Exposure to radiation using this remediation technology may be rare.

Control. Controls for radioactive materials include:
- Test soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist if any radioactive material above background levels is found to determine exposure potential and any necessary engineered controls or PPE.

CONTROL POINT: Design, Construction, Operations, Maintenance

d. Biological Hazards.

No unique hazards are identified.

Chapter 9
Dual-Phase Extraction (Bioslurping)

9-1. General

The processes of dual-phase extraction and bioslurping are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

9-2. Technology Description

Water immiscible contaminants (hydrophobic), such as many hydrocarbons and chlorinated hydrocarbons, can sink through the soil pore spaces to groundwater. When less dense than groundwater, the materials float in a spreading layer, depressing the groundwater surface tension slightly. Typical recovery is by a down-hole pump in a well. Material recovered is a mixture of hydrocarbons and groundwater.

a. Dual-Phase Extraction.

Dual-phase extraction modifies the typical design for well construction and recovery methods for groundwater non-aqueous phase liquids (NAPL) by the insertion of a vacuum extraction pipe ("straw") down the well casing bore to the water table surface. The wellhead is sealed, and the extraction pipe is connected to a vacuum pump (capable of drawing a relatively high vacuum, more than 0.5 atm) at the surface. The pump draws a mixture of air, water, and NAPL from the water surface by aspirating the liquid into the soil gas stream. The mixture of air, water, and NAPL is low in average density, which allows this extraction technique to be used at depths greater than an atmosphere pressure of water head. The two (or three) phases are separated on the surface in a series of separators, first liquid/vapor and then oil/water separators if needed. The soil gas replenishment is from the surrounding formation and eventually the surface so the process effectively aerates the vadose zone around the well. This can be used for biological enhancement, leading to the term "bioslurping." The process is illustrated in Figure 9-1.

b. Bioslurping.

The aeration of the vadose zone around the well can be used for biological enhancement or *bioslurping.* The three-phase flow (the combination of air and water flow above and below the NAPL) assists in pulling the NAPL into the well bore at a rate often exceeding conventional liquid pumping methods. The method may permit more effective dewatering of very tight soil formations. The method is applicable to NAPL sites and vadose zone contamination by volatile organic carbon compounds (VOCs) and degradable semi-volatile organic compounds (SVOCs). In bioslurping, the process is operated as described above, except the air and water movement are exploited to promote in-situ bioremediation during free-product recovery. This is occasionally done by reinjecting and reinfiltrating the recovered groundwater but with oxygen and nutrients added. This, in combination with the movement of unsaturated zone air, provides bioventing and closed loop in-situ bioremediation of the groundwater. Thus, bioslurping is a combination of free-product recovery, bioventing, and in-situ bioremediation.

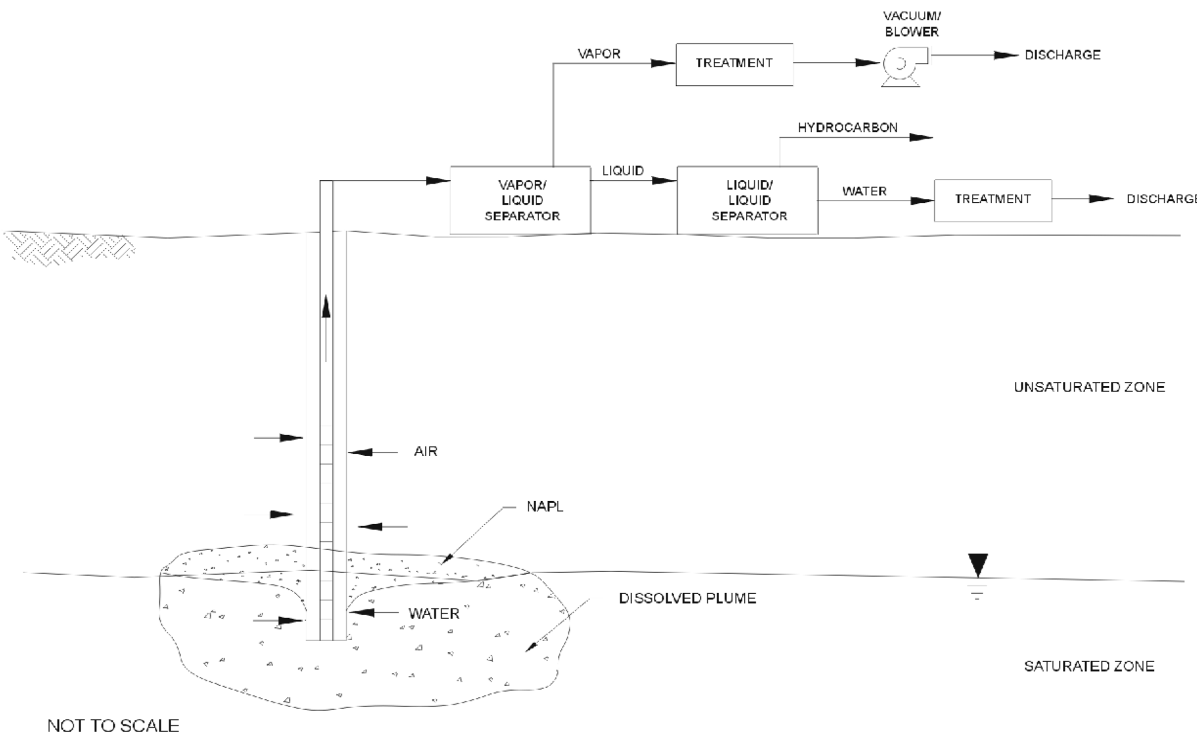


FIGURE 9-1. DUAL-PHASE EXTRACTION/BIOSLURPING

9-3. Hazard Analysis

Principal unique hazards associated with dual-phase extraction (bioslurping), methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire and Explosion Hazards (Drilling).*
Description. Soil boring using hollow-stemmed augers may cause a fire or explosion during drilling into soils saturated with flammable or combustible materials in unusual or extraordinary conditions. Sparks generated when a metal auger strikes against rocks, metal, or other underground objects may ignite a flammable atmosphere inside the borehole.

Control. A control for fire/explosion includes:

- Train operators in the hazards of drilling into or through flammable liquids or materials.

- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Use methods such as mud or water rotary drilling, which add moisture to the cutting area.

CONTROL POINT: Design, Construction

(2) *Utility Contact Hazard.*
Description. Fire, explosion, or electrocution hazards may exist during hollow-stemmed auger drilling if the rotating auger contacts and ruptures underground utilities, such as electrical or gas lines, or comes in contact with overhead electric lines.

Control. Controls for utility contact hazards include:

- Train operators in the hazards of drilling in the vicinity of underground or overhead utilities.
- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Contact local utilities and public works authorities to determine the locations of all utilities. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to guide when raising a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction

(3) *Fire and Explosion Hazards (Transfer of Flammable Gas/Liquids).*
Description. During the transfer of extracted flammable or combustible liquids (such as jet fuel) and gas from the recovery wells, a fire or explosion hazard may exist. The liquid or gas may be ignited by equipment or from the discharge of static electricity.

Control. Controls for fire and explosion hazards include:

- Train the operators in the hazards of the collection system including the reactivity of the contaminants extracted, and the sources of ignition including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.

- Verify that the hazardous area classifications, as defined in NFPA 70, Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use all controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Check for appropriate design and installation of equipment.
- Use grounded equipment or equipment provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Maintenance

(4) *Fire and Explosion Hazards (Recovery Tank).*
Description. If the product recovered by the technology is a flammable or combustible liquid (such as jet fuel), a fire or explosion hazard may exist with the product recovery tank.

Control. A control for fire or explosion in the recovery tank includes:

- Train the operators in the hazards of the collection system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard.

CONTROL POINT: Design, Construction, Maintenance

(5) *Fire and Explosion Hazards (Emissions/Flammable Vapors).*
Description. Emissions from collection equipment may be ignited, possibly causing a fire or explosion. In addition, ejector pumping systems produce mixtures of flammable vapors and air that may be ignited and result in an explosion.

Control. Controls for fire or explosion due to emissions include:

- Train the operators in the hazards of the collection system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Perform regular inspections of the collection equipment to identify and repair system leaks.

- Do not use piping systems and ejectors that mix air with flammable vapors.

CONTROL POINT: Design, Operations, Maintenance

(6) *Equipment Hazards (Drilling).*
Description. Loose clothing may become entangled in cables used to raise and lower drilling tools and equipment or on other equipment. Direct push drilling methods using hydraulic pressure to advance a soil boring may pose a crushing hazard to hands or feet.

Control. Controls for equipment hazards from drilling include:

- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may entangle loose clothing.
- Prohibit the wearing of loose fitting clothing.
- Keep hands and feet away from hydraulic push equipment.

CONTROL POINT: Construction, Operations, Maintenance

(7) *Rotating Equipment*.
Description. The rotating auger of a drill rig poses a hazard to workers as loose clothing may become entangled with the revolving auger.

Control. Controls for rotating equipment include:

- Prohibit the use of loose clothing.
- Use low-profile auger pins.
- Use long-handled shovels to remove soil cuttings from the borehole.

CONTROL POINT: Construction, Maintenance

(8) *Fire or Explosion (Containment Tank).*
Description. Containment tanks used for storage of recovered free product may overflow, creating the potential for fire or explosion.

Control. Controls for fire/explosion attributable to containment tanks include:

- Train the operators in the hazards of the collection containment system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Use NFPA-approved fluid level indicators appropriate for the fuels encountered.
- Install indicators on free-product recovery tanks to help prevent overflowing.
- Conduct regularly scheduled tank inspections.

CONTROL POINT: Design, Operations, Maintenance

(9) *Fire Hazard (Piping Systems).*
Description. Piping systems that become plugged may induce failure of the vacuum pump, causing an electrical fire.

Control. Controls for fire attributable to piping systems include:

- Train the operators in the hazards unique to the piping system, including the reactivity of the contaminants, and the sources of ignition including electrical fires.
- Train the operators in emergency procedures in case of a catastrophic failure of the piping system, in life saving first aid procedures including extinguishing flames, shutting down electrical power, extracting, extinguishing and stabilizing victims, and in emergency piping system isolation and shutdown procedures.
- Inspect and clean piping systems periodically to help prevent buildup of material that may cause blockage.

CONTROL POINT: Design, Operations, Maintenance

(10) *Heat Stress.*
Description. Workers may be exposed to elevated temperatures from hot blowers and other process equipment. The exposure may induce heat stress.

Control. Controls for heat stress include:

- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Vigorously train workers in recognizing heat stress symptoms and prevention. Use the Buddy System of observation for symptoms.
- Provide plain cool water for body fluid replacement and require frequent replenishment, breaks, and shaded break areas.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Design, Maintenance

(11) *Explosion (Separators).*
Description. Separators that generate flammable vapors may explode if ignited.

Control. Controls for explosion due to separators include:

- Train operators in the hazards unique to the separators, including the reactivity of the contaminants, and the sources of ignition, including static electricity.

- Train operators in emergency procedures in case of a catastrophic failure of the piping system, in life saving first aid procedures including extinguishing flames or neutralizing chemical reactions, shutting down electrical power, extracting, extinguishing and stabilizing victims, and in emergency piping system isolation and shutdown procedures.
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Use grounded equipment or equipment provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.
- Permit only trained, experienced personnel to work on the systems.
- Ventilate areas adequately to help prevent the accumulation of flammable gases.
- Include appropriate lock-out/tag-out equipment and procedures in the O&M of the system.
- Provide fire extinguishers rated for energized electrical systems where electrical equipment is installed and operated.

CONTROL POINT: Design, Operations, Maintenance

(12) *Steam Pressure Washing.*
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(13) *Blower Hazards.*
Description. High levels of noise may be generated by blowers and compressors and may result in hearing loss. Unguarded blowers and fans may entangle workers or their clothing, causing injury.

Control. Controls for blower noise and unguarded movement include:

- Control equipment noise with insulation, barriers, and proper equipment lubrication and maintenance.
- Use hearing protection around elevated noise levels.

- Use guards on all moving and rotating equipment.
- Inform workers that guards must be in place for equipment operation. Do not allow workers near unguarded machinery.

CONTROL POINT: Design, Operations

(14) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle injuries include:
- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14). Utilize more than one worker to manage loads.
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(15) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:
- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(16) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Liquid Waste Materials*.
Description. Piping systems may leak from over-pressurization and spray workers with liquid waste materials. As a result, workers may be exposed to the liquid waste through inhalation, ingestion or dermal contact.

Control. Controls for liquid waste materials include:
- Conduct regular system inspections, testing, and maintenance to prevent or minimize leaks and resulting exposures.
- Install hazard-warning alarms to alert workers of vessel over-pressurization and potential chemical hazards.
- Train the workers in the unique exposure hazards associated with the waste streams and in the controls to implement to prevent harmful exposures.

CONTROL POINT: Design, Operations, Maintenance

(2) *Contaminants (Well Installation).*
Description. During well installation, workers may be exposed to contaminants, such as VOCs, dusts, and metals in soil and development water through the inhalation/ingestion/dermal contact routes.

Control. Controls for contaminants include:
- Apply water or an amended water solution to the area during well installation to help control the generation of airborne dusts, particulates, and VOCs.
- Use respiratory protection including approved filters/cartridges such as N, R or P100 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Analyze work tasks and potential for chemical exposure to determine the correct personal protection equipment (PPE) or respirator cartridges. The analysis should include a chemical waste profile to help ensure that the PPE specified will be appropriate for the respective chemical hazards.

CONTROL POINT: Construction, Operations, Maintenance

(3) *Chemical Exposure Via Dual-Phase Extraction.*
Description. During operation of a dual-phase extraction system, workers may be exposed to chemical materials, such as hydrogen sulfide, VOCs, and intermediate byproducts.

Control. Controls for chemical exposure include:
- Wear respiratory protection to control inhalation exposures based on an analysis of the type of respirator required before issuance.

- Include a chemical profile on the waste materials to ensure that the specified respirator and filter/cartridge or supplied air will be appropriate.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) *Radioactive Materials*.
Description. In some geological settings, workers may be exposed to naturally occurring radon gas. Radon gas and radon progeny do not present a significant external hazard. While radon progeny may present an internal hazard, the quantities of radon progeny normally present would not pose a significant exposure hazard.

Control. Controls for radioactive materials include:

- Check operation of emission control technologies to limit exposure.
- Consult a qualified health physicist for proper guidance if excessive levels are suspected or encountered.

CONTROL POINT: Design, Operations, Maintenance

(2) *Radioactive Devices*
Description. Fire and smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose devices in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites, but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.

- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 10
Air Sparging/Oxygen Enhancement With Air Sparging

10-1. General

The process of air sparging, its applications, and effectiveness are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

10-2. Technology Description

a. Air Sparging Methods.

Groundwater air sparging involves the injection of air into the groundwater to achieve the following objectives:

- Increased oxygen supply to promote aerobic biodegradation of certain contaminants.
- Removal of volatile organic compounds (VOCs) by physical mechanisms (e.g., desorption and volatilization of compounds directly into the enhanced air stream).

A typical air sparging system consists of specially designed injection wells to inject air into the formation, typically accompanied by a properly designed soil vapor extraction (SVE) system to capture the contaminated off-gas. Air is injected into the subsurface under pressure, where it creates an inverted cone of partially aerated soils surrounding the injection point well. The air displaces pore water, volatilizes organics, and exits the saturated zone into the vadose zone. Off-gas is then captured by an SVE system installed in the unsaturated zone and treated prior to release. The sparged air also transfers dissolved oxygen into the groundwater, capillary fringe water, and soil moisture in the unsaturated zone.

Nutrients can be injected into the unsaturated zone in water or injected into the saturated zone, dissolved in water slugs, and moved through sparging points or secondary injection wells. Indigenous microbes use the injected oxygen and nutrients in enzyme reactions, resulting in the transformation or destruction of the contaminants. A schematic diagram of an air sparging system is presented in Figure 10-1.

b. Applications.

Air sparging is effective for removing substantial quantities of volatile hydrocarbons and chlorinated organics in certain geological settings. Air sparging can be enhanced by the use of oxygen, hydrogen peroxide, or ozone. Oxygen enhancement by the injected air can increase the oxygen content of the groundwater and soil gas, thus aiding bioremediation processes. Additions of ozone in sparging treatments can partially oxidize hard-to-treat organic compounds, such as chlorinated ethylene and complex aromatics, enhancing more traditional treatments by aerobic bioremediation and volatilization.

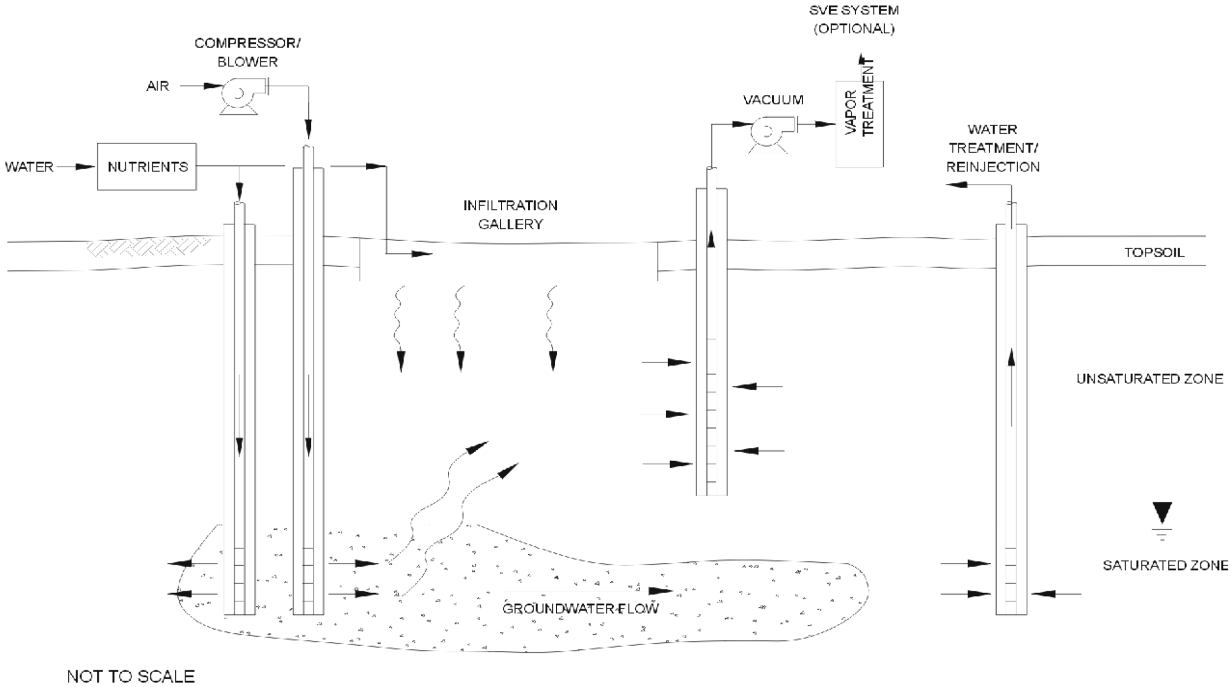


FIGURE 10-1. AIR SPARGING/BIOSPARGING

c. Effectiveness.

The effectiveness of air sparging depends on the geological characteristics of the site, especially the ease of transmission of air through the soil pore structure. Groundwater air sparging occasionally requires groundwater pump-and-treat systems as well, since sparging effectively creates groundwater mounding around the sparge points, causing radial flow away from the points, and thus the potential to spread groundwater contamination.

10-3. Hazard Analysis

Principal unique hazards associated with air sparging/oxygen enhancement, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire and Explosion Hazards (Drilling).*
Description. Soil boring using hollow-stemmed augers may cause a fire or explosion during drilling into soils saturated with flammable or combustible materials in unusual or extraordinary conditions. Sparks generated when a metal auger bit strikes against rocks, metal, or other underground objects may ignite a flammable atmosphere inside the bore hole.

Fire or explosion may also result from drilling into soil contaminated with readily flammable/combustible wastes such as carbon disulfide, gasoline, or explosives such as metal fulminates.

Control. Controls for fire/explosion hazards include:

- Train the operators in the hazards of drilling into or through flammable liquids or materials.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames or neutralizing chemical reactions, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Use mud or water rotary drilling methods, which add moisture to the cutting area.
- Fill bore holes to prevent vapor accumulation.
- Have adequate fire fighting equipment always at hand to extinguish any fires generated.

CONTROL POINT: Construction, Maintenance

(2) *Utility Contact Hazard.*
Description. Fire, explosion, or electrocution hazards may exist when using hollow-stemmed auger drilling methods if the rotating auger contacts or ruptures underground utilities such as electrical and gas lines or contacts overhead electric lines.

Control. Controls for utility contact hazards include:

- Train the operators in the hazards of drilling in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Contact local utilities and public works authorities to determine the locations of all utilities. When there is any doubt or uncertainty, conduct a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to guide when raising a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction, Maintenance

(3) *Fire (Oxygen Enhancement).*
Description. Owing to the presence of high levels of oxygen in an enhanced air sparge system, there may be an increased risk of starting a fire.

Control. Controls for fire due to oxygen enhancement include:

- Train the operators in the hazards of handling and operating with pure oxygen and in the nature and likely sources of static electricity buildup within the enhanced air sparge system.
- Inspect oxygen delivery systems regularly for leaks and the elimination of all sources of ignition.

CONTROL POINT: Operations, Maintenance

(4) *Fire and Explosion (Flammable Gas).*
Description. Fires and explosions may occur because of emissions of flammable VOCs at the surface or in the SVE collection system. Sparks, heat sources, and static electricity may ignite explosive gases, causing rupture of the collection system.

Control. Controls for fire/explosion due to flammable gas include:

- Train the operators in the hazards unique to the SVE collection system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames or neutralizing chemical reactions, extracting, extinguishing and stabilizing victims, and in emergency SVE system isolation and shutdown procedures.
- Verify that the hazardous area classifications, as defined in NFPA 70, Chapter 5, 500.1 through 500.10, are indicated on the drawings.
- Use all controls, wiring, and equipment in gas collection that complies with EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Use grounded equipment or equipment with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70.
- Inspect systems regularly for leaks.
- Control all sources of ignition.
- Ventilate areas adequately to help prevent the accumulation of flammable gases.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) *Equipment Hazards (Drilling).*
Description. The rotating drilling auger poses a hazard to workers as loose clothing may become entangled with the auger.

Control. Controls for equipment hazards during drilling include:

- Prohibit the use of loose clothing.
- Drill rigs will be level and blocked wherever soil conditions warrant.
- Use low-profile auger pins.
- Use long-handled shovels to remove soil cuttings from the borehole.

CONTROL POINT: Construction, Maintenance

(6) *Blower Hazards*.
Description. Blowers may be equipped with unguarded pulleys that may cause entanglement of body parts or loose clothing.

Control. Controls for blower hazards include:

- Use guarded pulleys and guarded moving or rotating mechanical devices on blowers.
- Inform workers that guards must be in place for equipment operation.
- Do not allow work in the vicinity of unguarded pulleys or moving machinery.

CONTROL POINT: Design, Operations, Maintenance

(7) *Noise Hazards*.
Description. The air sparging and SVE collection systems may expose workers to elevated noise levels in the work areas owing to the operation of air blowers and vacuum pumps. The noise level may interfere with safe and effective communications and promote hearing loss.

Control. Controls for noise hazards include:

- Train workers in the use of hearing protection and establish a hearing protection program (see 29 CFR 1910.95).
- Use personal electronic communications devices, such as a dual ear headset with speaker microphone, to overcome ambient noise in areas where noise is prevalent and effective communication is critical for operation and worker safety. The device reduces ambient noise levels while enhancing communication. Avoid using hearing protectors that overprotect against ambient noise and in this way effectively prevent necessary communication.
- Establish noise-free areas during operations to provide breaks from the noise, which can cause fatigue and inattention.

CONTROL POINT: Design, Operations

(8) *Fire Hazard (Piping Systems).*
Description. Piping systems that become plugged may induce failure of the vacuum pump causing an electrical fire. Also, pipes or joints may burst from excessive pressure.

Control. Controls for fire due to piping systems include:

- Train the operators in the hazards unique to the piping system, including the tendency to plug, reactivity of the contaminants, and the sources of ignition, including electrical fires caused by overloaded electrical machinery and equipment.
- Train the operators in emergency procedures in case of a catastrophic failure of the piping system, in life saving first aid procedures including extinguishing flames or neutralizing chemical reactions, shutting down electrical power, extracting, extinguishing and stabilizing victims, and in emergency piping system isolation and shutdown procedures.

- Inspect and clean piping systems periodically to help prevent blockage by material buildup.

CONTROL POINT: Design, Operations, Maintenance

(9) *Heat Stress*.
Description. Workers may be exposed to elevated temperatures because of excessive heating of blowers and other process equipment. The work exposure may induce heat stress.

Control. Controls for heat stress include:

- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Vigorously train workers in the signs and symptoms of heat stress.
- Use the Buddy System and provide easy access to water.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Design, Operations, Maintenance

(10) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Equip washers with deadman or kill switch if not provided by manufacturer.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(11) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle injuries include:

- Do not require workers to lift heavy loads manually.

- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14). Utilize more than one worker to manage loads.
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(12) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(12) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Toxic Ozone Exposure*.
Description. The use of oxygen or ozone enhancement may create an increased flammability potential or toxic (ozone) exposure.

Control. Controls for toxic (ozone) exposure include:

- Ventilate the affected area adequately.

- Inspect piping systems regularly for leaks.
- Monitor for ozone and train workers in ozone hazards and recognition including odor identification.

CONTROL POINT: Design, Operations, Maintenance

(2) *Contaminants (Well Installation).*
Description. During well installation, workers may be exposed to contaminants, such as VOCs, dusts, and metals in soil and development water through the inhalation/ingestion/dermal contact routes.

Control. Controls for contaminants include:

- Apply water or an amended water solution to the area during well installation to help control the generation of airborne dusts, particulates, contaminated with VOCs.
- Use respiratory protection including approved filter/cartridges such as N, R or P95 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE or respirator cartridges. The analysis should include a chemical profile on the waste materials to help ensure the equipment specified will be appropriate for the respective chemical hazards.

CONTROL POINT: Construction, Maintenance

(3) *Chemical Materials and Byproducts (Operation).*
Description. During operation of the system equipment, workers may be exposed to chemical materials, such as hydrogen sulfide, VOCs, carbon dioxide, and intermediate byproducts by the inhalation/ingestion/dermal contact exposure routes.

Control. Controls for chemical exposure include:

- Use proper ventilation.
- Wear appropriate personal protection equipment (PPE) (e.g., an air-purifying respirator with organic vapor cartridges (air-purifying respirators for H_2S exposure are for escape only) or supplied-air respirators where the contaminants exhibit poor warning properties such as H_2S).
- Check closed systems, such as SVE, routinely for leaks with PIDs, air samples, oxygen meters, leak detection fluids, explosive gas meters, or specific gas tests such as Draeger-type tubes. Repair leaks immediately.
- Use vent stack heights that are adequate to disperse off-gas above and beyond the breathing zone of the workers.
- Designers: anticipate byproducts and products and make certain that the technology for off-gas treatment (e.g., activated carbon, condensation, catalytic oxidation) is effective and safe.

CONTROL POINT: Design, Operations, Maintenance

(4) *Ozone Exposure*.
Description. Ozone exposure may occur via the inhalation route from leaks in equipment used to generate ozone. Ozone is an irritant to skin, eyes and mucous membrane systems.

Control. Controls for ozone exposure include:
- Use closed delivery systems for the addition of ozone to help minimize worker exposure.
- Test the equipment used to generate ozone for leaks prior to use.
- Perform regular maintenance and leak tests according to the manufacturer's instructions.
- Train workers in ozone hazard recognition.
- Provide emergency use chemical cartridge, gas canister or supplied air respirators.

CONTROL POINT: Design, Operations, Maintenance

(5) *Hydrogen Peroxide Exposure*.
Description. During handling of hydrogen peroxide, workers may be exposed to liquid hydrogen peroxide via the inhalation/ingestion/dermal contact exposure routes. Hydrogen peroxide is an irritant to the skin, eyes, and mucous membranes.

Control. Controls for hydrogen peroxide exposure include:
- Use closed delivery systems for the addition of hydrogen peroxide to help minimize worker exposure.
- Test the system for leaks prior to use.
- Perform regular maintenance and leak tests according to the manufacturer's instructions.
- Train workers in hydrogen peroxide hazard recognition.
- Provide emergency use supplied air respirators.

CONTROL POINT: Design, Operations, Maintenance

(6) *VOC Migration*.
Description. Injection (sparging) wells may cause migration of VOCs into subsurface structures, such as basements and sewers. The VOCs may be toxic or flammable, resulting in chemical exposure or the potential for a fire or explosion.

Control. Controls for VOC migration include:
- The designer must determine the pressure range of the system and install hazard warning alarms to prevent over-pressurization.
- Periodically test air in basements and other areas where VOCs may migrate to ensure safe levels.

- Train workers in the air sparging VOC dispersion patterns to expect and the potential hazard of accumulating VOCs in subsurface structures and low-lying areas in the vicinity of the air sparging systems.

CONTROL POINT: Design, Operations, Maintenance

(7) *Confined Space Chemical Hazards*.
Description. During entry into confined space, such as a manhole to collect condensate samples, workers may be exposed to airborne chemical hazards if the atmosphere in the confined space contains a toxic chemical or is oxygen deficient.

Control. Controls for confined space chemical hazards include:

- Train workers in confined space hazards and on safety procedures to employ in confined space entry.
- Design the confined space to maximize natural ventilation, accessibility with adequately sized access doors, and space for easy sample collection.
- Develop a pre-entry confined space permit. Implement a confined-space entry program to assess hazards including air testing the space's interior both prior to and throughout the work planned (see 29 CFR 1926.21).
- Ventilate confined spaced if a hazardous atmosphere exists.

CONTROL POINT: Operations

(8) *Toxic Intermediate Products*.
Description. Biological degradation of certain chlorinated organic compounds may produce toxic intermediate products, including vinyl chloride. Vinyl chloride exists as a gas and may accumulate to higher levels in boreholes or in the system. Workers may be exposed to intermediate products during operation or maintenance of the system.

Control. Controls for toxic intermediate products include:

- Ventilate the affected area.
- Select the proper respirator according to 29 CFR 1910.1017 or 29 CFR 1910.134 for other intermediate products if exposures are not less than the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL).
- Check with the respirator manufacturer to verify use in atmospheres containing vinyl chloride.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

Radon Exposure.
Description. In some geological settings, workers may be exposed to naturally occurring radon gas. The gas is drawn from the soil in the SVE stream. Radon gas and radon progeny do not present a significant external hazard. While breakdown products

of radon (progeny) may present an inhalation/ingestion hazard, quantities of radon progeny normally present would not pose a significant exposure hazard.

Control. Controls for radon exposure include:

- Check for proper operation of emission control technologies to limit exposure to acceptable levels.
- Consult a qualified health physicist if excessive levels are suspected or encountered.

CONTROL POINT: Design, Operations, Maintenance

d. Biological Hazards.

(1) Biological Contaminants.
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the soil may pose exposure hazards during system installation activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp.*, *Histoplasma sp.*, and *Mycobacterium sp.* if contaminated dusts become airborne.

Control. Controls for biological contaminants include:

- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, surfactant amended water, or emission-suppressing foams to the active excavation/drilling areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Erect windscreens and use portable surface covers.
- Use the proper types of PPE: an air-purifying respirator with N, R, or P100 or N, R or P95 particulate air filters approved for microbial inhalation hazards, and appropriate gloves.
- Use experienced workers, repeated health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Construction, Maintenance

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for pests include:

- Periodically inspect the site to identify stinging insects and to check for snakes and rodents.
- Use professional exterminating companies if necessary.

- Use tick and insect repellents with N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 11
Landfarming

11-1. General

Landfarming, its requirements, application, and resulting waste streams are discussed in the chapter's first section. The second part of the chapter is a hazard analysis with controls and control points listed.

11-2. Technology Description

a. Landfarming Methods.

Landfarming is a biological remediation technology in which contaminants in soils, sediments, sludges, or soil-like materials are degraded by microorganisms to produce innocuous or stabilized byproducts.

During a landfarm operation, soils, sediments, sludges, or soil-like materials are treated in-situ, and then are applied to a soil surface or excavated and placed on liners to prevent further contamination (Figure 11-1). Populations of indigenous microorganisms are also stimulated to grow and transform the contaminants. The following parameters are usually monitored or controlled:

- Mixing (tilling).
- Leachate collection system (sand or gravel, or both).
- Geomembrane.
- Secondary leachate collection/leak detection layer constructed of sand/gravel.
- Secondary synthetic liner.
- Low permeability compacted clay liner.
- Moisture content (controlled by irrigation or spraying).
- Oxygen level (controlled by tilling the soil or aeration).
- Nutrients (nitrogen and phosphorus are controlled by adding fertilizer, as necessary).
- pH (controlled by adding lime).
- Soil bulking (controlled by blending soil amendments with soil, if necessary).
- Temperature (temperature is usually not controlled, operation is often seasonal).

b. Equipment and Land Requirements.

Landfarming utilizes commercially available farm equipment such as tractors, rotary tillers, chisel plows, soaker hoses, and rotary sprinklers. The nature of the technology is such that it requires substantial open areas to create land treatment units, and these areas must be prepared for proper drainage, equipment access, and materials management.

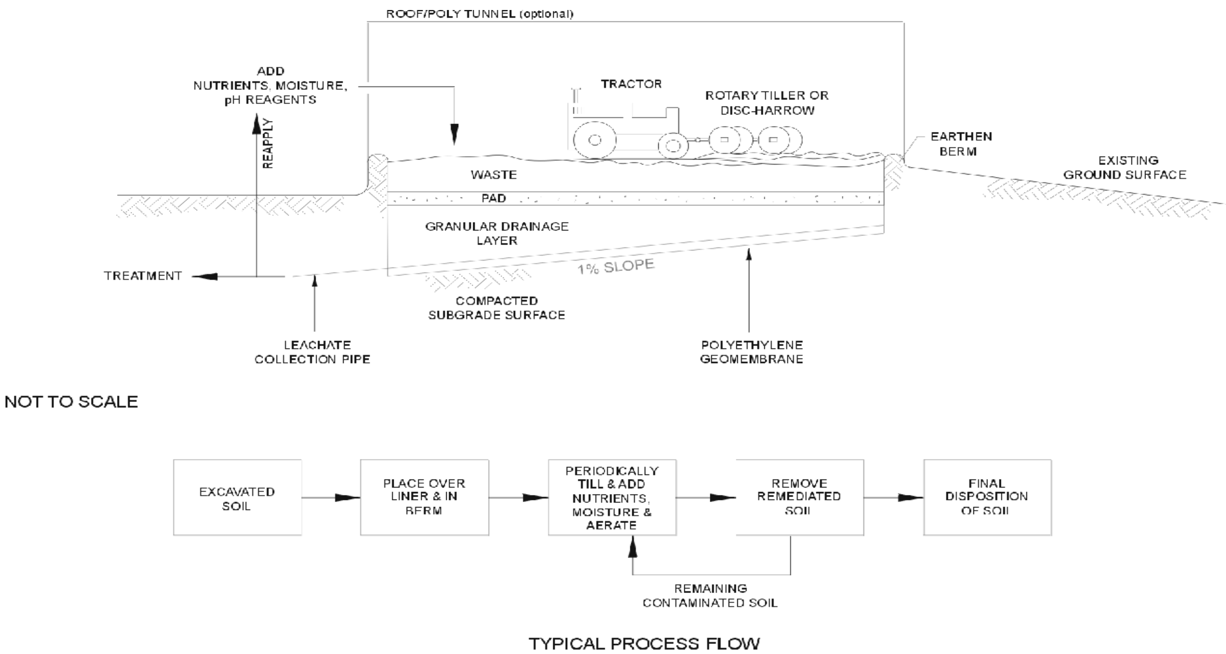


FIGURE 11-1. LANDFARMING

c. Applications.

Land farms have been most successful in treating petroleum hydrocarbons, such as diesel fuel, No. 2 and No. 4 fuel oils, JP-5, oily sludge, wood-preserving wastes (pentachlorophenol, polycyclic aromatic hydrocarbons [PAHs], and creosote), coke wastes, and some pesticides. Landfarm degradation rates decrease with an increase in molecular weight or with an increase in the number of aromatic or cyclic rings (e.g., PAHs). Chlorinated or nitrated compounds are also usually more difficult to degrade than hydrocarbons. Depending on regulatory requirements, treated soil may be backfilled to its original location, left on the land treatment unit, or disposed of off site.

d. Resulting Waste Streams.

Landfarming processes may produce three streams that may require additional handling:

- Wastewater (may require additional treatment).
- Treated soil (or soil-like materials).
- Volatile emissions from soil tilling.

11-3. Hazard Analysis

Principal unique hazards associated with landfarming, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Equipment Operation*.
Description. During soil excavation and landfarm construction, workers may be seriously injured or killed by heavy equipment such as tractors, rotary tillers, chisel plows, and rotary sprinklers. Landfarm construction may include the preparation of berms that may be steep and become slippery in wet or rainy conditions.

Control. Controls for equipment hazards include:
- Equip all heavy equipment with backup alarms.
- Provide equipment spotters where beneficial.
- Provide all workers working in the vicinity of the operating heavy equipment with fluorescent orange or lime green traffic vests.
- Approach operating equipment from the front and within view of or direct communication with the operator, preferably making eye contact.
- Do not walk on or near the berms, especially during or after periods of heavy rainfall.
- Train workers in the potential operational hazards and safety features of the heavy equipment.

CONTROL POINT: Construction, Operations, Maintenance

(2) *Wind*.
Description. Installation of landfarm liners and covers in high winds can pose hazards to workers, as blowing liners can trip or knock down workers holding or standing on or beside unsecured liners.

Control. Controls for wind include:
- Install liners on calm days.
- Place soil or sand bags onto the liner to anchor it. The installer should determine the anchoring needs at the time of installation and ensure that anchoring specifications are met or exceeded.

CONTROL POINT: Construction, Maintenance

(3) *Slipping*.
Description. Installation of landfarm liners and covers can pose a slip hazard, particularly when wet. Plastic and wet clay liners can be very slippery, especially when placed on the slopes or for footing.

Control. Controls for slip hazards include:
- Use rope ladders for ascending/descending lined slopes.
- Select appropriate shoe soles for maximum traction.

- Erect barriers or warnings around excessively wet areas of liner.
- Lay high-traction walkways over the liners.
- Carry light loads or use more workers to carry larger single loads.
- Train workers on the liner characteristics that create slipping hazards.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) *Sharp Liner Edges*.
Description. Synthetic liners are made in varying thickness and rigidities. Some liner edges are sharp and stiff after being cut to shape and can inflict cuts and abrasions.

Control. Controls for sharp liners include:
- Wear long-sleeved shirts, full-length pants, safety boots, and appropriate work gloves (e.g., cut resistant, leather or leather-palmed) for better grip and protection.
- Wear safety glasses or goggles to help prevent eye injuries.
- Workers should position themselves to avoid direct line of contact with sharp liner edges.

CONTROL POINT: Construction, Maintenance

(5) *Heat Stress*.
Description. Heat-related illnesses may occur during liner installations. Because most synthetic liner materials are dark or black to enhance ultraviolet (UV) resistance, they absorb radiant energy and emit considerable heat. The polished surfaces of liner materials can also reflect considerable angled radiant energy, enhancing the energy absorbed by the worker even when under a canopy or wearing a hat. Heat stress that can result in heat exhaustion and heat stroke, can affect workers during operations under conditions that contribute to the heat load. Hot and humid conditions combined with operations, such as liner welding or other heat-producing activities, may further increase the potential for heat-related illnesses.

Control. Controls for heat stress include:
- Vigorously train workers in the signs and symptoms of heat stress.
- Use the Buddy System.
- Provide easy access to water, frequent mandatory breaks, and canopies or other shaded break areas.
- Require the use of sun hats and other protective clothing. Loose clothing and sun hats should not be worn around moving parts or equipment that may snag the worker and draw him or her into a danger zone. Equipment operators may use UV skin barrier cream. All UV skin barrier creams should be pre-approved.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH)

"TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) *Muscle Injuries*.
Description. Manual lifting and moving of large rolls of liner material or weighted anchoring materials may expose workers to lower back and shoulder strain.

Control. A control for muscle strain includes:
- Use mechanical lifting equipment, such as backhoes with cables, and spreaders to lift and move liner material.
- Train the workers in proper load handling using heavy lifting machinery and in personal lifting techniques. Utilize more than one worker and the buddy system including spotters in managing the loads.

CONTROL POINT: Construction, Operations, Maintenance

(7) *Burns*.
Description. Burn hazards to the skin may exist with different types of operating equipment, including a liner extrusion welder and generators.

Control. Controls for burn hazards include:
- Train all personnel using or exposed to hot operating equipment during liner installation in hazards associated with the equipment.
- Guard all exposed, heated surfaces to prevent accidental contact.
- Prepare procedures for the safe operation, repair, and maintenance of equipment and include a testing procedure for determining safe temperature.
- Use insulated gloves with gauntlets, coveralls, and face protection appropriate for eliminating the hazard.

CONTROL POINT: Construction, Maintenance

(8) *Moving Equipment*.
Description. Landfarm units may require periodic aeration by mechanically turning over soils with heavy equipment, such as tractors equipped with mixing equipment, rototillers, plows, discs, and tillers. Other devices, such as a "scarab"-type device, may throw debris during the turning process. Prescreening or sizing equipment, such as grinders, shakers, and screeners may pose hazards if unguarded. Body parts or loose clothing may become entangled in pulleys, drive shafts, and other moving equipment.

Control. Controls for moving equipment include:
- Keep clear of operating equipment and approach only when within view of the operator.
- Guard all moving or rotating equipment to prevent accidental contact.

- Operate the system with the machine guards in place.
- Prohibit the use of loose clothing around equipment.
- Train workers in the hazards and safety features of operating the heavy equipment.

CONTROL POINT: Construction, Operations, Maintenance

(9) *Puncture Hazards*.
Description. Workers may be exposed to puncture and cut hazards to feet and hands from rough or jagged waste materials during landfarming operations.

Control. Controls for puncture hazards include:
- Wear safety boots with steel shanks and puncture resistant soles.
- Minimize manual handling of waste material.
- Wear puncture and cut-resistant gloves if contact with waste materials is necessary.
- Train workers in unique material handling hazards associated with landfarming waste materials.

CONTROL POINT: Construction, Operations, Maintenance

(10) *Trip Hazards*.
Description. Trip hazards may exist with hoses and piping systems used for irrigation of the landfarm.

Control. Controls for trip hazards include:
- Exercise caution when walking over hoses and pipes.
- Use extra lighting if necessary to ensure adequately illuminated walkways.
- Train workers in potential trip hazards associated with the waste material.

CONTROL POINT: Design, Maintenance

(11) *Respirable Quartz*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geologists to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): “Standard Test Method for Particle Size Analysis of Soils” followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:
- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.

- Use respiratory protection, such as an air-purifying respirator equipped with N, R, or P100 particulate air filters.
- Train workers in the hazards of crystalline silica inhalation exposures.

CONTROL POINT: Construction, Operations

(12) *Electrocution*.
Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for electrocution include:
- Locate overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs, at least 10 feet from a power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.

CONTROL POINT: Design, Construction, Operations

(13) *Equipment Operation (Slopes).*
Description. Equipment used to move soil and liner materials on steep slopes may roll over, seriously injuring or killing the operator.

Control. Controls for equipment use on slopes include:
- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction.
- Use equipment with roll-over protective devices (ROPS).
- Do not operate equipment on excessively steep slopes or unstable ground.
- Wear seat belts during operation.
- Train workers in the potential operational hazards and safety features of the heavy equipment.

CONTROL POINT: Design, Construction, Operations

(14) *Traffic Hazards*.
Description. During the implementation of field activities, equipment and workers may come close to traffic. Equipment may also need to cross public roads. The general public may be exposed to traffic hazards during loading and transporting soil.

Control. Controls for traffic hazards include:
- Post warning signs according to the criteria of the “Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.”
- Provide traffic guides with fluorescent orange or lime green safety traffic vests.

- Develop a traffic management plan before remediation activities commence to help prevent accidents involving site equipment. EM 385-1-1, Section 21, provides plan details.

CONTROL POINT: Design, Construction, Operations

(15) *Emergency Wash Equipment***.**
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(16) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) *Vapors and Solvents*.
Description. Heating or cementing cover and liner materials may generate vapors, either from the cement applied, thermal decomposition, or both; from off-gassing of liner material components, such as plasticizers (e.g., phthalate esters, adipate esters); or from the solvents contained in the cementing agent (e.g., methyl ethyl ketone, methylene chloride). A vapor inhalation hazard may exist to workers during liner installation. A dermal hazard may also exist from skin

contact with the cementing chemicals or waste materials generated during installation.

Control. Controls for hazardous vapors and solvents include:

- Ventilate the area or use appropriate respirators to control exposures during installation.
- Select respirator cartridges (e.g., organic vapor cartridges) based on consultations with the liner manufacturers and the potential compounds that may be emitted.
- Use personal protective equipment (PPE) such as chemically inert gloves (e.g., nitrile for many petroleum distillates) to help control dermal exposure.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE or respirator cartridges if necessary. The analysis should include a chemical profile on the liner or cementing agents to ensure appropriate equipment.
- Train the workers in the chemical inhalation and contact hazards of the cementing materials and thermal decomposition properties of the liners.

CONTROL POINT: Construction, Maintenance

(2) *Contaminants.*
Description. Workers can be exposed to contaminants of concern and chemical reagents. The addition of urea or other ammonia-based fertilizers may result in worker exposure to ammonia. Intermediate degradation products, resulting from breakdown of contaminants of concern, may also represent exposure hazards. Exposure may occur via inhalation/ingestion/dermal contact routes during loading, unloading, preprocessing, tilling, turning, and other landfarming processes where soils are agitated.

Control. Controls for chemical contaminants include:

- Use PPE (e.g., butyl rubber gloves for exposure to nitrogen compounds) to control dermal exposure during urea and nitrogenous fertilizer additions.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE or respirator cartridges, if needed. The analysis should include obtaining specific chemical hazard information to ensure appropriate PPE.
- Use respiratory protection including the use of an air-purifying respirator equipped with N, R or P95 particulate air filters or appropriate chemical or organic vapor cartridges.
- Train the workers in the unique chemical hazards and hazard controls of the contaminants of concern.

CONTROL POINT: Operations

(3) *Enclosed Land Treatment Facilities.*
Description. If the land treatment unit facilities are enclosed or tented, workers entering the landfarm may be entering a confined space and require respiratory protection.

Control. Controls for enclosed treatment facilities include:

- Test the atmosphere within the enclosure or tent frequently to ensure a safe atmosphere.
- Design both natural or mechanical ventilation into the enclosed space, as appropriate to reduce the buildup of noxious or toxic interiors.
- Develop and implement a confined-space entry program if the testing indicates atmospheric contaminants or oxygen depletion (see 29 CFR 1910.146).

CONTROL POINT: Design, Operations

(4) *Acid/Base Hazards*.
Description. Workers may be exposed to chemical burn hazards while handling acids and bases used for pH control. Some materials used in landfarming may pose explosion hazards if contact is made with other incompatible materials (e.g., ammonium nitrate and fuels). Others may be hygroscopic, which may result in chemical reactions.

Control. Controls for acidic or caustic chemicals include:

- Train workers in the chemistry involved in the landfarm system design and operation, in the heat of reaction of the chemical reactions, or in handling the reactive materials and landfarm chemical additives.
- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including halting and neutralizing chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency isolation procedures.
- Minimize contact with acidic or corrosive chemical materials by using mechanical chemical delivery methods.
- Wear gloves (e.g., nitrile) and other PPE that is resistant to the materials handled including eye and face protection.
- Segregate chemical reagents used in landfarming to prevent accidental mixing of reactive chemicals, especially ammonium nitrate fertilizers and fuels.

CONTROL POINT: Design, Operations

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

(1) *Pathogenic Microbes*.
Description. Landfarm activities can expose workers via inhalation/ingestion/dermal contact to pathogenic microbes. The hazard may increase during dry and windy periods when microbe-entrained dusts become airborne from soil agitation, aerators, or wind. Exposure can occur during installation of

the landfarm liner or during agitation of the waste material. Inhalation of pathogenic microbes may cause allergic reactions or illness.

Control. Controls for pathogenic microbes include:

- Apply water periodically to limit airborne dust and exposure.
- Use PPE such as rubber gloves to help prevent dermal exposure to microorganisms.
- Use respiratory protection such as an air-purifying respirator with N, R or P100 or N, R or P95 particulate air filters approved for protection against microbial hazards during dusty periods.
- Train the workers in pathogenic hazards found in the media being treated by the landfarming activities.

CONTROL POINT: Construction, Operations

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for pests include:

- Periodically inspect the site to identify bee hives and wasp nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents containing the active ingredient, N,N-diethyl-m-toluamide (DEET) 25% for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically.
- Train the workers in the biota presenting hazards in the areas of potential contact.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 12
Composting

12-1. General

Composting, equipment requirements, applications, and resulting waste streams are discussed in the chapter's first section. The second part of the chapter is a hazard analysis with controls and control points listed.

12-2. Technology Description

a. Composting Methods.

Composting is a biological remediation technology in which contaminants in soils, sediments, sludges, or soil-like materials are biodegraded or transformed to produce innocuous or stabilized byproducts.

During a composting operation, soils, sediments, sludges, or soil-like materials are treated ex-situ in piles or windrows (Figure 12-1). Populations of indigenous microorganisms are stimulated to grow and transform the contaminants. The following parameters are usually monitored or controlled:

- Mixing (tilling).
- Moisture content (controlled by irrigation or spraying).
- Oxygen level (controlled by tilling or aeration).
- Nutrients (nitrogen and phosphorus are provided by adding organic amendments).
- pH (soil and amendments usually provide sufficient buffering capacity).
- Soil bulking (controlled by blending organic amendments with soil).
- Temperature (proper mixing, moisture, and amendment selection is required to maintain thermophilic conditions).

In composting soils, sediments, sludges, or soil-like materials are mixed with organic amendments such as wood chips, manure, hay, and vegetable (e.g., potato) wastes. The process generates elevated temperatures (in the range of 43 to 65°C) from heat produced by microbial activity. Maximum degradation is achieved by maintaining thermophilic conditions for an extended period of time. Three different approaches to composting can be utilized:

- Compost is formed into piles and aerated with blowers or vacuum pumps (aerated static pile composting).
- Compost is placed in a reactor vessel where it is mixed and aerated (mechanically agitated in-vessel composting).
- Compost is placed in long piles (windrows) and periodically mixed with mobile equipment (windrow composting). Windrow composting is generally thought to be the most cost-effective form.

After the composting process is completed, the treated material is typically placed in designated locations on the site, in accordance with regulatory requirements.

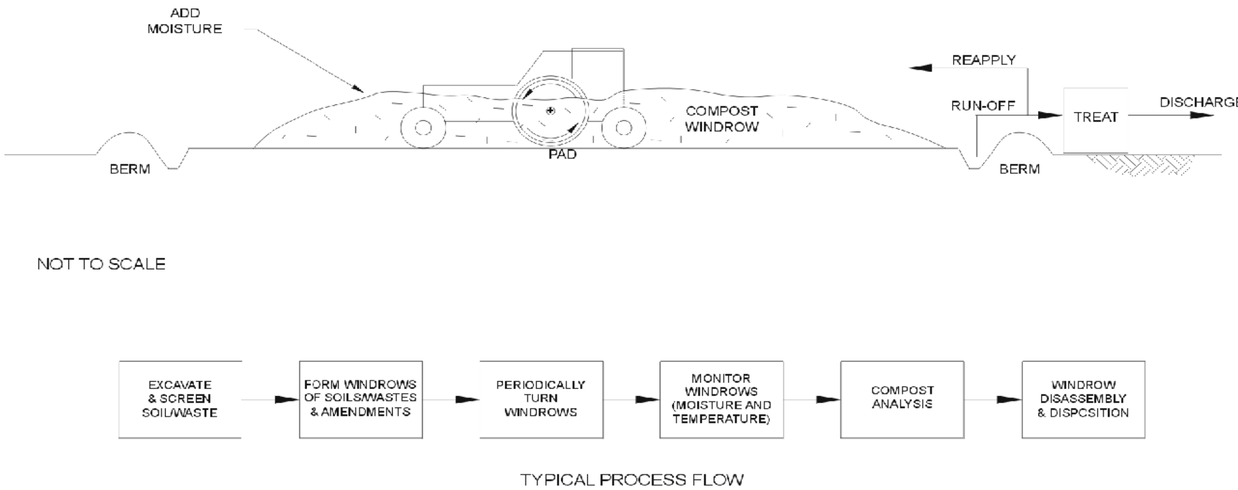


FIGURE 12-1. COMPOSTING

b. Equipment Requirements.

Composting techniques may utilize commercially available farm equipment such as tractors, rotary tillers, and irrigation devices. Composting requires substantial space and will result in a volumetric increase in material owing to the addition of the amendments. For hazardous waste applications, specialized implements are usually required to turn the compost.

c. Applications.

Aerobic, thermophilic composting has been shown to be effective for the remediation of explosives (TNT, RDX, and HMX), PAHs, and some pesticides. Although some solution may occur, composting does not treat heavy metals and most other inorganic contaminants.

d. Resulting Waste Streams.

Composting processes may produce three streams that may require additional handling:

- Wastewater (may require additional treatment).
- Treated soil (or soil-like materials).
- Volatile emissions.

12-3. Hazard Analysis

Principal unique hazards associated with composting, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Equipment Operation*.
Description. During soil excavation and compost pile construction, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. Construction may include the preparation of berms that may be steep and become slippery in wet or rainy conditions.

Control. Controls for equipment hazards include:

- Use heavy equipment with a backup alarms.
- Provide workers in the vicinity of operating heavy equipment with fluorescent orange or lime green traffic safety vests.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Do not walk on or near the berms, especially during or after periods of heavy rainfall.
- Train workers on safe operation and safety features of the heavy equipment.

CONTROL POINT: Construction, Operations, Maintenance

(2) *Moving Equipment*.
Description. Windrows require periodic aeration using specialized equipment for turning the compost. Other devices, such as a scarab-type device may throw debris during the turning process. Pre-screening or sizing equipment, such as grinders, shakers, and screeners, may pose hazards if unguarded. Appendages or loose clothing may become entangled in pulleys, drive shafts, and other moving equipment.

Control. Controls for moving equipment include:

- Keep clear of operating equipment and approach only when within view of the operator.
- Guard all moving or rotating equipment to prevent accidental contact.
- Operate the system with the machine guards in place.
- Prohibit the use of loose clothing around the equipment.
- Train workers in pinch-point and entanglement hazard identification for the equipment in use.

CONTROL POINT: Construction, Operations, Maintenance

(3) *Sunlight/UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight with its corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions, combined with heat from the composting process, can significantly contribute to the

worker's heat load, thereby increasing the risk of heat injury such as heat exhaustion, heat cramps, and heat stroke.

Control. Controls for sunlight, UV radiation and heat stress include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length unbloused pants, and by applying UV barrier sunscreen to exposed skin. Loose clothing and sun hats should not be worn around moving parts or close to operating equipment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved.
- Shade work and break areas, if possible.
- Minimize exposure to heat stress conditions by training the workers in the symptoms of heat stress, practicing the Buddy System, taking frequent breaks, drinking adequate fluids, and working during the cooler part of the days. Tasks with inherent heat stress risks should be identified and PPE mandated. Heat stress levels and preventive measures as per accepted protocols shall be documented.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(4) *Puncture Hazards*.
Description. Workers may be exposed to puncture and cut hazards to feet and hands from rough or jagged waste materials during composting operations.

Control. Controls for puncture hazards include:

- Wear safety boots with steel shanks and puncture resistant soles to prevent punctures or cuts.
- Minimize manual handling of waste material.
- Wear puncture and cut-resistant gloves wherever contact with waste materials is required.
- Train workers to identify puncture and cut hazards unique to composting operations.

CONTROL POINT: Construction, Operations, Maintenance

(5) *Trip Hazards*.
Description. Trip hazards may exist with hoses and piping systems used for irrigation of the composting unit.

Control. Controls for trip hazards include:

- Exercise caution when walking over hoses and pipes.
- Use extra lighting if necessary to ensure adequately illuminated walkways.

- Train workers in potential trip hazards associated with working with composting equipment.

CONTROL POINT: Design, Maintenance

(6) *Fire*.
Description. Fire hazards may exist with composting, as elevated temperatures and drying may increase the potential for spontaneous combustion.

Control. Controls for fire hazards include:
- Mix composting material periodically and maintain the proper water content to control compost temperature and prevent fires.
- Reduce the dimensions of the compost windrows (and the piles of compost) to prevent temperatures from exceeding desired levels.
- Train workers in the potential hazards of exothermic biochemical processes occurring in composting.

CONTROL POINT: Design, Operations

(7) *Respirable Quartz*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geologists to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline quartz content.

Control. Controls for respirable quartz include:
- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air-purifying respirator equipped with a N, R or P100 particulate air filters.
- Train workers in the hazards of crystalline silica inhalation exposures.

CONTROL POINT: Construction, Operations

(8) *Electrocution*.
Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for electrocution include:
- Locate overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs, at least 10 feet from a power line according to Occupational Safety and Health Ad-

ministration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.

CONTROL POINT: Design, Construction, Operations

(9) *Equipment (Slopes).*
Description. Heavy equipment (small and large) used to move compost, soil, and liner materials on steep slopes may roll over, seriously injuring or killing the operator.

Control. Controls for equipment use on slopes include:

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction.
- Use heavy equipment with roll-over protective devices (ROPS).
- Do not operate equipment on excessively steep slopes or unstable ground.
- Require the use of seat belts.
- Permit only properly trained and authorized personnel to operate or work in the vicinity of the heavy equipment.

CONTROL POINT: Design, Construction, Operations

(10) *Traffic Hazards*.
Description. During the implementation of field activities, equipment and workers may come close to traffic. Equipment may also need to cross or use public roads. The general public may be exposed to traffic hazards during loading and transporting soil.

Control. Controls for traffic hazards include:

- Post warning signs according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site equipment. EM 385-1-1, Section 21, provides plan details.

CONTROL POINT: Design, Construction, Operations

(11) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Contaminants*.
Description. Workers may be exposed to contaminants of concern and degradation products of contaminants. Exposure may occur via inhalation/ingestion/dermal contact routes during loading, unloading, preprocessing, tilling, turning, and other operations where soils are agitated.

Control. Controls for chemical contaminants include:

- Analyze work tasks and potential for chemical exposure to determine the correct personal protective equipment (PPE) or respirator cartridges, if needed. The analysis should include obtaining specific chemical hazard information to ensure appropriate PPE.
- Use respiratory protection, including an air-purifying respirator, e.g., equipped with N, P, or P100 or N, R, or P95 particulate filters or organic vapor cartridges, or both.

CONTROL POINT: Operations

(2) *Enclosed Facilities*.
Description. If composting facilities are enclosed or tented, workers may be entering a confined space and require respiratory protection. Elevated levels of CO_2 may accumulate during composting. It is also typical for some ammonia gas to be generated. Exposure to ammonia vapors may occur, especially during windrow turning operations. Although aerobic conditions should be maintained in the compost, if anaerobic conditions are allowed to develop, methane and hydrogen sulfide may be generated.

Control. Controls for enclosed facilities include:

- Test the enclosed atmosphere prior to each entry to ensure safety.
- Develop and implement a confined-space entry program if the testing indicates atmospheric contaminants or oxygen depletion (see 29 CFR 1910.146).

CONTROL POINT: Design, Operations

(3) *Explosion Hazards*.
Description. Some materials used in composting may be explosive, especially when in contact with other incompatible materials (e.g., ammonium nitrate and fuels). Others may be hygroscopic, which may result in chemical reactions.

Control. Controls for explosive hazards include:

- Train operators in the chemistry involved in the compost system design and operation, in the heat of reaction of the chemical reactions, and in handling the compost and compost chemical additives.
- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including halting and neutralizing chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency isolation and shutdown procedures.
- Minimize contact with acidic or corrosive chemical materials by using mechanical chemical delivery methods.
- Wear gloves (e.g., nitrile) and other PPE that is resistant to the materials handled.
- Segregate chemical reagents used in composting to prevent accidental mixing of reactive chemicals, especially ammonium nitrate fertilizers and fuels.

CONTROL POINT: Design, Operations

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

(1) *Pathogenic Microbes*.
Description. Composting activities may expose workers via inhalation/ingestion/dermal contact exposure routes to pathogenic microbes. The hazard may increase during dry and windy periods when microbe-entrained dusts may become airborne from soil agitation, aerators, or wind. Exposure may occur during agitation of the waste material. It is possible for pathogens to be present in compost amendments (e.g., bird manure has been implicated as a source of histoplasmosis). Exposure to mold spores, including *Aspergillus fumigates*, may occur during composting operations. Inhalation of pathogenic microbes may cause allergic reactions or illness.

Control. Controls for pathogenic microbes include:

- Apply water periodically to limit airborne dust and exposure.
- Use PPE, such as rubber gloves, to help prevent dermal exposure to microorganisms.
- Use respiratory protection, such as an air-purifying respirator with N, R or P100 or N, R, or P95 particulate filters, approved for microbial hazards during dusty periods.

CONTROL POINT: Construction, Operations

(2) *Snakes and Harmful Animals*.
Description. Snakes and other potentially harmful animals such as rodents are attracted to the higher temperatures associated with composting operations.

Control. Controls for snakes and other animals include:

- Inform workers of the potential for snakes and other animals around the compost facility, especially during cooler periods and provide training in the potential hazards associated with the presence of these animals.
- Use loud noises, such as talking and stamping or scuffing feet, to alert animals to the presence of workers in the area.

CONTROL POINT: Operations, Maintenance

(3) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, massive fly hatches, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for pests include:

- Periodically inspect the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents such as formulated with N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 13
Bioreactors

13-1. General

Bioreactor methods, applications, and resulting waste streams are discussed in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

13-2. Technology Description

Bioreactors are contained systems (tanks or ponds) used to degrade contaminants in aqueous solution, utilizing suspended or attached microbial systems. Contaminated soil or sludges may be slurried and then fed into bioreactors for treatment.

a. Suspended Growth Systems.

Suspended growth systems include continuous flow, activated sludge processes, or batch reactors. In these systems, contaminated material is circulated in an aeration basin where microbes aerobically or anaerobically degrade organic matter, and ideally produce CO_2, H_2O, methane, and new cells. The cells form a sludge, which is settled out in a clarifier (Figure 13-1). Sludge is then recycled into the aeration basin to maintain acclimated microorganisms or sent for disposal.

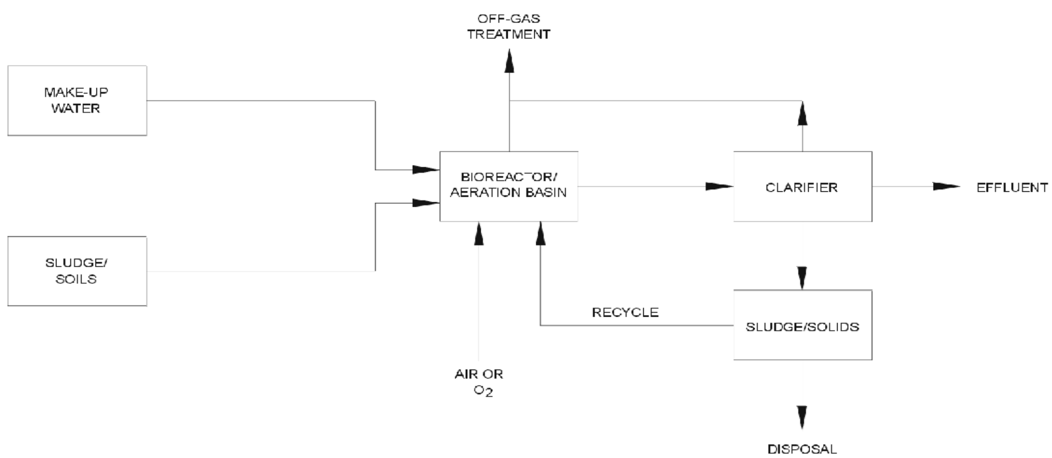


FIGURE 13-1. TYPICAL PROCESS FLOW FOR BIOREACTORS (SUSPENDED GROWTH SYSTEMS)

The levels of contaminants in groundwater usually are not high enough to use suspended growth bioreactors. However, more concentrated waste streams, such as landfill leachate, may be suitable to treatment via suspended growth reactors.

b. Attached Growth Systems.

Attached growth systems (Figure 13-2) include upflow fixed film bioreactors, fluidized bed reactors, rotating biological contactors (RBCs), and trickling filters. In these systems, microbes grow attached to a support matrix. Liquid waste is circulated through the attached growth system where contaminants are removed and degraded by the microbes. "Clean" water is further processed in a clarifier, where sludge is settled and water that meets effluent criteria is discharged. Attached growth systems include the use of active supports (such as activated carbon) that adsorb the contaminant and slowly release it to the microbial population for degradation. Active supports also include wetland ecosystems and column reactors.

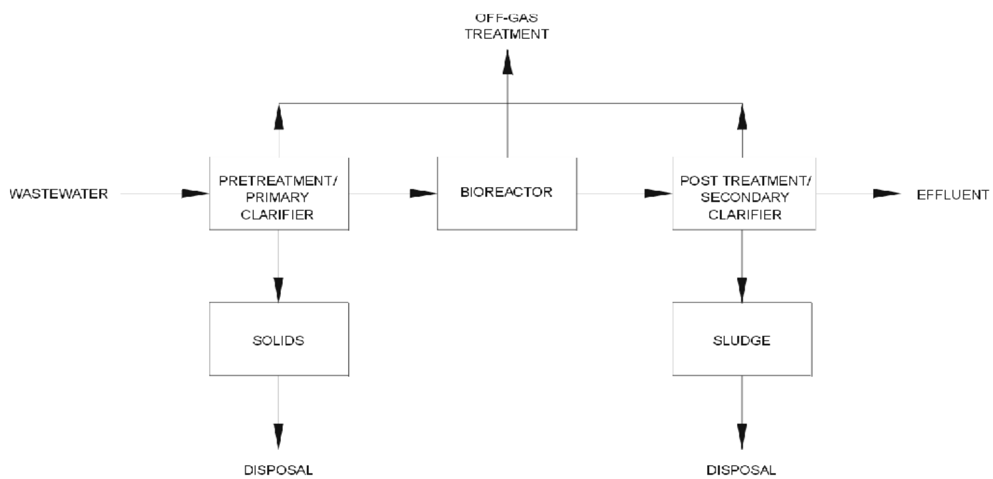


FIGURE 13-2. TYPICAL PROCESS FLOW FOR BIOREACTORS (ATTACHED GROWTH SYSTEMS)

c. Applications.

Bioreactors are used primarily to treat semi-volatile compounds, petroleum hydrocarbons, and halogenated compounds such as chlorobenzene, dichlorobenzene isomers, and some pesticides. Because of the limitations of mixing equipment, the solids content in slurry reactors is usually not more than 20%, by weight.

d. Resulting Waste Streams.

Bioreactors produce four streams that may require additional handling:

- Emissions from equalization tank or other pretreatment operations (may require additional treatment).
- Emissions from bioreactor (may require treatment).
- Effluent water from waste treatment.
- Sludge (may require additional treatment prior to disposal).

13-3. Hazard Analysis

Principal unique hazards associated with bioreactors, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire or Explosion Hazards*.
Description. Storage of methanol or other additives or supplements may cause fire or explosion if these materials are spilled and allowed to mingle with incompatible chemicals or are ignited by a source of ignition.

Control. Controls for fire or explosion hazards include:

- Meet mandatory storage requirements of 29 CFR 1910.106, “Flammable and Combustible Liquids.”
- Follow appropriate fire and electrical codes.
- Verify that drawings indicate hazardous area classifications, as defined in NFPA 70, Chapter 5, 500.1 through 500.10.
- Use controls, wiring, and equipment near the tanks that conform to the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Use grounded equipment or equipment with ground-fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70.
- Train operators in the chemical hazards associated with storing methanol and other chemical additives used in the process, in the heat of reactions and flammability properties of the chemicals, and in handling and transferring the chemicals.
- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including halting and neutralizing chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency sludge system isolation and shutdown procedures.
- Locate, install, and maintain emergency eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1990.)
- Permit only those trained, experienced, and authorized workers to work around the storage areas.
- Direct tank vents to prevent contact with sources of ignition.
- Make fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) *Confined Spaces*.
Description. Because bioreactors typically generate carbon dioxide gas as a byproduct, workers entering tanks or clarifiers may be exposed to confined spaces with oxygen-deficient atmospheres.

Control. Controls for confined-space entry include:

- Train operators and workers in confined space hazards and the unique processes that generate the toxic atmospheric hazards, and on safety procedures to be employed in confined space entry. (See 29 CFR 1910.146.)

- Design the bioreactors to maximize easy operation, physical cleaning, and maintenance to include accessible, adequately sized access doors or entry ports, and to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Develop a pre-entry confined space permit. Implement a confined space entry program to access hazards, including atmospheric testing.
- Provide ventilation of the tank, the vessel interior prior to and during the confined space entry to eliminate oxygen deficient or toxic atmospheres.
- Wear appropriate personal protective equipment (PPE), including respiratory protection including supplied air, as needed.
- Use the Buddy System.

CONTROL POINT: Design, Operations, Maintenance

(3) *Electrocution.*
Description. If permanent and temporary electrical equipment that is not ground-fault protected contacts water or other liquids, an electrocution hazard exists.

Control. Controls for electrocution include:

- Identify on drawings the hazardous area classifications defined in NFPA 70, Chapter 5, sections 500.1 through 500.10.
- Use all controls, wiring, and equipment that meet requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Provide ground fault protection where required by EM 385-1-1, Section 11, or NFPA 70.
- Permit only trained, experienced, and authorized workers in equipment areas.

CONTROL POINT: Design, Construction, Maintenance

(4) *Unguarded Equipment.*
Description. Blowers may be equipped with unguarded pulleys that may cause cuts or entanglement of body parts or loose clothing. Floating aerators may be equipped with unguarded propeller blades.

Control. Controls for unguarded equipment include:

- Use pulleys and other moving or rotating mechanical devices with guards and operate with guarding in place.
- Design and install emergency shut-off systems if there is a threat of workers falling into actively aerated tanks or ponds with bladed aerators.
- Establish lock-out procedures for shutting down aerators prior to operations on a pond or tank water surface.
- Equip tanks with guardrails, grab rails, and ladders as required.
- Prohibit the use of loose clothing around the equipment.

- Train workers in the hazards of working near unguarded machinery and power equipment. Prohibit workers from working in the vicinity of the unguarded hazards. Use the buddy system.

CONTROL POINT: Design, Operations, Maintenance

(5) *Treatment Buildings*.
Description. Permanent or semi-permanent treatment buildings may present life safety hazards, such as inadequate egress, fire suppression systems, or emergency lighting systems, or walkways without fall protection.

Control. Controls for treatment buildings include:

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1, "Minimum Design Loads for Buildings and Other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code" and the "Uniform Building Code."
- Comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, Base Realignment and Closure (BRAC), or Formerly Used Defense Sites (FUDS) project sites.

CONTROL POINT: Design, Operations

(6) *Fire Hazard (Oxygen-Enriched Atmospheres).*
Description. If pure oxygen is used for aeration, workers can be at increased risk of injury from an oxygen-enriched atmosphere that, with an ignition source, can cause fire that can quickly engulf the work area. Usually air, rather than pure oxygen, is used for aeration.

Control. Controls for fire hazards include:

- Design and construct oxygen systems according to NFPA 50, "Bulk Oxygen Systems at Consumer Sites."
- Provide oxygen systems with safety relief devices in accordance with CGA S-1.3, "Safety Relief Devices for Compressed Gas Storage Containers."
- Inspect oxygen delivery systems regularly for leaks.
- Eliminate all sources of ignition during application of oxygen.
- Train workers in the hazards associated with working with pure oxygen.

CONTROL POINT: Operations, Maintenance

(7) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

CONTROL POINT: Design

(8) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from predesign field activities include:
- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Waste Contaminants and Additives*.
Description. Workers may be exposed to waste contaminants by inhalation, ingestion, or absorption. Biological activity of the bioreactors may be enhanced with the addition of nutrients or other chemical agents. These agents may include nutrients, methanol, or other chemicals for pH adjustment (e.g., acids and bases). Workers may be exposed to these chemicals during their application either as a powder or in a liquid state. Overexposure symptoms may include irritation of the eyes, skin, and respiratory tracts.

Control. Controls for waste contaminants and additives include:
- Use personal protective equipment (PPE) during the application process. PPE requirements may include air-purifying respirators with approved filter/cartridges such as N, R or P100, or N, R, or P95 filters for particulates, organic vapor cartridges for vapors, or combination filter/cartridges for dual protection, chemical barrier gloves (e.g., nitrile for some petroleum distillates), splash goggles, and aprons.
- Design mechanical addition systems to minimize exposure.

CONTROL POINT: Design, Operations, Maintenance

(2) *Toxic Intermediate Products*.

Description. Biological degradation of certain organic compounds may produce toxic intermediate products. Degradation of trichloroethylene (TCE) can produce dichloroethylene (DCE) and vinyl chloride (VC). Vinyl chloride exists as a gas and may accumulate to higher levels in collection system boreholes or in the treatment system. Workers may be exposed to intermediate products during operation or maintenance of the system. Anaerobic processes can produce toxic or explosive products, such as methane or hydrogen sulfide, particularly in confined space areas. Workers may also be exposed to VOCs released from aeration tanks.

Control. Controls for toxic intermediate products include:

- Anticipate and understand the generation and management of process products such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), or vinyl chloride (VC) and design for their management.
- Ventilate the affected area.
- Use air-supplied respiratory protection if required (air-purifying respirators are not recommended for vinyl chloride).
- Cover aeration tanks to prevent the release of VOCs into the work environment.
- Monitor the dissolved oxygen and biological oxygen demand (BOD) levels within aerobic bioreactors to determine if aerobic conditions are being maintained.
- Check periodically for the presence of hydrogen sulfide or install automated alarms.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) *Radioactive Materials.*
Description. Radiological materials may have been buried or naturally occurring radioactive material (NORM) may be present in soils, sludge, or groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion, although this may be a rare hazard.

Control. Controls for radioactive materials include:

- Test the soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist to determine the exposure potential and if any necessary engineered controls or PPE are required.

CONTROL POINT: Design, Operations

(2) *Radioactive Devices.*

Description. Fire and smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling of exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

(1) *Opportunistic Insects and Animals*.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations, and Maintenance

(2) *Pathogenic Microbes*.
Description. Bioreactors may expose workers to pathogenic microbes during operation and maintenance. However, exposure to pathogens is usually not a significant concern unless the waste feed contains pathogenic agents. If the bioreactors are equipped with open aerators, microbe-entrained mists may become airborne. Inhalation of pathogenic microbes may cause allergic reactions or illness such as that caused by legionella bacteria. During sludge handling activities, workers' hands may be exposed, resulting in accidental ingestion of pathogenic material.

Control. Controls for pathogenic microbes include:

- Install aerators that minimize generation of mists or install partitions or barriers to contain the mist.

- Test and monitor for suspect microbial pathogens such as legionella when conditions warrant.
- Minimize skin exposure through the use of PPE, such as chemically resistant gloves (e.g., nitrile), splash aprons, face shields, or respirators equipped with N, R or P100 or N, R, or P95 particulate filters approved for protection against microbes.
- Provide adequate hand washing facilities equipped with bactericidal soaps.

CONTROL POINT: Design, Operations, Maintenance

(3) *Sludge Contaminants*.
Description. Biological sludge, after drying, may become airborne and thus be accidentally inhaled or ingested.

Control. Controls for sludge contaminants include:

- Disinfect sludge through pasteurization or long-term storage if necessary. Maintain sludge in a damp condition to minimize free dust; sludge is often dewatered prior to disposal. (Sludge drying beds are the most widely used method of dewatering sludges from municipal wastewater in the United States. Pathogens are usually a greater concern for municipal wastewater applications than for hazardous waste applications.)
- Use appropriate PPE such as an air-purifying respirator with N, R, or P100 or N, R, or P95 particulate filters when handling sludge in dusty conditions.
- Provide access to adequate hand washing facilities equipped with bactericidal soaps.

CONTROL POINT: Operations, Maintenance

Chapter 14
Biofiltration (Vapor)

14-1. General

The process of biofiltration and its applications are described in the chapter's first section. The second portion is a hazard analysis with controls and control points listed.

14-2. Technology Description

a. Process.

Biofiltration uses biodegradation to treat air stream contaminants (volatile organic compounds [VOCs]) prior to releasing the stream to the atmosphere. It can be viewed as a self-renewing adsorption bed. The VOC-laden vapor is passed over a porous bed of high surface area packing that serves both as a support surface for the appropriate microbes and as an adsorbent surface for the VOC. This increases the retention time of the VOC in the bed and permits the microbes more time to degrade organic compounds. The air contaminants are solubilized and in turn are degraded by the microbes. Materials that can serve as packing include sand, activated carbon, ceramic supports, peat moss, wood chips, and glass and plastic beads. As this is a destructive process, the unit operating cost is usually less than adsorbent regeneration processes such as activated carbon. Nutrients and water may be added by spraying across the top surface of the bed. If water is not added, the entering air stream must be humidified to prevent the bed from drying out (which will inhibit microbial activity). Specifically, cultured organisms may be used in an effort to shorten the acclimation time at the start of operations. The biofiltration process is illustrated in Figure 14-1.

b. Applications.

The technology is best suited to steady-flow streams where the VOC composition and concentration changes slowly if at all. The bed will generally not keep the exhaust air stream in compliance during periods of shock loading as the microbes require time to grow and adapt to different concentrations of substrate.

Vapor biofiltration has been successfully used for odor control in the food industry (bakeries and breweries), for solvent vapor treatment from fiber glassing and painting operations, and for the treatment of SVE exhaust streams prior to atmospheric release.

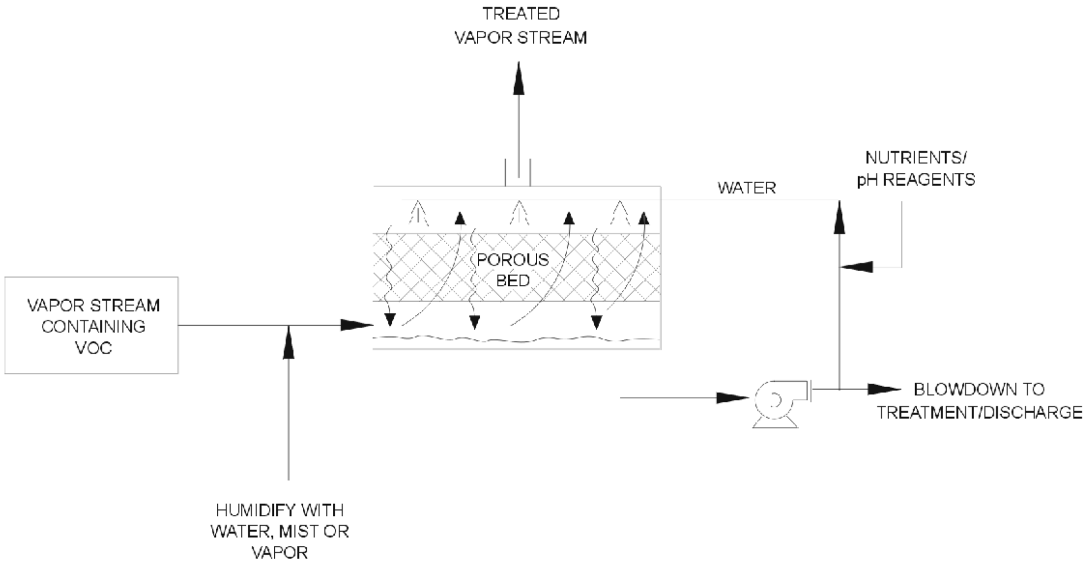


FIGURE 14-1. TYPICAL PROCESS FLOW FOR BIOFILTRATION (VAPOR)

14-3. Hazard Analysis

Principal unique hazards associated with vapor biofiltration, methods for control, and control points are described below.

a. Physical Hazards.

(1) Confined Space.
Description. Entering process vessels and tanks to inspect and maintain them is a permit-required confined-space entry. Associated hazards include asphyxiation from the lack of oxygen, overexposure to toxic wastes and byproducts, and engulfment or entrapment by the filtration media.

Control. Controls for confined-space entry include:

- Train operators and workers in confined space hazards and in safety procedures to be employed when entering confined spaces.
- Design the biofiltration and reaction vessels to maximize easy operation, physical cleaning, and maintenance, to include accessible, adequately sized access doors or entry ports, and to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Develop a pre-entry confined space permit. Implement a confined space entry program to access hazards, including atmospheric testing inside the tanks. Use confined-space entry procedures for any entry activities (see 29 CFR 1910.146).

- Provide ventilation of the vessel interior prior to and during the confined space entry to eliminate the oxygen-deficient or toxic atmosphere.
- Wear appropriate personal protective equipment (PPE), including respiratory protection (e.g., an air-purifying respirator with organic vapor cartridges) or supplied air, as needed.
- Use the Buddy System for such operations.

CONTROL POINT: Operations, Maintenance

(2) *Electrocution.*
Description. Workers may be exposed to electrical hazards when working around biofilters. If permanent and temporary electrical equipment that is not ground-fault protected contacts water or other liquids, an electrocution hazard exists.

Control. Controls for electrocution include:

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70, Chapter 5, sections 500.1 through 500.10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G, and NFPA 70 for the identified hazard areas.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use grounded or GFCI-protected equipment if required by EM 385-1-1, Section 11, or NFPA 70.
- Permit only trained, experienced workers in equipment areas.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) *Treatment Buildings.*
Description. Permanent or semi-permanent treatment buildings may present life safety hazards, such as inadequate egress, fire suppression systems, or emergency lighting systems, or walkways without fall protection.

Control: Controls for treatment buildings include:

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1: “Minimum Design Loads for Buildings and Other Structures,” the “National Fire Code,” the “National Standard Plumbing Code,” “Life Safety Code,” and the “Uniform Building Code.”
- Comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, Base Realignment and Closure (BRAC) or Formerly Used Defense Sites (FUDS) project sites.

CONTROL POINT: Design, Operations

(4) *Emergency Wash Equipment.*
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(5) Design Field Activities.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from predesign field activities include:

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Additives.
Description. Biological activity of the biofilters may be enhanced with the addition of nutrients or other chemical agents. These agents may include nutrients (e.g., ammonia nitrate, urea) or other chemicals (e.g., hydrochloric acid, sodium bicarbonate). Workers may be exposed to these chemicals during their application. Overexposure symptoms may include eye, skin, and respiratory tract irritation.

Control. Controls for additives include:

- Consult chemical manufacturers' Material Safety Data Sheets (MSDS) for potential hazard information and controls, including appropriate personal protective equipment (PPE), and train workers accordingly.
- Use recommended PPE (e.g., an air-purifying respirator with organic vapor cartridges) during the application or blending processes.
- Design mechanical addition systems to minimize exposure.

CONTROL POINT: Design, Operations, Maintenance

(2) Fire or Explosion.
Description. Storage of the materials may cause fire or explosion if they are spilled and allowed to mingle with incompatible chemicals.

Control. Controls for fire or explosion include:
- Store incompatible materials separately or in secondary containment.
- Train operators in chemical hazards and potential reactions, and in storing, handling, and transferring the materials and chemicals.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including halting and neutralizing chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency storage area isolation and shutdown procedures.
- Locate, and maintain emergency eyewashes and showers at critical locations in the area. (See ANSI Z358.1 – 1998)
- Consult the manufacturer or the Material Safety Data Sheets for incompatibilities.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

(1) Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:
- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.

- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

(2) *Pathogenic Microbes.*
Description. Biofilters can expose workers to pathogenic microbes, especially during maintenance activities where the reactor may need disassembly or when workers are required to enter the biofiltration vessels. Inhalation of pathogenic microbes, such as legionella bacteria, can cause allergic reactions or illness. During support media handling activities, workers' hands can be exposed to the microbes and result in accidental ingestion of pathogenic material.

Control. Controls for pathogenic microbes include:

- Install partitions or barriers to contain the mist.
- Test or monitor for suspect microbes such as legionella.
- Use N, R or P100 or N, R or P95 particulate filter air-purifying respirators approved for microbial inhalation hazards.
- Minimize skin exposure with PPE such as gloves (e.g., butyl rubber) and chemically resistant disposable coveralls.
- Practice good decontamination by thoroughly washing hands and face before exiting the work area.

CONTROL POINT: Design, Maintenance

Chapter 15
Precipitation

15-1. General

The process of precipitation, its applications, and resulting waste streams are described in the first section of the chapter. The chapter's second portion is a hazard analysis with controls and control points listed.

15-2. Technology Description

a. Process.

Precipitation is a treatment process in which soluble metals and inorganics are precipitated into relatively insoluble metals and inorganic salts by the addition of a precipitating agent (see Figure 15-1). Precipitates, which are small or colloidal, are then settled or filtered out of solution, leaving a lower concentration of metals and inorganics in the effluent. Precipitating agents include soluble hydroxide, sulfide, carbonate, and xanthate compounds. If the precipitate does not settle rapidly, a polymer may be added as a coagulant to increase agglomeration and settling. Inorganic iron and aluminum derivatives, such as ferric chloride and aluminum, may also be used to enhance coagulation. The solids are settled in a clarifier, and the supernatant liquid is discharged or sent to primary treatment. The thickened solids are then disposed of.

b. Applications.

Precipitation is a primary method of treating metal-contaminated aqueous waste streams. Most metals will precipitate from solution at some concentration of their hydroxide, sulfide, or carbonate salts. Additions of more soluble salts of these compounds to an aqueous stream may precipitate metals whose salts have a lower solubility than the additive ions.

Precipitation is a candidate technology for the remediation of groundwater contaminated with heavy metals (including radionuclides) and is an effective pretreatment method for other remediation technologies (such as chemical oxidation or air stripping) where the presence of metals may interfere with the treatment process.

c. Resulting Waste Streams.

Precipitation reactors will produce two streams that may require additional handling:

- The treated effluent wastewater stream.
- Sludges (such as metal hydroxide sludges) that must pass TCLP tests for land disposal.

Adequate solids separation techniques (such as clarification, coagulation, flocculation, or filtration) are required for efficient treatment. Treated effluent may be adversely affected by the rate of addition of reagents or by pH adjustment, which must be controlled to prevent unacceptable concentrations of total dissolved solids in the treatment effluent.

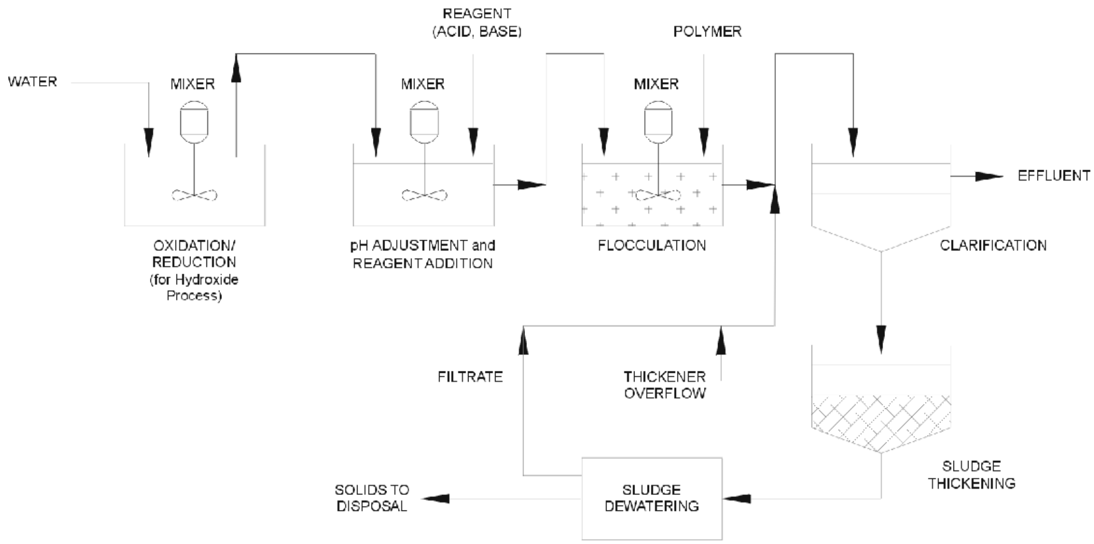


FIGURE 15-1. TYPICAL PROCESS FLOW FOR PRECIPITATION

For additional information on similar processes, see Chapter 16 and 18.

15-3. Hazard Analysis

Principal unique hazards associated with precipitation, methods for control, and control points are described below

a. Physical Hazards.

(1) *Incompatible Treatment Materials and Reagents.*
Description. Chemical reagents (e.g., soluble hydroxide, sulfide, carbonate, and xanthate compounds, polymers added as a coagulant to increase agglomeration and settling), inorganic iron and aluminum derivatives, such as ferric chloride and aluminum, may be used. The system design and materials of construction must be compatible with the reagents. Incompatible reagents and materials may cause corrosion, leaks, joint failures, flow obstructions, and over pressurization of lines.

Control. Controls for incompatible treatment materials and reagents include:

- Train operators in the system chemistry involved in the plant operation.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Use liquid transfer equipment (pumps, piping, pipe fittings, valves, and instruments) fabricated from materials that are chemically inert to the liquid streams. Use EM 1110-1-4008, “Liquid Process Piping,” for materials selection.

- Place automatic alarms (e.g., pH, temperature, pressure, reactant off-gas concentration detectors) with sensors at critical points throughout the system to monitor all reactions.
- Utilize appropriate chemical storage and handling procedures to prevent contact or mixture of incompatible reagents and materials.
- The design engineer's authorization is required for any equipment and material substitutions made during construction.
- Train operators in emergency procedures in case of a treatment system failure, in life saving first aid procedures including halting chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.

(2) *Plugged or Overpressured Waste Lines*.
Description. Precipitate may plug waste lines if the formation rate exceeds the rate of removal. Plugged lines may cause tanks to overflow; broken lines and pumps can cause slippery conditions, worker exposure, and environmental damage. Also, because of the wet environment and the use of electrical equipment, workers may be exposed to electrocution.

Control. Controls for plugged or overpressured lines include:
- Use auger-equipped waste lines to prevent plugged lines.
- Use flow controls to prevent plugged lines and overflowing tanks.
- Install alarms to alert operators of system over-pressurization.
- Allow adequate space for maintenance between equipment.
- Install slip resistant walking and working surfaces.
- Verify that drawings designate the hazardous area classifications as defined in NFPA 70, Chapter, 5 500.1 through 500.10.
- Use controls, wiring, and equipment, both temporary and permanent, that conforms to EM 385-1-1, Section 11, and NFPA 70 for each of the identified hazard areas.
- Use grounded equipment or equipment provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70.
- Permit only trained and experienced workers in the areas.

CONTROL POINT: Design, Operations, Maintenance

(3) *Tank Mixing/Sludge Handling Equipment*.
Description. Tank mixing equipment may splash chemical reagents (e.g., acids or hydroxides) or may entangle workers who come in contact with propellers or shafts. Sludge press areas are notoriously wet and congested work areas with slips, trips, and falls present as ongoing hazards.

Control. Controls for mixing equipment include:
- Train the operators in the operating characteristics of the tank mixing equipment, in all potential pinch points and rotating part or splash exposures from

the equipment, in the chemistry involved, in the heat of reaction of the chemical reactions, and in handling and transferring the chemicals.

- Use tanks designed to protect people from harmful splashing of rotating mixers or entanglement with shafts or motors.
- Install deadman switches on the equipment and implement lock-out/tag-out procedures when performing maintenance on the mixers.
- Treat floor surfaces around mixing and precipitation equipment, such as sludge handling equipment, with no-skid floor coverings.
- Train workers in potential chemical contact hazards and control measures (see 29 CFR 1910.1200). Train the operators in emergency procedures in the event of a chemical splash exposure or physical entanglement, in life saving first aid procedures including emergency de-energizing equipment, halting and neutralizing chemical reactions, extracting, decontaminating, and stabilizing victims, and in emergency sludge system isolation and shutdown procedures.
- Install, and maintain emergency eyewash/showers at critical points with easy access to the mixing tank equipment. (See American National Standards Institute ANSI Z 358.1 – 1998.)

CONTROL POINT: Design, Operations, and Maintenance

(4) *Electrical Shock.*
Description. Electrical systems in wet or damp areas can cause electrical shock to operating personnel.

Control. Controls for electrical shock include:

- Train operators in the electrical systems used and in the potential electrocution hazards.
- Use ground-fault protected electrical systems in areas that could become wet or damp. Electrical system design must follow "National Electrical Code" NFPA 70 and UFGS 16415A, "Electrical Work, Interior."
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use grounded or GFCI-protected equipment if required by EM 385-1-1, Section 11, or NFPA 70.
- Never allow the use of ungrounded temporary wiring or electrical cords during minor maintenance work on the units, or grounded temporary wiring in contact with water, or wet or damp surfaces that is not approved for these applications.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) *Emergency Wash Equipment.*
Description. Emergency shower/eyewash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: “Emergency Eyewash and Shower Equipment” for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(6) *Confined Spaces.*
Description. Process tanks are considered to be permit-required confined spaces. Entering process tanks and vessels for inspection and maintenance requires that adequate precautions be taken. Hazards associated with entry into confined space include asphyxiation from the lack of oxygen, exposure to toxic chemical vapors and gases, or poisonous gases from the reagents such as soluble hydroxides, sulfides, hydrogen sulfide, or acids and bases or treatment contaminants or slurries and sludge.

Control. Controls for confined-space entry include:

- Thoroughly train operators and workers in confined space hazards and on safety procedures to be employed in confined space entry.
- Design the mixing tanks and vessels to maximize easy operation, physical cleaning, and maintenance to include accessible, adequately sized access doors or entry ports; and to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Utilize pre-entry confined space permits as detailed in a confined-space entry program that includes a hazard assessment (see 29 CFR 1910.146) including interior atmosphere testing prior to and throughout the work planned.
- Ventilate tank and vessel interiors prior to and during the confined space entry to eliminate the oxygen-deficient or toxic and poisonous atmosphere (hydrogen sulfide or acid gas).
- Complete the mixing tank/vessel manufacturer’s shutdown procedures and lock-out/tag-out of associated mixing, pumping or electrically energized systems prior to entry. Eliminate possible buildup of static electricity.
- Use air-supplied respirators to control inhalation exposures to toxic chemicals and poisonous gases to prevent any potential for asphyxiation in situations where only constant mechanical ventilation prevents the buildup of a toxic or inert gas environment.

CONTROL POINT: Design, Operations, and Maintenance

(7) *Design Field Activities.*
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical sur-

veys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazard identification processes and control practices.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Chemical Reagents*.
Description. Precipitation treatment may expose workers to corrosive chemical reagents, e.g., HCL, lime, sodium hydroxide, carbonate salts, sulfide salts, etc. The reagents can be powder or liquid and may pose an exposure hazard through either inhalation, dermal, or ingestion routes. They may corrode piping system components. Some chemicals used in the precipitation process are hygroscopic and may develop unwanted reactions in the presence of moisture.

Control. Controls for chemical reagents include:

- Label all tanks and piping systems.
- Store all chemicals and reagents in accordance with NFPA, manufacturer, and Material Safety Data Sheet (MSDS) requirements. Do not store a greater chemical inventory than can be used within the acceptable storage period.
- Use temperature and moisture control in storage areas if advised by the manufacturer.
- Segregate acids, bases, and other reactive chemicals with dikes in storage areas.
- Determine reagent compatibility prior to placement in storage following their introduction into the system.
- Use a closed system for the delivery of chemical reagents (e.g., lime, sodium hydroxide solutions, etc.).
- Use the Buddy System and mix all chemical reagents in the mixing tanks in accordance with NFPA and manufacturers requirements, employing all prescribed protective equipment (PPE) including respirators, face shields, and chemical splash resistant suits.
- Install and maintain emergency eyewash/showers at critical points with easy access to the mixing tank equipment and the chemical storage areas. (See ANSI Z 358.1 – 1998.)
- Use PPE such as an air-purifying respirator using cartridges appropriate to the reagents.

- Consult MSDS prior to handling reagents to determine the specific chemical hazards and face shields, gloves, and aprons required.
- Train operators in the characteristics of the tank mixing equipment, splash exposures from mixing reagents, in the chemistry involved, in the heat of reaction and toxicity of the chemical reactions in handling and transferring the chemicals.
- Train operators in the emergency procedures in case of a chemical splash or toxic vapor exposure, in life saving first-aid procedures including emergency de-energizing equipment, halting and neutralizing chemical reactions, extracting, decontaminating, and stabilizing victims and in emergency reaction tank system isolation and shutdown procedures.
- Use appropriate materials in the design of piping and system components.

CONTROL POINT: Design, Operations, Maintenance

(2) *Uncontrolled Reactions*.
Description. If adding reagents in the oxidation/reduction reactions is not properly controlled, the reactions can cause heat and pressure buildup, producing a system release. The release may expose workers to chemical reagents or waste material. Exposure may cause irritation or chemical burns to eyes, skin, and respiratory tracts.

Control. Controls for reactions include:

- Use flow controls to help prevent addition of excessive amounts of chemical reagents (e.g., hydrochloric acid, sodium hydroxide, lime, etc).
- Store the oxidation/reduction reagents in separate areas under cool, dry conditions.
- Include pressure-relief systems and over-pressurization alarms as mandatory components in process design.
- Install an automatic shutoff to prevent the overflowing of storage tanks.
- Locate chemical piping low to the ground, if possible, in case of rupture.
- Provide insulation on pipes to prevent slipping hazards if pipes have moisture buildup.

CONTROL POINT: Design

(3) *High pH Sludge*.
Description. Sludge from the treatment process may have a high pH, which may cause skin burns for workers handling the material.

Control. Controls for high pH include:

- Train operators in the chemical safety and health hazards associated with sludge handling operations.
- Neutralize sludge prior to handling.
- Use PPE such as rain gear, rubber gloves (e.g., butyl rubber for hydrochloric acid or sodium hydroxide), and splash shields.

CONTROL POINT: Design, Operations, Maintenance

(4) H*ydrogen Sulfide Exposure*.
Description. The process may form metal sulfides, which may generate toxic gases, such as hydrogen sulfide (H_2S) or the sulfide sludge may spontaneously combust. If sulfide salts are used as a precipitating agent, H_2S will be generated if the solution is acidic.

Control. Controls for hydrogen sulfide exposure include:

- Ventilate to remove gas from the work area, process tanks, and vessels.
- Use pH control to keep the sulfides alkaline.
- Use water control systems to keep sulfide filter cakes moist.
- Install a H_2S monitor to avoid fatal overexposure where the generation of H_2S is most probable. Set monitors to alarm at 10 ppm.
- Make emergency escape respirators available for all operators in the event of a catastrophic system rupture or uncontrolled reaction.
- Train workers in hazard identification and control and in the chemistry and toxic reactions and effects of hydrogen sulfide.

CONTROL POINT: Design, Operations, Maintenance

(5) *Acids and Bases*.
Description. Workers may be exposed to acids or bases used for pH adjustment.

Control. Controls for acids and bases include:

- Construct secondary containment storage areas for acids and bases of compatible materials.
- Mark storage containers clearly.
- Store acids and bases in separate areas.
- Locate emergency showers and eye wash stations that comply with 29 CFR 1910.151(c) and the design requirements specified in ANSI Z358.1 - 1998 near the reagent storage areas.
- Automate handling of pH agents to the extent practical.
- Prepare an emergency plan and train workers in safe acid/base handling techniques.
- Restrict manual handling of acids and bases to trained and authorized personnel.
- Use PPE such as leather or rubber acid-resistant boots, chemical-resistant coveralls, goggles and face shields, air-purifying respirators (as indicated by the reagent), and rubber or other acid and base resistant gloves (e.g., nitrile) or gauntlets.

CONTROL POINT: Design, Operations, Maintenance

(6) *Treatment Buildings*.
Description. Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, or emergency lighting systems.

Control. Controls for treatment buildings include:

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1, "Minimum Design Loads for Buildings and Other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code," and the "Uniform Building Code."
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, Base Realignment and Closure (BRAC) or Formerly Used Defense Sites (FUDS) sites.

CONTROL POINT: Design, Operations

c. Radiological Hazards.

(1) *Radioactive Materials*.
Description. Many radioactive materials and naturally occurring radioactive materials (NORM) are metals that, if present in the water, can precipitate and be concentrated. This hazard may be considered out of the ordinary for this technology. Some radioactive materials may present an external exposure hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion.

Control. Controls for radioactive materials include:

- Consult a qualified health physicist to determine the exposure potential, any necessary engineered controls, or required PPE.

CONTROL POINT: Maintenance

(2) *Radioactive Devices*.
Description. Fire and smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose devices in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 16
Advanced Oxidation Processes

16-1. General

Advanced Oxidation Processes (AOP) and their applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

16-2. Technology Description

a. Process.

Advanced oxidation processes are destructive treatments that oxidize organic and explosive constituents in wastewater either photochemically or by direct oxidation through the addition of strong oxidizers, or a combination of the two. The photolytic oxidation reactions are achieved through the synergistic action of UV light, in combination with ozone (O_3) or hydrogen peroxide (H_2O_2) or other catalysts and reagents. Lamps that generate UV light shine on the flow path for the water stream, and the ozone or peroxide, or both, are injected upstream of the lamps. If complete mineralization is achieved, the final products of the oxidation are carbon dioxide, water, and salts. AOPs can use a combination of hydrogen peroxide, ozone, and peroxide catalyzed oxidation, or UV lights in combination with hydrogen peroxide alone, ozone alone, or a combination of hydrogen peroxide and ozone together to treat the aqueous stream.

The main advantage of AOPs is that they are destructive processes, as opposed to air stripping or carbon absorption, in which contaminants are extracted and concentrated in a separate phase. The oxidation process can be configured in batch or continuous flow modes, depending on the required flow and concentrations. See Figure 16-1.

b. Applications.

The process is effective only for relatively clear aqueous streams. Turbidity in the water will prevent UV light, if used, from fully penetrating the water stream.

For additional information on similar processes, see Chapter 18.

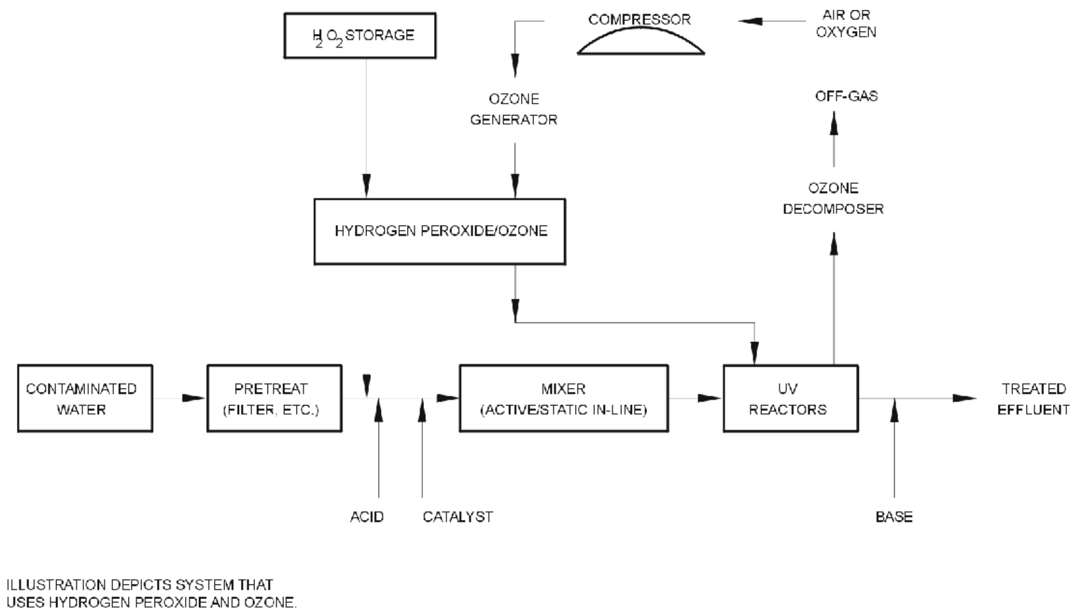


FIGURE 16-1. TYPICAL PROCESS FLOW FOR ULTRAVIOLET OXIDATION

16-3. Hazard Analysis

Principal unique hazards associated with advanced oxidation processes, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Heated Surfaces*.
Description. Certain components of UV type AOP treatment systems, such as the UV lamps' protective sheaths, the ozone generator, and the ozone off-gas destruction units, can generate heated surfaces that may cause burns to unprotected skin or create radiant heat hazards.

Control. Controls for heated surfaces include:
- Insulate or cool surfaces either by ventilation or through a heat exchanger.
- Wear insulated gloves to prevent thermal burns.
- Minimize worker exposure time on or near hot surfaces.
- If prolonged work is required near radiant heat sources, use appropriate eye and body protection.

CONTROL POINT: Design, Operations, Maintenance

(2) *Electrocution*.
Description. UV oxidation systems utilize high-voltage mercury lamps that may operate on voltages up to 3000 volts. Breakage of the lamps may cause electrocution or mercury vapor (see paragraph 16-3*b*(1) of this Chapter).

Control: Controls for electrocution include:

- Verify that drawings indicate the hazardous area classifications as defined in National Fire Protection Association (NFPA) 70, Chapter 5, sections 500.1 through 500.10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use grounded or ground fault interrupter circuit (GFIC)-protected equipment if required by EM 385-1-1, Section 11, or NFPA 70 (special grounding requirements).
- Verify UV lamp cover panel interlocks de-energize the system when doors are opened.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) *Explosion and Combustion Hazards*.
Description. Although hydrogen peroxide solutions (27–52%) are not combustible, as strong oxidizers they can greatly intensify combustion. They also present an explosion hazard because of violent decomposition when heated or contaminated with oxidizable materials including iron, copper, brass, bronze, copper, and other metals (see Material Safety Data Sheets for complete listing). Contact with reducing agents or organic and combustible materials (wood, paper) may cause immediate spontaneous ignition.

Control. Controls for explosion include:

- Implement a plant-specific lock-out/tag-out program designed after the requirements of 29 CFR 1910.147 for maintenance procedures.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Implement a plant-specific hazard communication program for plant operators on the reactive properties of hydrogen peroxide. Design in compliance with the requirements of 29 CFR 1910.1200.
- Store hydrogen peroxide solutions in properly vented, approved containers in a cool, clean, fire-resistant area away from combustible materials, catalytic metals, direct sunlight, and other potential sources of heat or ignition.
- Maintain the purity of the solution.
- Do not return unused material to its storage container after removal.
- Select, design, and maintain all equipment in contact with hydrogen peroxide solutions to minimize reactive hazards.
- Use secondary containment in storage areas.
- Supply an ample source of water for handling spills.
- Train the operators in emergency procedures in case of a catastrophic failure, in life saving first aid procedures including halting the thermal reac-

tions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.

- Locate emergency fire fighting equipment, eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(4) *Confined Spaces.*

Description. Workers may be exposed to confined space hazards when entering an AOP facility's treatment vaults and vessels that require entry as a normal part of inspection, operation, and maintenance. The units such as the hydrogen peroxide storage unit, the hydrogen peroxide/ozone combining chamber, or the mixing tank, can be operated under oxygen deficient or poisonous atmospheric conditions. All treatment units requiring periodic entry for maintenance present significant confined space hazards. Death or injury can be caused by inhalation in the oxygen deficient or poisonous atmosphere, or also by engulfment hazards

Control. Controls for confined spaces include:

- Eliminate confined space in the design where possible (designers). If confined spaces cannot be eliminated, design the process vaults, tanks, and vessels to maximize easy operation, and physical cleaning and maintenance to include accessible, adequately sized access doors and ports, and to minimize the frequency, duration, and extent of cleaning and maintenance required. Designs should minimize maintenance required in the spaces.
- Ensure that liquid oxygen storage vessels and distribution systems comply with the requirements, including labeling, specified in NFPA 50 and 29 CFR 1910.104 (designers).
- Implement and follow a plant-specific confined-space entry program designed after the requirements of the Occupational Safety and Health Administration's (OSHA's) confined-space standard in 29 CFR 1910.146.
- Test the atmospheres within the confined spaces prior to entry and monitor throughout the work being performed. (See 29 CFR 1910.146.)
- Design air ventilation to minimize or eliminate oxygen-deficient or poisonous gas pockets and rigorously ventilate prior to entry of personnel.
- Perform manufacturers shutdown procedures and lockout/tag out of electrically energized systems prior to entry.
- Use air-supplied respirators to control inhalation exposures to poisonous atmospheres and prevent any potential for asphyxiation in situations where only constant mechanical ventilation prevents the buildup of a toxic or inert gas environment.
- Implement a plant-specific hazard communication program for plant operators on the hazardous properties of liquid oxygen. Design in compliance with the requirements of 29 CFR 1910.1200.

CONTROL POINT: Design, Operations, Maintenance

(5) *Explosion and Fire Hazards*.
Description. Operation of AOP systems can generate gases and build pressure in the process units. There is a hazard for the workers for an explosion and release of the reagents and contaminated materials. Some UV/oxidation systems use liquid oxygen to generate ozone. Liquid oxygen storage creates the potential for fire and explosion.

Control. Controls for explosion and fire include:

- Include pressure-relief valves and vents discharged away from the work area (designers).
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Consider including alarm systems, monitors to detect pressure build-up and ozone, emergency release systems for head spaces, and emergency plans for operations.
- Train workers in hazards associated with all potential gases generated, including ozone odor detection.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting the thermal reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency fire fighting equipment, eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(6) *Treatment Buildings*.
Description. Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, or emergency lighting systems.

Control. Controls for treatment buildings include:

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1, "Minimum Design Loads for Buildings and Other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code," and the "Uniform Building Code."
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, Base Realignment and Closure (BRAC) or Formerly Used Defense Sites (FUDS) sites.

CONTROL POINT: Design, Operations

(7) *UV Radiation*.

Description. The operation of a UV-based treatment system utilizes lamps that emit UV radiation that may cause eye damage.

Control. Controls for UV radiation include:

- Wear the appropriate ANSI-approved eye protection, utilizing the appropriate shade.
- Verify that interlocks are functional.
- Verify that view ports properly filter UV rays.
- Verify that UV lamp sheaths are not cracked or broken.

CONTROL POINT: Operations, Maintenance

(8) *Noise hazards*.
Description. Noise hazards may be associated with the use of an air compressor to generate ozone.

Control. Controls for noise hazards include:

- Include isolated generator rooms in building design.
- Develop a hearing protection policy in accordance with 29 CFR 1910.95.

CONTROL POINT: Design, Operations, Maintenance

(9) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(10) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Toxic Material Exposure (Feed or Byproducts).*
Description. During operation of the AOP units, workers may be exposed to toxic components in the waste water, the toxic chemical additives, reagents or catalysts in the chemical storage units, the chemical feed and mixing tanks and in the reaction vessels; to oxygen deficient atmospheres and carbon dioxide; or to airborne poisons including hydrogen peroxide or ozone vapors or gas, catalysts, heavy metals such as mercury (e.g., broken mercury vapor lamps) or metal salts. Bulk chemical additives can create exposure potentials, both when the chemicals are replenished and when routine maintenance is done on the treatment units.

Control. Controls for exposure to toxic materials include:

- Train all workers involved in both the operation and maintenance of the AOPs and in all chemical hazards related to the generation, transport, and treatment of the contaminants, contaminant byproducts within the system, and the bulk chemical additives used to treat the contaminants.
- Characterize and classify the gaseous waste components prior to and following oxidation.
- Feed only liquid waste streams compatible with the process into the unit.
- Note design parameters on feed characteristics.
- Design chemical treatment technologies appropriate for the known or anticipated wastes.
- Design engineering controls for the system to prevent or minimize the generation or release of toxic materials/gases into the breathing zone of the workers, both during operation and maintenance. The engineering controls could include real time monitors with alarms and appropriate ventilation controls.
- Install, locate, and maintain emergency eyewash and shower units at critical points throughout the system. (See ANSI Z358.1 – 1998.)
- Use personal protective equipment (PPE) appropriate to the work task, to the contaminants to be treated, and to the oxidation byproducts, such as chemical protective gear, acid protective gear, chemical safety goggles, safety glasses, face shields, air-supplied respirators, etc. Train workers in the use of the PPE.

CONTROL POINT: Design, Operations

(2) *Mercury*.
Description. Workers may be exposed to mercury if mercury vapor-filled lamps are damaged or broken during installation, inspection, or replacement. Mercury overexposure may cause various symptoms, including damage to the central nervous system, conjunctivitis, and inflammation to the nose and throat.

Control. Controls for mercury include:

- Handle mercury lamps with caution to help prevent breakage.
- Remove mercury spills immediately.
- Make mercury spill kits available in the immediate work areas.

CONTROL POINT: Construction, Operations, Maintenance

(3) *Ozone*.
Description. Ozone may be produced via an on-site ozonator to enhance the performance of UV oxidation systems. Ozone may leak through seals or pipe junctions, or ozone levels may increase in the work environment if the ozonator fouls. Ozone is a potential experimental tumorigen and teratogen. Exposure to ozone may irritate exposed skin. Depending upon the degree of exposure, ozone may cause irritation of the eyes and respiratory tract, diminished lung function, painful or difficulty breathing, chest tightness, coughing, wheezing, increased sensitivity of the lungs to allergens and bronchoconstrictors, and increased susceptibility to lung-based bacterial and viral infections.

Control. Controls for ozone include:

- Use local or general ventilation of the work area. Observe wind direction, and proximity of wind to fresh air inlets.
- Use closed tops and controlled vents on the reaction chambers.
- Use gas-tight covers or active ventilation on sumps and holding tanks downstream of ozone generation systems.
- Vent vessels (passively or actively) through ozone decomposition equipment to the outside of the building.
- Interlock equipment with ozone generation equipment.
- Set equipment to shut ozone generation off if plant levels exceed the ACGIH TLV for ozone.
- Install real time monitors and alarm systems to warn plant operators if plant levels exceed the ACGIH TLV for the type of work performed by them , i.e., light, moderate, or heavy.
- Implement a plant-specific hazard communication program to identify and address the signs and symptoms of ozone exposure, including odor identification, and to provide procedures for reducing exposures.

CONTROL POINT: Design, Operations, Maintenance

(4) *Catalysts*.
Description. Worker inhalation/ingestion/dermal exposure may occur during the use of catalysts in conjunction with UV oxidation.

Control. Controls for catalysts include:

- Minimize all contact with catalysts. Adhere to the manufacturer's handling instructions and the recommendations of the MSDS for the catalyst.
- Wear personal protective equipment (PPE) and clothing such as an air-purifying respirator with N, R or P100 or N, R or P95 filters, chemically inert disposable coveralls, and protective gloves (e.g., nitrile) based on the materials to be handled.

CONTROL POINT: Design, Operations, Maintenance

(5) *Hydrogen Peroxide*.
Description. Hydrogen peroxide may also be used to help improve the efficiency of UV oxidation systems. Hydrogen peroxide is an oxidizer that may react violently with organic materials either in the waste stream or in other materials, causing fire or system over-pressurization. Exposure to hydrogen peroxide may cause irritation or chemical burns to the skin and damage eyes. Dermal or eye contact with or inhalation of hydrogen peroxide mists or solutions pose a hazard to personnel from chemical burns associated with acute exposure.

Control. Controls for hydrogen peroxide include:

- Provide secondary containment for storage of hydrogen peroxide.
- Use PPE when solution handling is required. Gloves made of natural rubber or nitrile offer good chemical resistance to solutions of 30–70% hydrogen peroxide. Leather and many fabrics, including cotton, rayon, and wool, should not be worn when handling hydrogen peroxide solutions because they present a fire hazard if spills occur. Instead, wear polyester-acrylic (anti-static treated) garments.
- Wear splash-proof chemical safety goggles and face-shields.
- Use local ventilation or respiratory protection to control mists as determined by a qualified health and safety professional.
- Train workers in hydrogen peroxide hazard identification/control.

CONTROL POINT: Design, Operations, Maintenance

(6) *Acids and Bases*.
Description. Workers may be exposed to pH control agents (acids and bases) during operations.

Control. Controls for acids and bases include:

- Construct secondary containment storage areas for acids and bases and use compatible storage materials.
- Mark storage containers clearly.
- Store acids and bases in separate areas.
- Locate emergency showers and eye wash stations that comply with 29 CFR 1910.151(c) and ANSI Z358.1 - 1998 near the reagent storage areas.

- Automate handling of pH agents to the extent practical.
- Prepare an emergency plan and train facility personnel to safely handle acids and bases.
- Restrict manual handling of acids and bases to personnel familiar with their properties. Follow the guidelines of the MSDS.
- Use PPE such as leather or rubber acid-resistant boots, chemical-resistant coveralls, goggles and face shields, air-purifying respirators (as indicated by the reagent), and rubber or other acid and base resistant gloves (e.g., nitrile) or gauntlets.
- Train workers in safe acid/base handling techniques.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) *UV Radiation*.
Description. The mercury lamps used in the treatment generate high levels of UV radiation. Typically, the UV is contained within the treatment unit. However, radiation that is released may damage eyes or increase the risk of skin cancer.

Control. Controls for UV radiation include:

- Equip the reactor vessel with interlocks that de-energize the system when the door is opened.
- Equip viewing ports in reactor walls with glass covers that prevent transmission of UV radiation.

CONTROL POINT: Design, Operations, Maintenance

(2) *Radioactive Devices*
Description. Fire and smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.

Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 17
Passive Treatment Walls

17-1. General

The process of passive treatment walls, installation methods, and their applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

17-2. Technology Description

a. Process.

Passive treatment walls (also called reaction walls) are installed in the ground to treat materials in groundwater that can be readily converted to a non-toxic or inert form. The technology's purpose is to passively route contaminated groundwater through reactive media.

The materials used to construct the wall must:

- Not be made from toxic materials.
- Not produce toxic products or byproducts from the reaction.
- Be thick enough to react with all of the targeted material present.
- Be porous enough to permit the groundwater to flow through.

b. Installation.

The reactive media can be installed by a variety of trenching techniques, including a backhoe or clamshell. Other techniques for installing the reactive cell include caissons, a continuous trencher, mandrel, or pressurized jetting techniques. For funnel and gate configurations, the funnel walls are placed as impermeable barriers with techniques such as sheet piling or slurry walls. See Figure 17-1 for an example layout.

The wall is installed downgradient from the contaminated groundwater. The water may be channeled or forced to flow through the treatment wall by constructing slurry walls to channel the flow. The method is passive in that the target material flows downgradient dissolved in the groundwater through the reaction wall without pumping or recovery. However, treatment walls typically use destructive or essentially irreversible conversions that chemically or biologically alleviate the toxicity problem.

c. Applications.

The technique is most effective for chemicals that are readily soluble in water, have low retardation factors in the subsurface (little interaction with the soil), and are readily reacted into non-toxic forms. An example is the construction of a funnel and gate system containing iron filings as the reactive media for the treatment of TCE in a groundwater plume. The reactive media are designed to react with all of the TCE and its toxic breakdown products such as vinyl chloride.

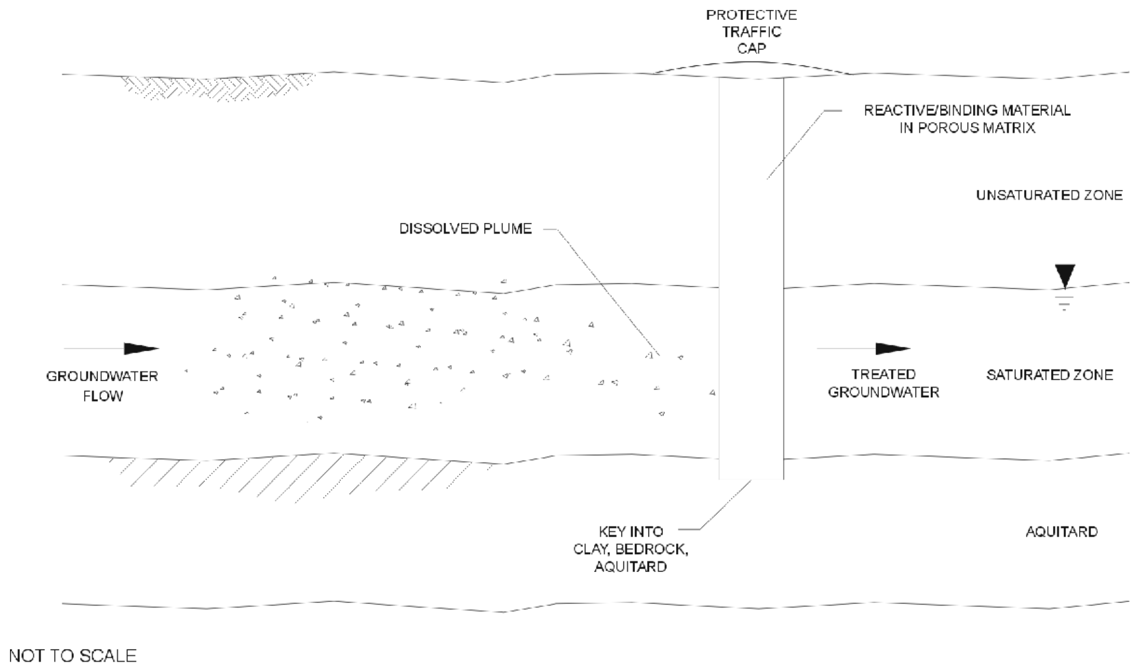


FIGURE 17-1. PASSIVE TREATMENT WALLS

17-3. Hazard Analysis

Principal unique hazards associated with passive treatment walls, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Equipment Hazards*.
Description. During installation of sheet pile walls, workers may be seriously injured or killed by heavy equipment such as front-end loaders, cranes, and pile drivers.

Control. Controls for equipment hazards include:

- Use spotters, and require and maintain backup alarms on all heavy equipment.
- Approach operating equipment from the front and within view of the operator. Do not proceed into the swing radius of equipment until presence is clearly acknowledged by the operator.

CONTROL POINT: Construction

(2) *Utility Hazards*.
Description. During the excavation of the trench, prior to the installation of the passive treatment wall, fire or explosion hazards may exist if excavation equipment ruptures an underground utility such as electrical or gas lines.

Control. Controls for utility contact hazards include:

- Establish and document utility clearances. Contact local utilities and public works authorities to determine the locations of all utilities. When there is any doubt or uncertainty, conduct a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of utilities. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to supervise when raising equipment.
- Maintain safe distances as recommended in EM 385-1-1, Section 11.

CONTROL POINT: Construction

(3) *Trench Hazards*.
Description. Entry into an unshored or unbenched trench poses a safety hazard of trench wall collapse. An inhalation hazard exists if the trench serves as an accumulation point for off-gassing of toxic materials (such as chlorinated solvents) from the soil.

Control. Controls for trench hazards include:

- Inspect excavations daily with a competent person. See EM 385-1-1, Section 25.
- Shore walls to prevent collapse according to the requirements of 29 CFR 1926.650-652.
- Provide emergency egress to workers entering the excavations and trenches at intervals that do not exceed 25 feet.
- Consider trench entry as a confined-space entry (see 29 CFR 1910.146).
- Train workers in confined space hazards and on safety procedures to be employed in confined space entry, including engulfing hazards from unshored trench walls.
- Develop a pre-entry confined space permit. Implement a confined-space entry program to assess the hazards.
- Test the atmosphere within the excavation to determine the level of airborne contaminants and oxygen prior to entry.
- Use engineering controls such as forced ventilation to eliminate any hazardous atmosphere detected through the pre-entry atmosphere testing. PPE respiratory protection should be considered a last option for working in trenches.

CONTROL POINT: Construction

(4) *Steam Pressure Washing*.

Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:
- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(5) *Respirable Quartz Hazard.*
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline quartz content.

Control. Controls for respirable quartz include:
- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air-purifying respirator equipped with N, R or P100 particulate air filters.
- Train workers in the potential inhalation hazards associated with crystalline silica exposures.

CONTROL POINT: Design, Construction, Operations

(6) *UV (Ultraviolet) Radiation.*
Description. During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts that may snag the worker and draw him into a danger zone. All UV skin barrier creams should be pre-ap-

proved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.

- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(7) *Electrocution.*
Description. Personnel may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for electrocution include:

- Note overhead power line location, either existing or proposed, in the predesign phase.
- Keep all lifting equipment, such as cranes, forklifts, and pile drivers at least 10 feet from a power line and according to Occupational Safety and Health
- Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.

CONTROL POINT: Design, Construction, Operations

(8) *Traffic Hazards*.
Description. During field activities, equipment and workers may come close to public vehicular traffic. Also, equipment may need to cross or use public roads. The general public may be exposed to traffic hazards and the potential for accidents.

Control. Controls for traffic hazards include:

- Post warning signs according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."
- Develop a traffic management plan before remediation activities begin to help prevent accidents. EM 385-1-1, Section 21, provides plan details.
- Use traffic spotters donned in highly visible hazard vests.

CONTROL POINT: Design, Construction, Operations

(7) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: “Emergency Eyewash and Shower Equipment” for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(8) *Design Field Activities.*
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from predesign field activities include:

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Contaminants (Soil).*
Description. Workers may be exposed via inhalation, ingestion, or dermal exposure to contaminants during trench excavation. Dusts and volatile organic compounds (VOCs) entrained with waste materials may become airborne during the excavation, exposing workers to the contaminants.

Control. Controls for contaminants in the soil include:

- Place the trench outside the area of contamination to the extent practical.
- Apply water to control airborne dusts.
- Use personal protection equipment (PPE) such as an air-purifying respirator with organic vapor cartridges to help control worker exposure.
- Train the workers in both the potential contaminated dust hazards and the proper use of the controls, including the PPE.

CONTROL POINT: Design, Construction, Operations

(2) *Treatment Wall.*
Description. Workers may be exposed to materials such as iron pyrites, coal (dust), metal chelators, and microbes used as the treatment medium during installation of the treatment wall. In addition, metals or other contaminants in the wall material may pose a higher risk during replacement or maintenance operations.

Control. Controls for chemicals in treatment walls include:

- Wet materials periodically to control airborne dust.
- Use PPE selected by a qualified health and safety professional based on the contaminants in the wall matrix. For example, for chelated metals, use an air-purifying respirator with N, R or P95 particulate air filters, chemically inert coveralls, and chemically inert gloves (e.g., nitrile).
- Review and follow handling procedures contained in each product's MSDS.

CONTROL POINT: Construction, Maintenance

c. *Radiological Hazards*.

No unique hazards are identified.

d. Biological Hazards.

No unique hazards are identified.

Chapter 18
Chemical Reduction/Oxidation

18-1. General

The process of reduction/oxidation (redox), its applications, and resulting waste streams are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

18-2. Technology Description

a. Process.

Redox reactions chemically convert hazardous contaminants to less hazardous or non-hazardous compounds that are more stable, less mobile, less toxic, or inert. This is accomplished by chemical reactions that involve electron transfer (and usually other chemical groups) from one reactant (oxidized compound) to another compound (reduced compound).

As shown in Figure 18-1, excavated soil is screened and oversized rejects are combined with the sludge for disposal. Water is added to the screened soil, and the slurry is transferred to a reactor, where reagents (such as ozone, hydrogen peroxide, hypochlorites, chlorine, or chlorine dioxide) are added to react with targeted constituents. The reagent/soil mixture is transferred to a separator, where excess reagent is removed and recycled back into the reactor. The treated soil is washed and dewatered. Water from the dewatering process is recycled back to the soils washer. The dewatered sludge is combined with oversized rejects for disposal.

b. Applications.

In addition to soils treatment, chemical redox is an established technology for the disinfection of drinking water and wastewater. Ultraviolet (UV) oxidation is an example of a UV-stimulated version of this treatment approach. The technology can be applied to both liquid and solid wastes.

The target contaminants for redox reactions are usually inorganic species, especially cyanide or chromium-containing wastes, but can also be used for phenols and other readily oxidized organics. The technology is less effective for non-halogenated volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), fuel hydrocarbons, pesticides, and high contaminant concentrations. Oil and grease in the waste should be minimal to prevent excessive side reactions and increase process efficiency.

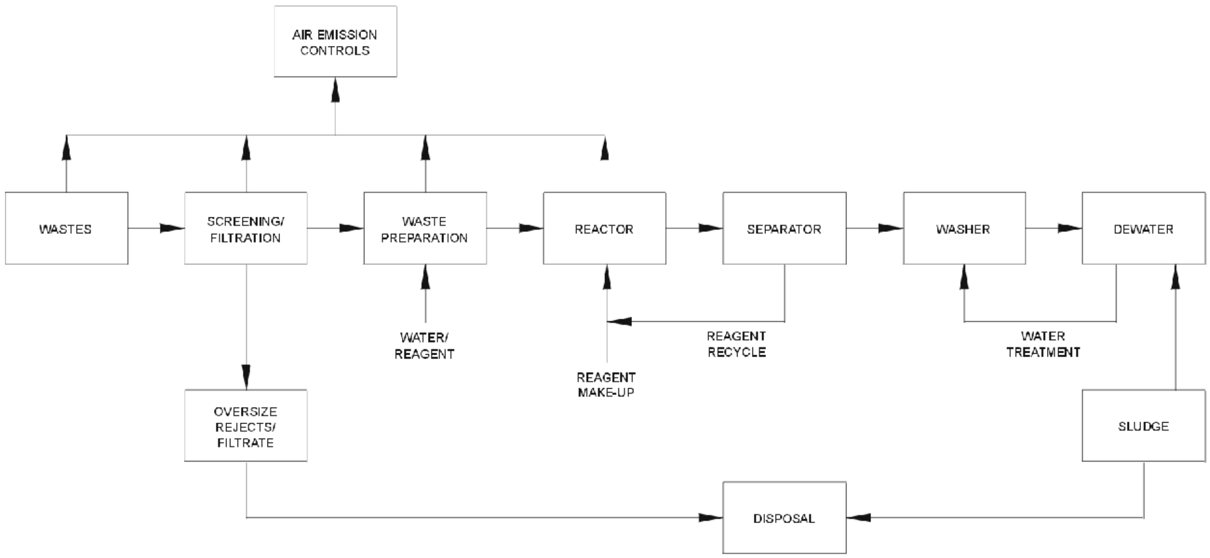


FIGURE 18-1. TYPICAL PROCESS FOR CHEMICAL REDUCTION/OXIDATION PROCESS

c. Resulting Waste Streams.

The technology produces three streams that may require additional handling:

- Emissions from soil excavation (requires additional treatment).
- Effluent water from dewatering (may be recycled or may be discharged after treatment).
- Sludge and oversized rejects (may require additional treatment prior to disposal).

If the process is not optimized, formation of intermediate contaminants or incomplete oxidation (such as organic acids or aldehydes) may occur.

For additional information on similar processes, see Chapters 15 and 16.

18-3. Hazard Analysis

Principal unique hazards associated with chemical reduction/oxidation, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Incompatible Treatment Materials and Reagents.*
Description. Because of the reactive nature of the chemical reagents (e.g., sulfuric acid, ozone, hypochlorites), system components must be compatible with the reagents, waste stream, and treatment byproducts. System incompatibility may result in fires, system over-pressurization, environmental release, or an explosion.

Control. Controls for incompatible treatment materials and reagents include:

- Train operators in the site and process-specific chemical and physical hazards that will be encountered.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Use liquid transfer equipment (pumps, piping, pipe fittings, valves, and instruments) that are chemically resistant to the liquid streams. Use EM 1110-1-4008, "Liquid Process Piping," for materials selection.
- Identify all tanks, drums, and chemical transfer equipment in accordance with 29 CFR 1910.1200 requirements.
- Utilize automatic alarm systems (e.g., pH, temperature, pressure, reactant off-gas concentration detectors) with sensors installed at critical points throughout the system to monitor all phases of the reactions.
- Implement appropriate chemical storage and handling procedures to prevent contact or mixture of incompatible reagents or materials.
- Use secondary containment systems for drums containing hazardous chemicals exceeding reportable quantities, and recommend use of secondary containment systems for hazardous chemicals not exceeding reportable quantities but that continue to pose a risk to the workers or environment.
- During construction, the design engineer must authorize all equipment and material substitutions.
- Train operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.

CONTROL POINT: Design, Construction, Maintenance

(2) *Uncontrolled Reactions*.
Description. Improper chemical handling, e.g., mixing concentrated acids or bases without sufficient cooling or dilution, may generate excessive heat and pressure within the system, resulting in out-of-control reactions and fire or explosions.

Control. Controls for reactions include:

- Train operators in proper chemical handling and storage procedures and potential associated chemical reactions and effects.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Monitor the injection of reagents.
- Monitor the process temperatures at critical points.
- Provide for automatic feed shutdowns at preset temperatures.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, and decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.

- Locate emergency eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(3) *Flushing Agents*.
Description. Treatment and cleaning reagents may be incompatible. Cleaning reagents are often used to flush the system prior to startup. These reagents can be incompatible with any residual treatment reagents (e.g., chlorine, hypochlorites) left in the system. The reaction of these chemicals may cause heat and pressure buildup within the system, possibly resulting in an explosion.

Control. Controls for flushing agents include:

- Train the operators on the process chemistry that will be used, including the heat of reaction, handling, and potential chemical incompatibilities.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Train the operators in emergency procedures to implement in the event of a catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate, install, and maintain emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Operations, Maintenance

(4) *Plugged Waste Lines*.
Description. Sludge from the chemical reduction/oxidation process may plug pipes if the rate of precipitation exceeds the rate of sludge removal. Plugged lines may result in an explosion from system over-pressurization or fire if the pump motor heats.

Control. Controls for plugged waste lines include:

- Train the operators in the chemistry involved in the sludge system operation, in the heat of reaction of the chemical reactions, in handling and transferring sludge.
- Use auger-equipped waste lines or flow controls.
- Install alarms to alert operators of system over-pressurization.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting and neutralizing chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency sludge system isolation and shutdown procedures.
- Locate, install, and maintain emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(5) *Tank Mixing Equipment*.
Description. Tank mixing equipment may splash chemical reagents (e.g., acids or hydrogen peroxide) or entangle workers who come in contact with propellers or shafts.

Control. Controls for mixing equipment include:

- Train operators in the characteristics of the tank mixing equipment, in all potential pinch points and rotating part or splash exposures from the equipment, in the chemistry involved, in the heat of reaction of the chemical, and chemical handling or transfer.
- Use tanks and mixers designed to reduce or prevent splashing or entanglement with shafts or motors.
- Implement lock-out/tag-out procedures when performing maintenance activities on the mixers.
- Train workers in potential chemical contact hazards and control measures (see 29 CFR 1910.1200). Train the operators in emergency procedures in the event of a chemical splash exposure or physical entanglement, in life saving first aid procedures including emergency de-energizing equipment, halting and neutralizing chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency sludge system isolation and shutdown procedures.
- Install, locate, and maintain emergency eyewash/showers at critical points with easy access to the mixing tank equipment. (See ANSI Z 358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(6) *Electrical Shock*.
Description. Unprotected electrical cables and lines can be damaged by personnel, vehicles, or heavy objects that may split or tear protective insulation. Exposure to electricity in wet or damp areas can result in electrical shock, severe burns, or death.

Control. Controls for electrical shock hazards include:

- Train operators in electrical systems used and potential electrocution hazards.
- Use ground-fault protected electrical systems in areas that could become wet or damp. Electrical system design must follow “National Electrical Code” NFPA 70 and UFGS 16415A, “Electrical Work, Interior.”
- Use grounded or GFIC-protected equipment if required by EM 385-1-1, Section 11, or NFPA 70.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Never allow the use of unapproved wiring or temporary wiring, such as electrical cords, during maintenance work where contact with water, wet or damp surfaces could be encountered.

- Where possible bundle lines and secure a safe area by using cones, flagging, or mesh fencing to alert workers. Mark bundles with reflective tape for 24 hour per day operations.
- Do not bundle electrical lines with pressure lines.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: “Emergency Eyewash and Shower Equipment” for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(8) *Confined Spaces*.
Description. Workers who enter permit-required confined spaces, such as process vessels, for inspection and maintenance can encounter serious hazards, including asphyxiation from the lack of oxygen. exposure to toxic chemical vapors and gases; or poisonous gases from the redox reagents such as ozone, hydrogen peroxide, hypochlorites, chlorine, or chlorine dioxide, and treatment contaminants such as cyanide, or chromium-containing wastes, phenols and other readily oxidized organics, and engulfment/entrapment by the treatment slurry.

Control. Controls for confined-space entry include:

- Thoroughly train operators and workers in confined space hazards and safety procedures employed in confined spaces.
- Design redox vessels to maximize ease of operation, cleaning, and maintenance to include accessible, adequately sized access doors or entry ports, and to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Develop a confined space permit program that includes hazard assessment requiring atmospheric testing inside the vessels both prior to and throughout the work planned. (See 29 CFR 1910.146.)
- Ventilate the vessel interior prior to and during entry to eliminate the oxygen-deficient, toxic, or poisonous atmosphere. (The treatment slurry in the redox vessels may exhibit a measurable oxygen deficit creating a oxygen-deficient atmosphere.)

- Complete the vessel manufacturer's shutdown procedures and lock-out/tag-out of associated pumping or electrically energized systems prior to entry. Eliminate possible buildup of static electricity.
- Use air-supplied respirators to control inhalation exposures to toxic chemicals and poisonous gases to prevent any potential for asphyxiation in situations where only constant mechanical ventilation prevents the buildup of a toxic or inert gas environment.

CONTROL POINT: Design, Construction, Operations, Maintenance

(9) *Respirable Quartz Hazard*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard during the excavation phase of the treatment process. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet soil periodically with water to minimize worker exposure. Wetting of soil may require additional controls to deal with resulting water, ice, mud, etc. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air purifying respirator equipped with N, R or P100 particulate air filters.
- Train workers in the potential inhalation hazards of crystalline silica dust exposures.

CONTROL POINT: Design, Construction, Operations, Maintenance

(10) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Chemical Reagents (Use and Storage).*
Description. Treatment workers can be exposed to toxic and reactive chemical reagents such as ozone and hydrogen peroxide. Storage requirements may include heat and moisture content, ambient temperature, or relative humidity. The reagents may deteriorate and react under certain conditions to generate heat and pressure within their storage containers. Mixing incompatible reagents in the reaction tanks may generate toxic vapors (such as hydrogen or chlorine) or generate sufficient heat to ignite combustible materials.

Control. Controls for chemical reagents include:

- Label all tanks and piping systems.
- Store all chemicals and redox reagents in accordance with NFPA, manufacturer, and Material Safety Data Sheet requirements. Do not store a greater chemical inventory than can be used within the acceptable storage period.
- Use temperature and moisture control in storage areas.
- Segregate storage areas by dikes. Ensure dikes do not commingle at drains.
- Use spill control equipment.
- Determine reagent compatibility prior to placement in storage and following their introduction into the system.
- Use the Buddy System and mix all chemical reagents in reaction tanks in accordance with NFPA and manufacturers requirements, employing all prescribed personal protection equipment (PPE), including respirators, face shields, and chemical splash resistant (rubber) suits.
- Install, and maintain emergency eyewash/showers at critical points with easy access to the mixing tank equipment and the chemical storage areas. (See ISEA Z 358.1 – 1998.)
- Consult Material Safety Data Sheets to determine the specific chemical hazards associated with the reagent chemicals and train workers in hazard avoidance techniques (see 29 CFR 1910.1200). Ensure MSDSs are current and meet all OSHA requirements. MSDSs over 3 years old should be renewed.
- Consult NIOSH and other recognized research agencies to augment weak sections of MSDSs, particularly the PPE section.
- Train the operators in the operating characteristics of the tank mixing equipment, splash exposures from mixing reagents, in the chemistry involved, in the heat of reaction and toxicity of the chemical reactions, and handling and transferring the chemicals.
- Train the operators in emergency procedures in the event of a chemical splash or toxic vapor exposure, in life saving first aid procedures including emergency de-energizing equipment, halting and neutralizing chemical reactions, extracting, decontaminating, and stabilizing victims, and in emergency reaction tank system isolation and shutdown procedures.

- Ensure that a Spill Prevention Containment Control (SPCC) Plan is prepared and workers understand how it applies to their job duties.
- Check local and state requirements for the SPCC Plan. Ensure that fire and emergency agencies are aware of the chemical hazards and have access copies of the SPCC as required.

CONTROL POINT: Design, Operations, Maintenance

(2) *Chemical Reagent Exposure*.
Description. Chemical reagents are listed in CEGS 11242, "Chemical Feed Systems." Workers may be exposed to these chemical reagents or to byproducts of chemical reduction/oxidation via the inhalation/ingestion/dermal exposure routes. Materials may be toxic (such as carbon monoxide and chlorine) or explosive (as with hydrogen).

Control. Controls for chemical reagent exposure include:

- Train operators in the characteristics of the mixing equipment, potential splash hazards from mixing reagents, in the chemistry involved, in the heat of reaction and toxicity of the chemical reactions, and in handling and transferring the chemicals.
- Train the operators in emergency procedures in the event of a catastrophic release, chemical splash or toxic vapor exposure, in life saving first aid procedures including emergency de-energizing equipment, extinguishing, halting and neutralizing chemical reactions, extracting, decontaminating, and stabilizing victims, and in emergency reaction tank system isolation and shutdown procedures in accordance with the SPCC Plan.
- Install, and maintain emergency eyewash/showers at critical points with easy access to the mixing tank equipment and the chemical storage areas. (See ANSI Z 358.1 – 1998.)
- Pressure test all piping connections.
- Consult Material Safety Data Sheets to determine the specific health hazards associated with the specific chemical reagents utilized in the process. Material Safety Data Sheets describe the specific personal protective equipment (PPE) required and appropriate neutralization measures in the event of a spill or exposure.
- Test the atmosphere inside tanks prior to each entry (see Paragraph 18-3*a*(8) of this chapter).
- Ventilate the system to prevent the accumulation of hydrogen, chlorine, or other toxic and explosive gases.
- Equip areas where byproducts, such as carbon monoxide, chlorine, and hydrogen, are generated with local exhaust ventilation. If the generation of ozone, CO, Cl_2, or hydrogen is significant and cannot be properly exhausted, install carbon monoxide or hydrogen monitors with visual and audible alarms to alert operators.

CONTROL POINT: Design, Operations, Maintenance

(3) *Improper Chemical Amounts*.
Description. Effluent water may contain significant concentrations of reagents that can cause skin and eye damage. In instances where too much chemical has been used, the residual chemical can cause reactions and high temperatures. The under-use of chemicals can cause incomplete process reactions that may cause over-pressurization of the system and subsequent leaks.

Control. Controls for chemical amounts include:

- Train the operators in the characteristics of over- or under-mixing reagents, in the chemistry involved, in the heat of reaction and toxicity of the chemical reactions resulting from improper mixing, and in handling and transferring the chemicals.
- Use oxidation or reduction mixing/retention tanks with monitors and alarms for chemical dosages or operational temperatures that exceed preset limits.
- Ensure that a Design Analysis includes failure-mode analyses. Include control logic in facility design to shut down chemical transfer systems under upset conditions. Ensure that possible failures and errors trigger shut downs in the safest mode possible, even if it means equipment damage.
- Train the operators in emergency procedures in the event of a dangerous increase in the rate of reaction and temperature or pressure rise, toxic vapor release, in life saving first aid procedures including emergency de-energizing the tanks or transfer equipment, halting and neutralizing chemical reactions, extracting, decontaminating, and stabilizing victims, and in emergency reaction tank isolation and shutdown procedures.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) *Chemical Reagents (Compatibility).*
Description. Flushing the system prior to startup may cause chemical reactions and increased pressure with the reagents during system operation.

Control. A control for chemical reagents includes:

- Review the compatibility of the chemical reagents used in system operation prior to addition and mixing of these reagents.
- Make Material Safety Data Sheets, in accordance with ANSI 2400.1, available to operators. Ensure that MSDSs are current and meet all OSHA requirements. MSDSs over 3 years old should be renewed.
- Use NIOSH and other authorized research agencies to augment weak sections of MSDSs, especially the PPE section.
- Train operators in the characteristics of the mixing reagents, in the chemistry involved, in the heat of reaction and toxicity of the chemical reactions resulting from improper mixing, handling and transferring the chemicals.

CONTROL POINT: Design, Operations, Maintenance

(5) *Chemical Exposure From Equipment Failure*.

Description. Reactive chemicals used in the process may corrode pipes, gaskets, and connectors, causing leaks and worker exposure. Workers may be exposed to reactive chemical reagents, including hydrogen peroxide, hypochlorites, and chlorine.

Control. Controls for chemical exposure resulting from equipment failure include:

- Ensure that possible failures and errors trigger shut downs in the safest mode possible, even if it means equipment damage.
- Design/construct process equipment with compatible materials. Use EM 1110-1-4008, “Liquid Process Piping,” for appropriate selection of materials.
- Feed reagent chemicals automatically into the system via a closed piping system.
- Wear proper PPE for handling the reagents if manual addition is required.
- Train workers in potential chemical hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(6) *Contaminants (Screening Process).*
Description. When screening contaminated materials, employees may be exposed, via dermal or inhalation routes, to soils, sludge, dust, or oversized rejects.

Control. Controls for exposure to contaminants include:

- Use water during soil screening to minimize the amount of dust generated.
- Perform dust monitoring if necessary to determine when respiratory protection, such as air-purifying respirators equipped with N, R or P100 or N, R or P95 particulate air filters, should be donned.
- Wear chemical-resistant coveralls and gloves (match compounds with manufacturers charts on break through times [BTT] and permeation rates) to prevent direct contact with the contaminated soils. Such controls prevent workers from carrying any contamination home on their clothing.
- Ensure work rules include hygiene policies and requirements.
- Ensure that designs include hygiene facilities to meet these requirements. Facilities may include portable showers, change areas and lockers, hand and face wash areas, boot wash areas, and contaminants clothing and PPE drop-off stations.
- Ensure that clean PPE, such as respirators and suits, are stationed for easy access before entering dust or chemical hazard areas.

CONTROL POINT: Operations

c. Radiological Hazards.

Radioactive Devices.

Description. Fire ands smoke detection devices, fluid level devices and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 19
Liquid-Phase Carbon Adsorption

19-1. General

The process of liquid-phase carbon adsorption and its applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

19-2. Technology Description

a. Process.

Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous waste streams. In liquid-phase carbon adsorption, contaminated water is pumped through activated carbon contained in a vessel or series of vessels and the dissolved contaminants are adsorbed. When the contaminants saturate the carbon, it is regenerated in place, removed and regenerated off site, or removed and sent off-site for disposal. Often, carbon used for explosives or metals-contaminated water cannot be regenerated and will require off-site disposal. See Figure 19-1.

Each chemical has a different affinity for the activated carbon, depending on its chemical and physical properties, such as its configuration. Therefore, each chemical is adsorbed to a different degree (and mass ratio). Adsorption isotherms for many organic chemicals are available from manufacturers of the activated carbon. These isotherms predict what weight of the chemical will be adsorbed at standard equilibrium conditions at specified temperatures per unit weight of carbon.

The treatment is not destructive, but binds the contaminants to the carbon and concentrates them in the carbon. The used carbon can then be readily processed or transported for post-treatment destruction of the target chemicals.

b. Application.

The effectiveness of activated carbon is a function of the individual chemicals being treated, their combination with other chemicals, residence time, temperature, and other factors. Activated carbon is most effective in adsorbing non-polar molecules, such as aromatic hydrocarbons. Chlorinated volatile organic compounds are generally not adsorbed as well as their non-chlorinated hydrocarbon analogues. The method is particularly effective on multi-ring compounds, such as aromatic hydrocarbons (PAH) and chlorinated biphenyls (PCB), which are strongly adsorbed.

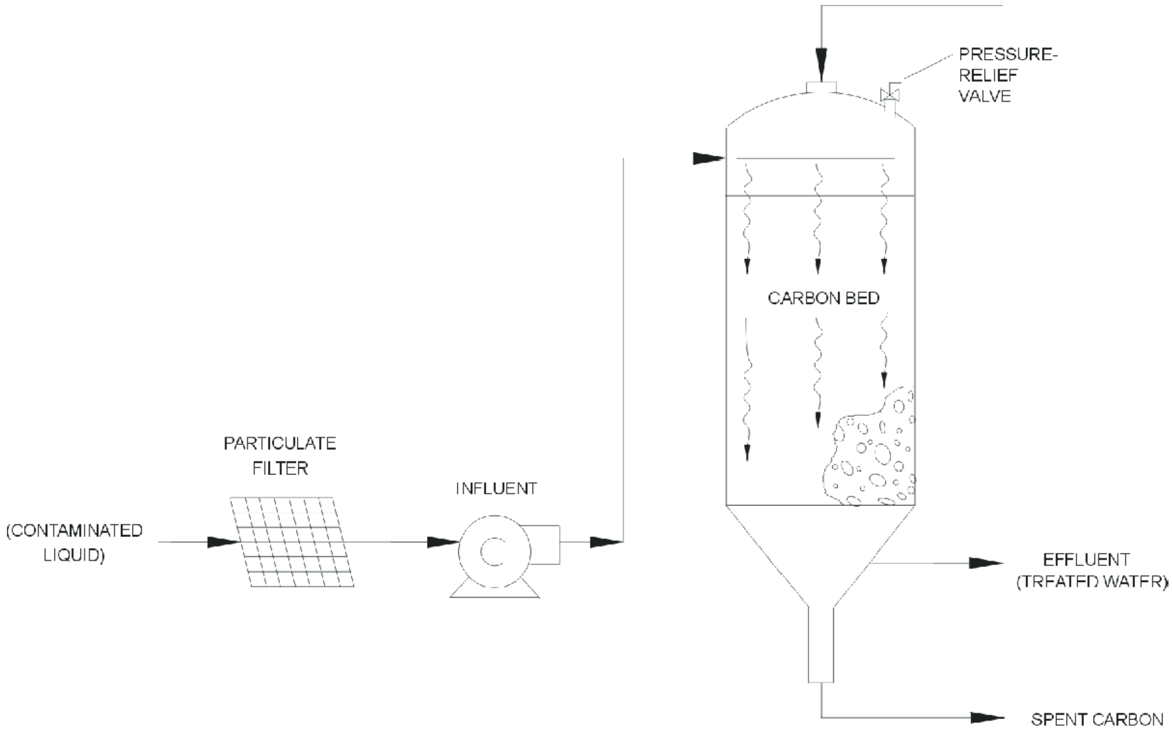


FIGURE 19-1. LIQUID-PHASE CARBON ADSORPTION

The treatment is less effective for short, volatile organic compounds (VOC) and chlorinated VOCs, such as alkanes and alkenes, which are not strongly adsorbed. Oxygenated solvents and very small organic molecules (e.g., acetone, methyl ethyl ketone (MEK) and vinyl chloride) may not be adsorbed to any useful degree. For metals, the adsorption ability of the carbon is limited.

This technology is best suited to streams with low concentrations of the organics. Streams with relatively high organic loadings will require more carbon per unit of flow than more dilute streams.

19-3. Hazard Analysis

Principal unique hazards associated with liquid-phase carbon adsorption, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Confined Spaces.*
Description. Entering the carbon bed tanks for activities such as inspection, repair, and maintenance may constitute a confined-space entry. Hazards associated with entry into confined space include asphyxiation from the lack of oxygen, exposure to toxic contaminants and poisonous gases, inhalation of fine

carbon particles, which may carry microbes, and engulfment/entrapment by the carbon.

Control. Controls for confined spaces include:

- Design the carbon bed tanks to maximize ease of operation and maintenance and minimize the frequency, duration, and extent of cleaning and maintenance that will be required.
- Implement a confined-space entry program. Develop a pre-entry confined space permit (see 29 CFR 1910.146) to include atmosphere testing inside the tanks both prior to entry and throughout the work.
- Ventilate the tank prior to and during the confined space entry. Activated carbon in the confined vessels can exhibit a measurable oxygen demand, which can create the oxygen-deficient atmosphere.
- Complete the carbon bed tank manufacturer's shutdown procedures and lock-out/tag-out of associated pumping or electrically energized systems prior to entry. Eliminate possible buildup of static electricity.
- Use air-supplied respirators to control inhalation exposures to toxic chemicals and prevent any potential for asphyxiation in situations where constant mechanical ventilation does not adequately prevent the buildup of a toxic or inert gas.

CONTROL POINT: Operations, Maintenance

(2) *Fire/Explosion (Spent Carbon).*
Description. Spent carbon used to remove explosive or reactive contaminants may pose a potential explosion and fire hazard during carbon regeneration or removal from the tank.

Control. Controls for spent carbon include:

- Do not regenerate carbon used to remove potentially explosive contaminants (e.g., explosives, highly volatile organic chemicals). Heat used to regenerate the carbon may ignite or explode the adsorbed material.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Thoroughly train operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, decontaminating, and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(3) *Fire/Explosion (Over-Pressurization).*
Description. Carbon beds are normally operated under pressure. Over-pressurization may result in explosion or fire from overheating of the pump motor.

Control. Controls for over-pressurization include:

- Use experienced operators and supervisors who are trained in operating carbon bed and waste stream transfer systems.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Hydro test systems in accordance with UFGS 11225A, "Downflow Liquid Activated Carbon Adsorption Units," before the system is put into operation.
- Add warnings for contents under pressure.
- Train operators in emergency procedures in the event of catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, decontaminating, and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction

(4) *Electricity*.
Description. Electrical systems in wet or damp areas can cause electrical shock, burns or death.

Control. Controls for electrical shock include:

- Verify that drawings indicate hazardous area classifications as defined in NFPA 70, Chapter 5, sections 500.1 through 500.10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11, NFPA 70, and UFGS 16415A, "Electrical Work, Interior."
- Use grounded equipment or equipment with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70.
- Perform all electrical work according to codes and under the supervision of a state licensed master electrician.
- Never allow the use of ungrounded, temporary wiring during maintenance work or wiring that is not approved for contact with water, or use in wet or damp conditions.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) *Life Safety (Treatment Buildings).*
Description. Treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, or emergency lighting systems.

Control. Controls for treatment buildings include:

- Meet the following construction requirements for permanent and semi-permanent treatment buildings: ANSI 58.1, "Minimum Design Loads for Buildings and Other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code," and the "Uniform Building Code."

- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, Base Realignment and Closure (BRAC), or Formerly Used Defense Sites (FUDS) projects.

CONTROL POINT: Design, Operations

(6) *Fire*.
Description. Some of the chemicals in the waste stream may present a fire hazard during treatment; for example, hydrogen sulfide may cause carbon bed fires owing to the high heat of adsorption or peroxides may auto-ignite.

Control. A control for fire includes:

- Use experienced operators and supervisors. Train them in both the flammability/reactivity characteristics of the waste feed liquid and possible reaction outcomes when in contact with carbon, the exposure hazards of the waste feed, and the design operating parameters of the carbon beds.
- Audit and apply proper quality assurance/quality control (QA/QC) to assure the pretreatment and carbon bed systems are operated as designed.
- Operate the system and waste feed system within design parameters.
- Do not allow the waste stream flow to exceed the capacity of the system.
- Monitor and control temperatures of carbon beds continuously.
- Select an alternate technology during design if the known or anticipated contaminants pose an unmanageable threat of fire.
- Thoroughly train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design

(7) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: “Emergency Eyewash and Shower Equipment” for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(8) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Waste Chemical Exposure (Tank/Pipe Corrosion).*
Description. Workers may be exposed to waste chemicals from system leaks when activated carbon corrodes tanks and piping systems that are made from carbon steel or other corrodible material incompatible with the waste stream to be treated.

Control. Controls for chemical exposure include:
- Do not use carbon steel to contain activated carbon.
- Use stainless steel, thermoplastic, or other chemically inert tank materials.
- Consult EM 1110-1-4008, “Liquid Process Piping,” and UFGS 15200A, “Liquid Process Piping,” for appropriate materials for pumping various fluids.
- Paint, coat, or line tank interiors to prevent contact between activated carbon and corrodible substructures.
- Install spill or leak detection instruments, including alarms if necessary.
- Include drip pans or receivers to monitor leaks and sources of potential exposures where leaks may occur.
- Locate, install, and maintain emergency eyewash and showers at critical points throughout the system. (See ANSI Z 358.1 – 1998.)
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Construction, Maintenance

(2) *Plugged Waste Lines*.
Description. Sludge from the waste may plug transfer lines or piping at slow flow velocities. Plugged waste lines may cause tanks to increase pressure, possibly causing a leak that exposes workers to waste material.

Control. Controls for plugged waste lines include:

- Include adequate flow controls and pipe velocities in design.
- Use filters to remove solids prior to carbon bed treatment.
- Implement a routine system operation inspection.

CONTROL POINT: Design, Operations, Maintenance

(3) *Carbon Holding Tanks/Drums*.
Description. Carbon holding tanks or drums may leak or spill over into the surrounding areas, resulting in worker exposure during operations or loading and unloading of carbon.

Control. Controls for carbon holding tanks/drums include:

- Equip holding tanks or drums with adequate spill containment.
- Install spill or leak monitors and alarms if necessary.
- Train workers in proper handling techniques and the hazards associated with handling and exposure to new or spent carbon.

CONTROL POINT: Design, Operations, Maintenance

(4) *Water Transfer Equipment*.
Description. Water transfer system equipment (pumps, piping, pipe fittings, valves, and instruments) in contact with contaminated liquids can corrode or dissolve to a point of failure and cause facility damage or worker exposure to waste chemicals.

Control. Controls for water transfer equipment include:

- Use water transfer system equipment fabricated from materials that are chemically resistant to the contaminants.
- Consult EM 1110-1-4008, “Liquid Process Piping,” and UFGS 15200A, “Liquid Process Piping,” for appropriate pumping materials.
- Include containment drip pans or receivers where leaks may occur.
- Install spill or leak detection instruments.
- Implement a routine system operation inspection.

CONTROL POINT: Design, Construction, Maintenance

(5) *Plugged Carbon Bed (Biological Growth).*
Description. Under certain operating conditions, biological growth can occur inside carbon beds. This growth may foul or plug the carbon bed flow pores, which may cause an increase in system pressure. The pressure may cause leaks that expose workers to chemicals.

Control. Controls for biological growth include:

- Train operators on system parameters in relation to the waste stream being treated.

- Develop and implement QA/QC procedures to optimize and maintain optimal performance of the carbon beds.
- Periodically feed biocides into the system.
- Backwash with biocides or bleaches to minimize or remove the biological growth.
- Replace, regenerate, or dispose of the carbon.

CONTROL POINT: Maintenance

c. Radiological Hazards.

(1) *Radioactive Material*.
Description. In some geological settings, dissolved naturally occurring radioactive materials (NORM) or radioactive contaminants may be drawn up with the groundwater. Depending on the chemical form, the radioactive component may be trapped by the activated carbon and concentrated in the filter to a point where a radiation hazard may develop.

Control. A control for radioactive material includes:

- Consult a qualified health physicist if elevated levels of NORM or radioactive contaminants are in the groundwater.

CONTROL POINT: Maintenance

(2) *Radioactive Devices.*
Description. Fire and smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 20
Vapor-Phase Carbon Adsorption

20-1. General

This chapter is organized into two main sections. The first describes the process and application of vapor-phase carbon adsorption and the second contains a hazard analysis with controls and control points listed.

20-2. Technology Description

a. Process.

Activated carbon, contained in a reaction vessel, can be used to adsorb organic compounds from an air stream. The volatile organic compounds (VOCs) dissolved in the air stream are adsorbed from the stream and the effluent discharged to the atmosphere. In general, based on mass of activated charcoal used, vapor-phase canister systems adsorb more hydrocarbon mass than liquid based systems (see Chapter 19). Therefore, vapor systems are often used in conjunction with air stripping processes to treat VOC-contaminated water. Vapor-phase carbon adsorption is also used in conjunction with air stripping and soil vapor extraction (SVE) to remove compounds of concern from the vapor stream prior to its release to the atmosphere. See Figure 20-1.

In these systems, adsorbed chemicals are not altered chemically, only concentrated in the carbon media, which may require additional post-treatment destruction to meet final disposal requirements.

b. Applications.

This technology is applicable to the removal of VOCs and some semi-volatile organic compounds (SVOCs) from vapor streams. It is not suitable for removing compounds that cannot be readily volatilized. Each chemical has a different affinity for the activated carbon, depending on that chemical’s properties and configuration; thus, each chemical is adsorbed to different degrees (and mass ratio).

Adsorption isotherms for many organic chemicals are available from the activated charcoal manufacturers. These isotherms predict the weight of chemical adsorbed at standard equilibrium conditions per unit weight of carbon.

The effectiveness of treatment is a function of the chemicals being treated, chemical mixture (including water), residence time, temperature, and other factors. Activated carbon treatment is more effective for non-polar molecules and aromatic hydrocarbons than chlorinated analogues. Multi-ring compounds are strongly adsorbed so this method is particularly effective for polyaromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Treatment of short alkanes and alkenes, oxygenated solvents, and other small organic molecules (e.g., acetone, methyl ethyl ketone (MEK) and vinyl chloride) is significantly less effective.

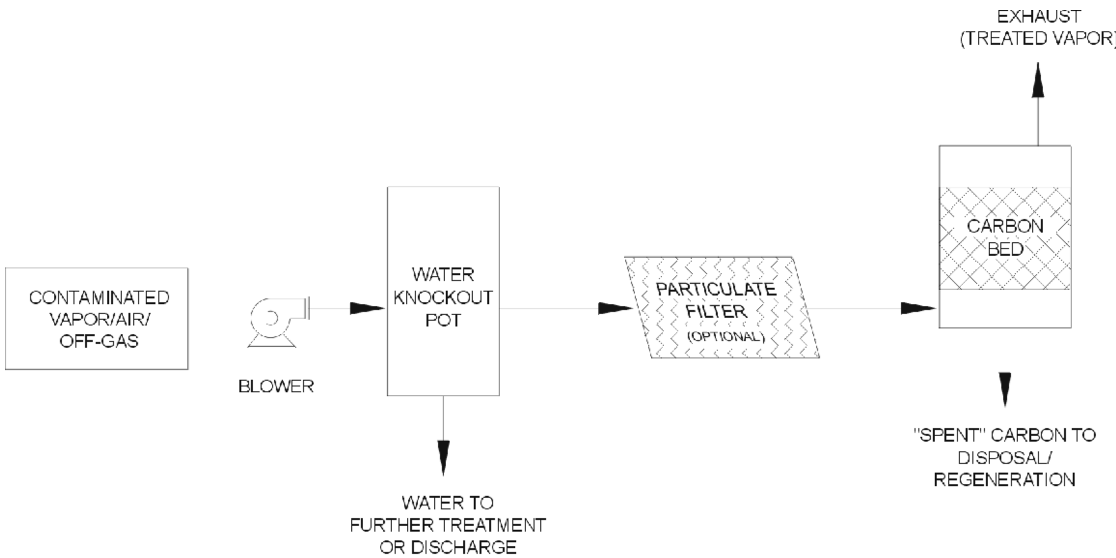


FIGURE 20-1. VAPOR PHASE CARBON ADSORPTION

Air streams that contain compounds that may form peroxides or otherwise auto-ignite are of particular concern when using vapor-phase activated carbon adsorption. Other compounds, such as hydrogen sulfide, which are adsorbed exothermically, may generate enough heat to ignite the activated carbon beds.

20-3. Hazard Analysis

Principal unique hazards associated with vapor-phase carbon adsorption, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire (Waste Components).*
Description. Fires may result when the treatment stream contains reactive compounds or chemicals that adsorb exothermally to the carbon, e.g., hydrogen sulfide or peroxides that may auto-ignite. Activated carbon fires occur when it is adsorbing any easily oxidizable organic solvents, especially carbonyls such as ketones. Activated carbon is especially prone to fires when 1) carbon with a high activity or ash content is used, 2) the moisture content of the carbon is critically reduced (e.g., 50%) throughout the operational cycles of adsorption, desorption, and cooling, 3) the carbon bed contains air flow restrictions or obstructions creating exothermic hot spots, or 4) the type of solvents being adsorbed are highly oxidizable and are exothermically adsorbed. (See "Preventing

Bed Fires in Carbon Adsorption Systems,", Miller K.J., C. R. Noddings, R. C. Nattkemper, 3M, St. Paul MN, For Presentation: 80th Annual Meeting of APCA NY, NY 21-26 June 1987.)

Control. Controls for fire include:

- Use experienced operators and supervisors trained in the flammability/reactivity characteristics of the vapor waste stream when adsorbed on the carbon, the exposure hazards of the waste vapor stream, and the design operating parameters of the carbon beds.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct deficiencies found.
- Audit and apply proper quality assurance/quality control (QA/QC) to assure the pretreatment units and the carbon bed systems are operated as designed.
- Properly ground all carbon treatment systems. See EM 385-1-1, Section 11, and NFPA 70.
- Operate the system and waste vapor stream system within design parameters.
- Do not allow the waste vapor stream flow to exceed the capacity of the system.
- Select proper activated carbon and start-up procedures for new carbon compatible with the contaminant being adsorbed.
- Control the activated carbon moisture by controlling the solvent-laden air temperature and percent relative humidity, using superheated steam for desorption, and optimizing cooling and drying cycle time and conditions.
- Design and maintain even airflow distribution throughout the activated carbon.
- Establish operating procedures for easily oxidizable solvents.
- Use an inert gas such as nitrogen during shutdowns. Flood the bed with water to make it inert and remove excess heat from hot spots.
- Monitor hot spots by monitoring off-gases such as CO or CO_2 above and below the beds.
- Continuously monitor and control the carbon bed operating temperatures.
- Select an alternate technology during design if the known or anticipated contaminants pose an unacceptable risk of fire.
- Thoroughly train the operators in emergency procedures, in life saving first aid procedures including extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation, shutdown and extinguishing procedures.
- Locate fire fighting equipment and emergency eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)

CONTROL POINT: Design

(2) *Confined Spaces*.
Description. Entering carbon bed tanks to inspect, repair, or maintain them may constitute a permit-required confined-space entry. Hazards associated with confined space include asphyxiation, exposure to toxic wastes or poisonous gases (such as PAHs, PCBs, or VOCs), and oxygen deficiency owing to an oxygen demand phenomenon associated with wet activated carbon in both liquid or vapor systems and the catalytic properties of activated carbon that may generate process off-gas by enhancing normal decomposition or oxidation (e.g., CO_2, ethanol, methane) in the confined activated carbon tank space, inhalation of carbon particles or microbes, and engulfment/entrapment in the carbon bed.

Control. Controls for confined-space entry include:

- Train operators and workers in confined space hazards and permit-required confined space entry procedures.
- Design carbon bed vessels to maximize ease of and maintenance activities and minimize the frequency, duration, and extent of maintenance required.
- Develop a confined space permit to include hazard assessment (see 29 CFR 1910.146), including atmosphere testing inside the vessels prior to and throughout the entry.
- Ventilate or purge the air space prior to and during the entry to eliminate risk of encountering an oxygen-deficient or toxic atmosphere. Activated carbon can exhibit a measurable oxygen demand, which can create the oxygen-deficient atmosphere.
- Complete carbon bed vessel manufacturer's shutdown procedures and lockout/tag-out of associated pumping or electrically energized systems prior to entry. Eliminate possible buildup of static electricity.
- Use air-supplied respirators to control inhalation exposures to toxic chemicals and prevent asphyxiation.

CONTROL POINT: Operations, Maintenance

(3) *Fire or Explosion (Gas Transfer).*
Description. In some situations the waste stream or the carbon bed can contain concentrations of VOC above the lower explosive limit (LEL). A fire or explosion may occur if equipment is not approved for flammable locations or if static electricity is discharged during vapor treatment or during removal of carbon from the vessel.

Control. Controls for fire during gas transfer include:

- Train the system operators on fire or explosion hazards during transfer and carbon replacement activities. Include the identification of potential ignition sources such as the creation of static electricity.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct deficiencies found.
- Verify that drawings include hazardous area classifications, as defined in NFPA 70-500-1 through 500-10.

- Use controls, wiring, and equipment on and near the beds that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Bond and ground transfer systems properly to prevent static discharge as required by EM 385-1-1, Section 11, or NFPA 70.
- Permit only trained, experienced personnel to work around the beds.
- Thoroughly train operators in emergency procedures in response to a catastrophic failure and in life saving first aid procedures. This should include halting fire reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown and extinguishing procedures.
- Locate fire fighting equipment and emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) *Carbon Holding Tanks/Drums.*
Description. Carbon holding tanks or drums containing VOC-saturated carbon may leak or spill over into the surrounding areas during operations or loading and unloading of carbon. The resulting spill may be easily ignited. Conditions during which the carbon may be heated may increase this risk.

Control. Controls for carbon holding tanks/drums include:

- Train operators in hazards associated with holding saturated carbon, including the unique hazardous physical properties of the adsorbed chemical being handled and potential for static electricity buildup during handling. Permit only trained and experienced workers in tank/drum areas.
- Equip carbon holding tanks or drums with adequate spill containment.
- Install spill or leak detection monitors and alarms when appropriate.
- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70, Chapter 5, 500.1 through 500.10.
- Use controls, wiring, and equipment on or near the tanks or drums that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Mark all electrical systems properly for potential hazards.
- Ventilate storage areas adequately to help prevent the accumulation of VOCs.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) *Vapor Transfer Equipment Design*.
Description. Vapor transfer equipment (pumps, fans, blowers, piping, pipe fittings, valves, and instruments) that contact contaminated vapors can corrode or dissolve and damage or destroy facilities and result in worker exposures to chemical and physical hazards.

Control. Controls for vapor transfer equipment include:

- Use vapor transfer equipment (pumps, fan, blowers, piping, pipe fittings, valves, and instruments) fabricated from materials that are chemically inert to contaminants in the system.
- Utilize electrical interlock systems to control vacuum pumps and blowers at critical temperatures within the system.
- Consult EM 1110-1-4008, "Liquid Process Piping," and UFGS 15200A, "Liquid Process Piping," for appropriate pumping materials. Require operator training in potential exposures to chemicals being transferred in the waste vapor stream and in the potential incompatibilities within the transfer system that could lead to a catastrophic release.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown and extinguishing procedures.
- Locate fire fighting equipment and emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction, Maintenance

(6) *Fires or Explosion (Carbon).*
Description. Carbon beds can be operated under pressure or vacuum. Systems designed to operate under pressure (e.g., fans, pumps, or blowers upstream from the carbon bed) have a potential risk of flammable vapor leakage that may explode if ignited. Carbon dust can also be ignited and cause explosions. Reactions of chemicals, such as ketones, with activated carbon can be exothermic and cause fires or explosions.

Control. Controls for fire or explosion include:

- Use experienced operators and supervisors trained in the design operating parameters of the carbon beds, waste vapor stream transfer systems, and in the operating incompatibilities that could lead to a catastrophic reaction.
- Perform a Process Hazard Analysis prior to startup and correct all deficiencies found.
- Use containment drip pans or receivers where leaks may occur.
- Install spill or leak detection instruments.
- Design tanks and piping around pressurized carbon beds to handle the maximum operating pressures plus an appropriate safety factor.
- Install over-pressure instrumentation to decrease the possibility of uncontrolled or fugitive vapor releases. Instruments can be set to shut down fans, blowers, or pumps.
- Assess the reactive compatibility of contaminants and carbon beds and evaluate risk of exothermic reactions.
- Minimize the generation of explosive dust or fines during carbon handling.

- Ground all carbon transfer equipment including vacuum trucks or vacuum drums to prevent static electricity from igniting the fine carbon dust. Vacuum trucks exert a tremendous vacuum and only trained, authorized personnel must be allowed to operate the systems.
- Ground and bond system components and include other design elements to minimize potential ignition sources, such as static electricity, electrical spark or open flame, particularly during change out of carbon.
- Thoroughly train the operators in emergency procedures in the event of catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation, shutdown, and extinguishing procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) *Fire or Explosion (Conditioning Inlet Air for Temperate and Humidity).*
Description. Vapor-phase carbon systems operate more efficiently if the inlet waste stream is at or below 50% relative humidity, for which inlet heaters may be used. However, if inlet vapors are overheated, the carbon beds can spontaneously ignite.

Control. Controls for temperature include:

- Train the operators on the relationship of the vapors, carbon bed, and temperature at which spontaneous ignition may occur.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Install temperature instrumentation to monitor and control the operating temperature of the system.
- Use alarms or automatic heat, fan, blower, or pump shutdowns if the carbon bed temperature exceeds 120°F (50°C).

CONTROL POINT: Design, Operations, Maintenance

(8) *Electrical Shock*.
Description. All system components rely on electricity for their operation and control. Personnel who contact electricity can be shocked, burned, or killed.

Control. Controls for electrical shock include:

- Verify that drawings indicate the hazardous area classifications, as defined in NFPA 70, Chapter 5, sections 500.1 through 500.10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11, NFPA 70, and UFGS 16415A “Electrical Work, Interior,” for the identified hazard areas.
- Perform all electrical work in accordance with applicable electrical codes and under the supervision of a state licensed master electrician.

- Train operators for electrical hazards of equipment and environmental factors that contribute to the generation of static electricity.
- Post electrical hazard warning signs.
- Never allow the use of ungrounded, temporary wiring for minor maintenance work on the pretreatment or carbon bed systems, or wiring not approved for contact with water, or on wet or damp surfaces when working under these conditions.

CONTROL POINT: Design, Construction, Operations, Maintenance

(9) *Treatment Buildings*.
Description. Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, or emergency lighting systems.

Control. Controls for treatment buildings include:
- Meet the following construction requirements for permanent and semi-permanent treatment buildings: ANSI 58-1, "Minimum Design Loads for Buildings and Other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code," and the "Uniform Building Code."
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations or local building codes on Superfund, BRAC, or FUDS project sites.

CONTROL POINT: Design, Operations

(10) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:
- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(11) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and

other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *VOC Exposure (Exhaust).*
Description. If the vapor-phase carbon adsorber becomes saturated or is operated on hot days, the carbon may adsorb VOCs less efficiently, causing an increase in VOC concentration in the exhaust. Workers in the area of the exhaust may be exposed to VOCs.

Control. Controls for VOCs exposure include:

- Monitor the discharge for VOCs and shut down the system if the VOC inlet concentration exceeds a predetermined level.
- Use respiratory protection (e.g., air-purifying respirator with organic vapor cartridges) against vapor exposures.
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(2) *VOC Exposure (Breakthrough of Carbon Bed).*
Description. Workers may be exposed to VOCs via inhalation when breakthrough of the activated carbon bed occurs. Breakthrough may result in high VOC concentrations in the exhaust.

Control. Controls for VOC exposure include:

- Monitor effluent to determine when breakthrough occurs.
- Replace or regenerate carbon on a predetermined, regular schedule based on the concentration and adsorption properties of the vapor being treated.
- Use respiratory protection (e.g., air-purifying respirator with organic vapor cartridges) to protect against vapor exposures.
- Train workers in potential chemical exposure hazards, controls, and personal protection equipment (PPE) (see 29 CFR 1910.1200).

CONTROL POINT: Operations, Maintenance

(3) *Chemical Exposure (Vessel/Pipe Corrosion).*
Description. Workers may be exposed to waste chemicals from system leaks when activated carbon corrodes vessels and piping systems that are made from carbon steel or other corrodible material incompatible with the waste vapor stream to be treated.

Control. Controls for chemical exposure include:

- Do not use carbon steel to construct activated carbon vessels. Use stainless steel, thermoplastic, or other chemically inert vessel materials. Consult EM 11101-1-4008, "Liquid Process Piping," and UFGS 15200A, "Liquid Process Piping," for appropriate materials for processing various fluids.
- Paint, coat, or line tank interiors to prevent contact between activated carbon and the carbon steel or corrodible vessels and transfer systems where these materials must be used.
- Install spill or leak detection instruments, including alarms.
- Include drip pans or receivers to monitor leaks, corrosion, and sources of potential exposures where leaks may occur.
- Locate, install, and maintain emergency eyewash and showers at critical points throughout the system where chemical breakthrough is possible. (See ANSI Z358.1 – 1998.)
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Construction, Maintenance

(4) *VOC Exposure (Saturated Carbon).*
Description. During removal of saturated carbon, workers my be exposed to VOCs.

Control. Controls for VOC exposure include:

- Monitor worker exposure to VOCs during carbon removal.
- Use respiratory protection appropriate for VOCs present (e.g., air-purifying respirator equipped with organic vapor cartridges) if worker exposure levels exceed permissible exposure levels (PELs).

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

Radioactive Devices.
Description. Fire and smoke detection devices and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as for safe retrieval and disposal in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Controls of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 21
Ion Exchange (Liquid/Vapor) and Resin Adsorption (Liquid/Vapor)

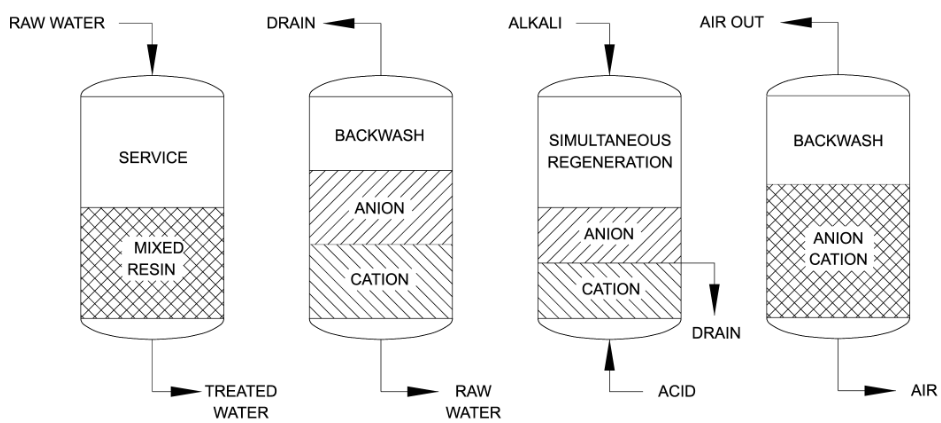
21-1. General

The processes of ion exchange and resin adsorption are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

21-2. Technology Description

a. Ion Exchange.

Ion exchange technology uses nonconductive resins (solid or semi-solid organic materials) or polymers with reversibly reactive side groups to remove ions such as heavy metals from liquid or gaseous streams. The removal occurs by exchange of cations or anions between the contaminated water/gas and the resin or polymer, and their difference in bonding potentials. In practice, gaseous streams are usually treated using wet ion exchange resin. The gaseous ions are dissolved in the water, after which the ion can interact with the resin for the exchange. In general, larger metal ions, such as copper, lead, and calcium, will bind more tightly to the resin than smaller, lighter metals, such as sodium or potassium. Therefore, ion exchange resins utilize this characteristic by containing exchangeable sodium or potassium functional groups. Resins can be regenerated for reuse using acids or bases, or strong solutions that contain the weaker binding ions. During the regeneration process, the waste solution containing the concentrated target ions can then be properly disposed of. Figure 21-1 illustrates both ion exchange (liquid/vapor) and resin adsorption (liquid/vapor).



PRINCIPLE OF MIXED-BED ION EXCHANGE: (A) SERVICE PERIOD. (B) BACKWASH PERIOD. (C) SIMULTANEOUS REGENERATION. (ILLINOIS WATER TREATMENT CO.)

SOURCE: *CHEMICAL ENGINEER'S HANDBOOK*, PERRY & CHILTON (5TH. EDITION)

FIGURE 21-1. ION EXCHANGE/RESIN ADSORPTION

b. Resin Adsorption.

Resin adsorption removes undesirable ions from water on the same chemical basis as ion exchange except that the resin is not exchanged with another metal ion such as sodium or potassium, but is exchanged with the proton or hydroxyl group. Elution of the heavy metals with an acid or base regenerates the resin by reversing the exchange.

21-3. Hazard Analysis

Principal unique hazards associated with ion exchange (liquid/vapor)/resin adsorption (liquid/vapor), methods for control, and control points are described below

a. Physical Hazards.

(1) *Electrocution*.
Description. Workers may be exposed to electrical hazards when working around resin beds. If permanent or temporary electrical equipment is not ground-fault protected or grounded, especially in wet or damp conditions, an electrocution hazard exists.

Control. Controls for electrocution include:
- Verify that drawings include hazardous area classifications as defined in NFPA 70, Chapter 5, sections 500.1 through 500.10.
- Use controls, wiring, and equipment with adequate ground-fault protection in accordance with EM 385-1-1, "Safety and Health Requirements Manual," Section 11.G, NFPA 70, and UFGS 16415A, "Electrical Work, Interior," for the identified hazard areas.
- Perform all electrical work in accordance with codes and under the supervision of a state licensed master electrician.
- Never use ungrounded, temporary wiring during minor maintenance work on the units, or temporary wiring in wet or damp environments that is not approved for these conditions.
- Train workers in potential electrical hazards.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) *Liquid Transfer Equipment Design*.
Description. Improperly selected construction materials, such as untreated steel, can corrode or dissolve to a point of failure and cause damage to the facilities or expose workers to hazards associated with falling or collapsing equipment.

Control. Controls for liquid transfer equipment include:
- Use liquid transfer equipment (pumps, fan, blowers, piping, pipe fittings, valves, and instruments) fabricated from materials that are chemically inert to the liquid streams and contaminants.
- Install spill or leak detection instrumentation if warranted.

- Install drip pans or receivers at mechanical junctions throughout the transfer system.
- Consult EM 1110-1-4008, “Liquid Process Piping,” and UFGS 15200A, “Liquid Process Piping,” for appropriate pumping materials. Include in the design containment drip pans or receivers for potential leaks and spills.

CONTROL POINT: Design, Construction, Maintenance

(3) *Pressurized System Failure*.
Description. Ion exchange systems utilize pressurized beds (e.g., tanks, pumps, and piping). These can leak or fail, causing exposure to the contaminated influent stream or reconditioning solutions.

Control. Controls for pressurized system failure include:

- Design tanks and piping for the maximum operating pressure expected.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Hydro test all systems in accordance with UFGS 11250A, “Water Softeners, Cation-Exchange (Sodium Cycle),” before the system begins treatment operation.
- Train operators on standard procedures for pressurized systems, potential system failures, and necessary corrective action that would be required.
- Include containment drip pans or receivers where leaks may occur.
- Prevent chemical mixing.
- Install spill leak detection instruments if necessary.
- Implement routine system and operating inspections.
- Train operators in emergency procedures including life saving first aid, halting chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Construction, Operations

(4) *Backwash System Failure*.
Description. Some systems have automatic backwash resin regeneration cycles that utilize acidic or basic wash solutions. System failure may expose workers to physical hazards associated with the disruption and concentrated process chemicals.

Control. Controls for backwash system failure include:

- Design redundant automatic backwash failure controls and alarms to shut down the system as needed.
- Train workers in acid/base exposure hazards and controls (see 29 CFR 1910.1200).
- Provide emergency eyewash and shower at locations near areas of potential exposure. See ANSI Z358.1-1998.

- Provide appropriate personal protective equipment stations near potential failure points in the system.
- Train operators in emergency procedures including life saving first aid, halting chemical reactions, extracting, decontaminating and stabilizing victims, and emergency system isolation and shutdown procedures.

CONTROL POINT: Design, Operations, Maintenance

(5) *Fire or Explosion (VOCs).*
Description. Workers may be exposed to a fire or explosion hazard if, during regeneration of the resin, the heat of the reaction is sufficient to ignite VOCs that may have accumulated within the vessel.

Control. Controls for fire or explosion in vapor-phase systems include:
- Purge the vessel's atmosphere with inert gas prior to, or during, the regeneration to prevent an explosion or fire.
- Install temperature/pressure alarms within the system to warn of sudden or abnormal temperature/pressure changes indicating a potential system failure.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct deficiencies found.
- Train operators in emergency procedures including life saving first aid, halting chemical reactions, extracting, decontaminating and stabilizing victims, and emergency system isolation and shutdown procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(6) *Explosion*.
Description. Workers may be exposed to an explosion hazard during the mixing of incompatible chemicals. The resulting reaction may generate heat and pressure buildup causing an explosion.

Control. Controls for explosion include:
- Design the system to shut down during over-pressurization. In addition, install emergency warning alarms and pressure-relief valves or vents that discharge away from work areas.
- Include temperature/pressure alarms within the reaction vessels to warn of abnormal or sudden temperature/pressure changes that may indicate potential system failure.
- Train operators in emergency procedures including life saving first aid, halting chemical reactions, extracting, decontaminating and stabilizing victims, and emergency system isolation and shutdown procedures.
- Locate emergency eyewashes and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)

CONTROL POINT: Design

(7) *Treatment Buildings*.
Description. Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, or emergency lighting systems.

Control. Controls for treatment buildings include:
- Meet the following construction requirements for permanent and semi-permanent treatment buildings: ANSI 58.1, "Minimum Design Loads for Buildings and other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code," and the "Uniform Building Code."
- Design structures in compliance with either Air Force Manuals for those located on Air Force bases, USACE Technical Manuals at Army installations, or local building codes at Superfund, BRAC, or FUDS sites.

CONTROL POINT: Design, Operations

(8) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards with ponding water, or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:
- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash waters.

CONTROL POINT: Design

(9) *Fire (Flammable Materials).*
Description. Ion exchange resins are generally fabricated from flammable materials that can be ignited under certain operating and storage conditions.

Control. Controls for fire include:
- Consult and adhere to the appropriate resin Material Safety Data Sheets (MSDS) and the manufacturers' recommendations for proper use and storage.
- Train operators in flammability characteristics of resins used and operating conditions that are likely to produce flash point temperatures.
- Include critical temperature alarms to allow rapid cool down or shut down of the system.

CONTROL POINT: Design, Construction, Operations

(10) *Design Field Activities*.

Description. Design field activities associated with subsequent construction of the ion exchange system may include surveying, biological, soil gas, and geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these activities may expose personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Deteriorating or Incompatible Chemicals*.
Description. Resins (solid or semi-solid organic materials) used in ion exchange treatment technologies may have specific storage requirements regarding heat and moisture content, ambient temperature or relative humidity, and may deteriorate, producing potentially hazardous conditions (such as acidic conditions). Acids (sulfuric and hydrochloric) and bases (such as sodium hydroxide) used during regeneration processes are incompatible with each other and must be stored physically separate in the containment area. Inadvertent mixing may generate toxic fumes or cause fires.

Control. Controls for deteriorating or incompatible chemicals include:

- Store resins and acids or bases according to NFPA, manufacturers, and MSDS requirements.
- Do not store more resin than can be used within the acceptable storage period.
- Store incompatible materials, such as acids and caustics, separately or in individual secondary containment.
- Design storage systems based on incompatibilities using known process chemistry and MSDS information. Design facilities that keep incompatible chemicals isolated from each other.
- Equip each chemical storage tank or drum with adequate spill containment.
- Install spill or leak detection instruments as required.
- Require proper loading and chemical handling procedures.
- Train operators in proper chemical handling and proper use of personal protective equipment (PPE).
- Locate, install, and maintain emergency fire fighting equipment and eyewash and emergency showers at critical points throughout the system. (See ANSI Z 358.1 – 1998.)

CONTROL POINT: Design, Operations, Maintenance

(2) *Chemical Reagent and Resin Handling*.
Description. Workers may be exposed via the inhalation/ingestion/dermal exposure routes when adding chemical reagents and resins to the system. The chemical reagents may include sulfuric and hydrochloric acid. This activity may occur either at the initial loading of the materials or during the regeneration stage. The resulting exposure may cause burns, irritation, or more severe tissue damage.

Control. Controls for reagent and resin handling include:
- Handle chemical reagents and resins under ventilated conditions.
- Utilize secondary containment units for bulk quantities of hazardous chemicals where possible.
- Use appropriate PPE, such as an air-purifying respirator with acid gas cartridges and butyl rubber gloves.
- Locate an eye wash/chemical spill shower near chemical handling areas. (See ANSI Z 358.1 – 1998.)
- Train workers in potential chemical exposures to expect and the associated controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(3) *Backwash Fluid Solution*.
Description. The eluted acidic or alkaline solution from resin regeneration process contains heavy metals.

Control. A control for backwash fluid solution includes:
- Handle the backwash fluid solution with the same procedures and protocols as those used for process fluids (e.g., proper containment precautions and observing all personal safety measures when handling the fluid material).
- Locate and install and maintain emergency eyewash and showers at critical points within easy access to the resin bed. (See ANSI Z 358.1 – 1998.)
- Allow only trained, authorized operators to perform operation.

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

(1) *Radioactive Contaminants*.
Description. Because the ion exchange treatment technology may remove radionuclides from aqueous waste solutions, the potential exists for worker exposure to radionuclides. In some geological settings, dissolved naturally occurring radioactive materials (NORM) or radioactive contaminants may be drawn up with the groundwater. Depending on the chemical form, the radioactive contaminant may be trapped by the ion exchange resin and concentrated to a point where a radiation hazard may develop.

Control. Controls for radioactive contaminants include:

- Test the contents of the waste stream.
- Determine the nature and extent of the radiation or radioactive materials if present.
- Consult a qualified health physicist to determine the exposure potential and any necessary engineering controls or PPE if radioactive material exceeds background levels.

CONTROL POINT: Maintenance

(2) *Radioactive Devices*
Description. Fire ands smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites, but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 22
Low-Temperature/High-Temperature Thermal Desorption

22-1. General

The processes, applications, and limitations of low-/high-temperature thermal desorption are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

22-2. Technology Description

a. Process.

Low- and high-temperature thermal desorption treat wastes by vaporizing water and organic compounds from the feed solids, such as soils (see Figure 22-1). In contrast to incineration processes, these are physical separation methods and are not designed to directly destroy organic compounds. Consequently, they operate at lower temperatures than incineration. In practice, the off-gas that is laden with the evaporated contaminants is often incinerated in higher temperature, smaller, and more economical secondary burners or incinerators. The off-gas contaminants can also be condensed for disposal or reuse. The terms low- and high-temperature thermal desorption are somewhat arbitrary classifications, as most units can operate across a range of temperatures. High- and low-range systems overlap considerably in capability.

Two common thermal desorption systems are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that are inclined and rotated during firing. Thermal screw units utilize screw conveyors or hollow augers to transport the medium through an enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium. When utilizing either system, particulates generated during desorption are removed by wet scrubbers, cyclones, electrostatic precipitators, or bag house (fabric) filters. Volatile contaminants are purged with a carrier gas or vacuum system and are removed through condensation followed by carbon adsorption, or they are destroyed in a secondary combustion chamber or catalytic oxidizer. Often the treated medium is returned to the excavation after testing. Both systems are available as transportable units that can be brought to sites.

b. Applications.

Low-temperature thermal desorption systems are effective for the removal of both non-halogenated and halogenated volatile organic compounds (VOCs) and petroleum hydrocarbons. Semi-volatile organic compounds (SVOCs) can be treated with reduced effectiveness. Soil decontaminated with a low-temperature thermal desorption system retains its physical properties.

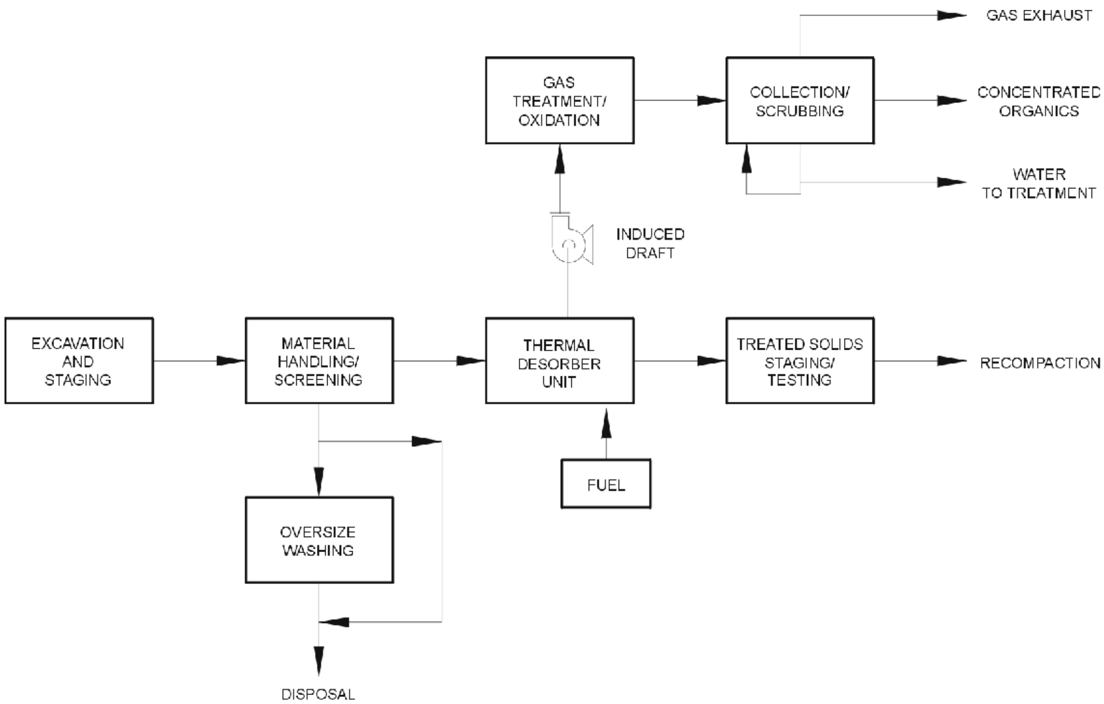


FIGURE 22-1. TYPICAL PROCESS FLOW FOR LOW-TEMPERATURE/ HIGH-TEMPERATURE THERMAL DESORPTION

High-temperature thermal desorption systems are effective for the removal of VOCs, SVOCs, polycyclic aromatic hydrocarbons (PAHs), such as coal tar wastes, creosote-contaminated soils, or polychlorinated biphenyls (PCBs), pesticides, paint wastes, and mixed (radioactive and hazardous) wastes. Volatile metals may be removed by high-temperature thermal desorption systems. Soils treated with high-temperature thermal desorption may lose many of their soil properties and may need to be amended if expected to provide structure.

c. Limitations.

Limitations are similar in both systems. Dewatering of the feed soils may be required to reduce the amount of energy required to heat the soil in both the low- and high-temperature thermal desorption systems. Clay and silt-based soils or high humic content soils may increase the required residence times because of binding of organic constituents. Heavy metals in the soil may produce a residue that requires stabilization prior to returning it to the excavation. Feed particle size limitations can affect applicability and cost for specific soil types, and abrasive feed streams may damage the processor unit.

22-3. Hazard Analysis

Principal unique hazards associated with low/high-temperature thermal desorption, methods for control, and control points are described below

a. Physical Hazards.

(1) *Noise Hazards*.
Description. Desorption treatment units may expose workers to elevated noise levels in the work area from the operation of air blowers, pumps, induced draft fans, high energy venturi scrubbers, fuel injection ports, and the ignition of fuels within the combustion chamber. Noise may interfere with safe and effective communications.

Control. Controls for noise hazards include:

- Follow the regulatory requirements of CEGS 02289, "Remediation of Contaminated Soils by Thermal Desorption."
- Train workers in the use of hearing protection and establish a hearing protection program (see 29 CFR 1910.95).
- Use hearing protection with appropriate NRR hearing protectors selected to eliminate the noise hazard without overprotecting, thus potentially preventing necessary voice communications.
- Use personal electronic communications devices, such as a dual ear headset with speaker microphone, to overcome ambient noise. The device reduces ambient noise levels while enhancing communication. Hearing protection and headset combinations are available commercially and should be used where needed.
- Establish vibration and noise-free areas during operations to provide breaks from the vibration and noise, which can cause fatigue and inattention.

CONTROL POINT: Design, Operations

(2) *Fire or Explosion (System Design).*
Description. Thermal desorption units, including the thermal desorbers and high temperature air pollution control systems such as bag houses located between the rotary drum and the afterburner units, can create a fire or explosion hazard owing to flammable hydrocarbon condensation onto the bag filters within the bag house. The accumulation of the condensed flammable hydrocarbons can be rapid or gradual, depending on contaminant type and concentration within the soil being treated.

Control. Controls for fire and explosion include:

- Operate the unit following the instructions in UFGS 02181A, "Remediation of Contaminated Soils by Thermal Desorption." This standard, in part, requires:
- A Startup Plan.
- A Proof of Performance Plan listing the proposed operating conditions for process parameters to be continuously monitored and recorded.
- An Operating Plan specifying detailed procedures for continued operation of the system, based on the proof of performance results.
- A Demobilization Plan.

- If practical, design parallel flow plants that include the particulate filter system as the final phase of the treatment process to eliminate the danger of condensation of VOCs within the bag house.
- If practical, destroy the VOCs before the gases enter the bag house, increasing the life of the bag filters and eliminating the potential for bag house fires.
- Routinely and safely inspect for condensation buildup and periodically replace bag filters. Condensation is a function of vapor pressures of the contaminants, which is directly related to concentration. As concentration increases, the gas temperature required to maintain the vapor state must increase to avoid condensation.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting the thermal reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency fire fighting equipment, eyewashes, and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)
- Perform a Process Hazard Analysis (PHA) prior to initial startup and correct all deficiencies found.

CONTROL POINT: Design, Operations, Maintenance

(3) *Fire or Explosion (High Operating Temperatures).*
Description. Thermal desorption units, including the thermal desorbers and high temperature air pollution control systems, such as electrostatic precipitators or bag houses with associated high temperature ventilation duct ash transfer systems that are operated above the ASTM E953 (R1998) “Standard Test Method for Fusibility of Refuse-Derived Fuel (RFD) Ash”-determined ash fusion temperature, may cause the solid waste material to build up or vitrify into a large, hot mass within the unit. The resulting heat and pressure buildup may exceed the equipment pressure rating of the unit, possibly causing a fire or explosion or release of hot ash or vitrified waste materials and gases during operation or maintenance procedures that require opening or entering the units.

Control. Controls for fire and explosion include:

- Operate the unit following the instructions in UFGS 02181A, “Remediation of Contaminated Soils by Thermal Desorption.” This standard, in part, requires:
- A Startup Plan.
- A Proof of Performance Plan listing the proposed operating conditions for process parameters to be continuously monitored and recorded.
- An Operating Plan specifying detailed procedures for continued operation of the system, based on the proof of performance results.
- A Demobilization Plan.

- Permit-required confined-space entry plan, including pre-entry unit shutdown and temperature verification prior to doing maintenance on the unit openings or interiors.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting the thermal reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency fire fighting equipment, eyewashes, and showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)
- Perform a Process Hazard Analysis (PHA) prior to initial startup and correct all deficiencies found.

CONTROL POINT: Design, Operations, Maintenance

(4) *Flammable/Combustible Fuels*.
Description. Thermal desorption usually requires storage of flammable or combustible fuels used to fire the thermal desorber (e.g., kerosene, waste fuels). Hazards associated with fuels include the potential for on-site spills or release of material. The release may cause worker exposure to the vapors generated, or a fire hazard may exist if the material is ignited.

Control. Controls for flammable/combustible fuels include:
- Use appropriate tanks, equipped with pressure-relief devices and bermed to help prevent release of material.
- Use electrical equipment and fixtures that comply with NFPA 70.
- Follow UFGS 02181A, "Remediation of Contaminated Soils by Thermal Desorption." It requires that fuel system installation/storage/testing comply with NFPA 30, "Flammable and Combustible Liquids Code," NFPA 31, "Installation of Oil Burning Equipment," NFPA 54, "National Fuel Gas Code," or NFPA 58, "Standard for the Storage and Handling of Liquefied Petroleum Gases."
- Ventilate the area adequately to help prevent the accumulation of flammable vapors.
- Authorize only trained and experienced personnel to work on the system.
- Use lock-out and tag-out procedures on all electrical systems during repair or maintenance.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) *Ignition of Saturated Soils*.
Description. During excavation of waste materials with low flash points, saturated soils may be ignited by sparks generated when the blade of the dozer or crawler contacts rocks or other objects under unusual or extraordinary conditions. If the soil will be crushed prior to feeding into the desorption unit, waste materials with higher than expected Btu values may ignite during the crushing/sorting process.

Control. Controls for ignition of saturated soils include:

- Apply water periodically to the soils (before and during crushing).
- Equip soil-handling equipment with non-sparking buckets or blades when highly flammable excavation materials are suspected.

CONTROL POINT: Operations

(6) *Fire or Explosion (High-Btu Feed).*
Description. If the Btu value of the waste feed is not controlled and high-Btu feed enters the thermal desorber unit, the temperature of the unit may exceed design specifications, possibly resulting in fire or explosion. If the concentration of the soil contaminants is high enough to create a VOC concentration in the gas stream exceeding the Lower Explosive Limit (LEL) in and throughout the thermal treatment unit, the mixture creates a potential for fire or explosion.

Control. Controls for fire include:

- Use experienced operators and supervisors.
- Audit and apply proper quality assurance/quality control (QA/QC) to assure that the unit is operating according to design and that the waste feed has a consistent Btu value based on design parameters.
- Design a gas volume based on the contaminant levels of the soil that exits in the rotary drum of the thermal treatment unit, producing a waste gas stream not exceeding 25% of the LEL for the contaminant. The greater the concentration of the soil contaminants, the greater is the volume of the gas stream exiting the rotary drum unit to maintain less than 25% LEL. In counter flow systems, where the exit gas temperature and, therefore, gas volume is fixed, the amount of feed contaminants must also be controlled to maintain the exit gas mixture to less than 25% LEL.
- Make the air within the thermal desorber inert and maintain this inert atmosphere throughout the treatment train during operation.
- Train the operators in emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency fire fighting equipment, eyewashes, and showers at critical points near the thermal desorber. (See ANSI Z358.1 – 1998.)
- Perform a Process Hazard Analysis (PHA) prior to initial startup and correct all deficiencies found.

CONTROL POINT: Design, Operations

(7) *Electrocution.*
Description. Because desorption treatment units operate electrical systems outdoors, workers may be exposed to electrocution hazards if the electrical equipment comes in contact with water or subunits are not properly grounded.

Control. Controls for electrocution include:

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70, Chapter 5, section 500.1 through 500.10.
- Use controls, wiring, and equipment with adequate ground-fault protection that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Perform all electrical work in accordance with applicable codes and under the supervision of a state licensed master electrician.
- Never allow the use of ungrounded, temporary wiring during small maintenance work on the units, or grounded, temporary wiring in contact with water, wet, or damp surfaces that is not approved for those applications.

CONTROL POINT: Design, Construction, Operations, Maintenance

(8) *Thermal Desorber Operation.*
Description. Workers may be exposed to toxic waste chemicals or exhaust gases via inhalation exposures if high-Btu waste material is fed into the thermal desorber at a rate that exceeds its design capacity. The heat and excessive exhaust gases may over-pressurize the system, resulting in a release of both combustion gases and unburned or partially burned waste material vapors into worker areas.

Control. Controls for incinerator operation include:

- Use experienced operators and supervisors.
- Audit and apply proper QA/QC to assure work is done as designed.
- Operate the system and waste material within design parameters.

CONTROL POINT: Design, Operations

(9) *Thermal Desorption System Design*.
Description. The thermal desorption process can be one piece of equipment with several exhaust gas treatment units in a treatment train following the thermal desorption unit. There may be exhaust gas conditioning equipment, such as electrostatic precipitators, bag houses, vapor scrubbers, and catalytic converters. Each piece of equipment has its own associated hazards; one example is the ever-present hazard of confined space entries to workers required to enter units for maintenance or repair. The EPA regulates the basic design requirements for thermal desorbers. Both the manufacturers and EPA specify design requirements to eliminate contaminant releases that may cause personnel or public exposures, and are also specified for assuring safe operation and maintenance.

Control. Controls for the thermal desorber system designs include:

- Design toxic and exhaust emission control to address all the individual subsystems in the overall system.
- Design the thermal desorber process according to EPA and manufacturer requirements. Consult OSHA standard 29CFR1910.146 “Permit-required Confined Spaces” to reduce to a minimum, the number of confined spaces designed into the system. Designers should also consult the requirements of

UFGS 02180A, “Remediation of Contaminated Soils and Sludges by Incineration.”

(10) *Transfer Equipment Design*.
Description. All transfer equipment (conveyors, piping, process units, and instruments) in contact with contaminated materials should be fabricated from materials that are chemically resistant to the given contaminant chemical. Improperly designed systems can corrode or dissolve, causing damage to the facilities or exposing workers to collapse hazards from falling equipment.

Control. Controls for transfer equipment include:

- Consult EM 1110-1-4008, “Liquid Process Piping,” and UFGS 15200, “Liquid Process Piping,” for appropriate materials for pumping various fluids.
- Use equipment fabricated from materials that are chemically inert to contaminants in the system.
- Install spill or leak detection instruments if necessary.
- Include containment drip pans or receivers for potential leaks and spills.
- Implement preventive maintenance program and complete periodic inspections.

CONTROL POINT: Design, Construction, Maintenance

(11) *Thermal Hazards*.
Description. The thermal desorption process uses high temperatures to heat treated materials and subunit equipment. The equipment, gasses generated, and processed materials may expose workers to possible thermal burn hazards.

Control. Controls for burns include:

- Design the thermal desorber and post-desorber treatment units to maximize ease of operation, physical cleaning, and maintenance to include adequately sized and easily accessible doors and ports where entry is required.
- Perform manufacturer recommended shutdown and cool-down procedures prior to working on, around, or entering the units.
- Use penetrating temperature probes to measure that internal temperatures of ash accumulations are ambient prior to entry into thermal treatment units to work.
- Develop and follow confined space entry permit and procedures and rigorously apply requirements.
- Verify function, and use manufacturer’s temperature safety control systems.
- Post signs warning of high temperatures.
- Use safety barriers to isolate critical sections of the equipment.
- Design systems to handle the materials exiting the system. Follow NFPA 30, 31, and 54 and UFGS 02181A, “Remediation of Contaminated Soils by Thermal Desorption” criteria.

- Train workers in hazards, use heat resistant gloves and protective gear, and permit maintenance by workers only after process equipment has cooled to ambient temperatures.

CONTROL POINT: Design, Operations, Maintenance

(12) *Transfer Systems*.
Description. Transfer systems such as screw conveyors or augers expose workers to injury if limbs or clothing are caught in the system.

Control. Controls for transfer systems include:
- Enclose or otherwise guard transfer system pinch points such as belts, pulleys, and conveyor end points or material transfer points to the maximum extent possible.
- Install emergency shutoff controls at multiple critical locations and include the shutoff control locations and operation in all worker training.
- Enforce lock-out/tag-out procedures rigorously.
- Train workers in identification of pinch points in the system.

CONTROL POINT: Design, Operations, Maintenance

(13) *Piping System Leaks*.
Description. Workers may be exposed via the inhalation exposure route to VOCs, such as toluene, if leaks occur in the piping system.

Control. Controls for leaks in the piping system include:
- Appropriately size the system to maintain negative pressure (e.g., ducts and piping) at the maximum expected operating pressure.
- Avoid or minimize fugitive emission hazards by designing appropriate pressure control and relief systems.
- Install and test fuel systems according to requirements of NFPA 30, “Flammable and Combustible Liquids Code” NFPA 31, Installation of Oil Burning Equipment,” NFPA 54, National Fuel Gas Code,” or NFPA 58, “Standard for the Storage and Handling of Liquefied Petroleum Gases.”

CONTROL POINT: Design, Operations, Maintenance

(14) *Respirable Quartz*.
Description. Depending on soil type of the material thermally treated, exposure to respirable quartz may be a hazard. Consult a geologist to confirm the presence of quartz in feed materials (i.e., determine if soil type is likely to be rich in quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 –2002: “Standard Test Method for Particle Size Analysis of Soils” followed by analysis of the fines by X-ray diffraction to determine crystalline quartz content.

Control. Controls for respirable quartz include:

- Eliminate airborne dust sources that penetrate workspaces, utilizing appropriate engineering controls. Construct water mist systems or implement local exhaust ventilation. Wet the soil periodically with water or amended water to minimize generation of airborne dust.
- Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Train workers on inhalation hazards of silica laden dust.
- Where engineering controls fail, provide appropriate respirators, medical screening, and associated employee training on use and limitations of respiratory protection, e.g., air-purifying respirators equipped with N, R or P100 particulate air filters. Verify appropriate use of respiratory protective equipment in identified hazardous work areas.

CONTROL POINT: Construction, Operations

(15) *Sunlight/UV Radiation*.

Description. During site activities, workers may be exposed to direct and indirect sunlight with its corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions combined with radiant heat from process equipment can significantly contribute to the worker's heat load, thereby increasing the risk of heat injury, such as heat exhaustion, heat cramps, and heat stroke.

Control. Controls for Sunlight, UV radiation and heat stress include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length unbloused pants, and by applying UV barrier sunscreen to exposed skin. Loose clothing and sun hats should not be worn around moving parts that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.
- Shade work and break areas, if possible.
- Minimize exposure to heat stress conditions by training the workers in the symptoms of heat stress, practicing the Buddy System, taking frequent breaks, drinking adequate fluids, and working during the cooler part of the day. Tasks with inherent heat stress risks should be identified and personal protective equipment (PPE) mandated. Heat stress levels and preventive measures as per accepted protocols shall be documented.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(16) *Electrocution Hazards*.

Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines or underground cables with material handling equipment; or if electrical equipment on the thermal desorption units contact water or are not properly grounded.

Control. Controls for electrocution include:

- Verify the location of overhead power lines, either existing or proposed, in the pre-design phase through contacting local utilities.
- Verify the location of and do not disturb energized underground utilities during subsurface and excavation activities. Verify that drawings indicate the hazardous area classifications as defined in NFPA 70, 500-1 through 500-10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Use adequate ground-fault protection.
- Keep equipment at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.
- Never allow the use of ungrounded, temporary wiring for minor maintenance work on the units, or wiring not approved for contact with water, or on wet or damp surfaces.

CONTROL POINT: Design, Construction, Operations

(17) *Traffic Hazards*.
Description. During field activities, equipment and workers may come close to moving vehicular and equipment traffic. In addition the general public may be exposed to traffic hazards and the potential for accidents.

Control. Controls for traffic hazards include:

- Position controllers and spotters at critical points in the traffic flow to safely direct it.
- Post warning signs according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site equipment. EM 385-1-1, Section 21, provides plan details.

CONTROL POINT: Design, Construction, Operations

(18) *Heated Surfaces*.
Description. Workers may be exposed to infrared radiation hazards associated with working in the vicinity of thermal desorbing treatment units. The exposure, depending on the temperature of the equipment, length of exposure, and other variables may increase the risk of cataracts.

Control. Controls for heated surfaces include:

- Minimize worker exposure time on or near hot operating equipment surfaces.
- Use eye protection with the appropriate shade safety glass or reflective full body radiation (radiant heat) protective suits if prolonged work near the radiant heat surface or source is required.

CONTROL POINT: Operations, Maintenance

(19) *Confined Spaces.*

Description. Workers may be exposed to confined-space hazards during entry into the process equipment for repair, inspection, or maintenance in thermal treatment unit and associated subsystems, such as the thermal desorber itself, dust/gas collection/ventilation duct work, electrostatic precipitators, cyclones, high energy wet scrubbers, and bag houses. High temperature, oxygen deficient, toxic, inert, and negative air conditions may be encountered. The treatment train dust collection units typically operate at the high temperature generated in the thermal desorber. Ash and dust suctioned from the desorber can accumulate in the electrostatic precipitator (ESP), bag house, or cyclone feed duct and collection hoppers. Hot ash can retain its fluid and thermal properties for an extended period, even many days, after shutdown. Improper entry into confined spaces has resulted in serious injuries and death. Confined-space hazards may cause death or injury by sudden release of hot or vitrified waste ash or material in the units during maintenance, such as by prematurely opening hopper doors. Before entry, assurance must be made that no accumulations of ash are impounded behind the doors. Death or injury can be caused by inhalation exposure to heated inert gases, severe oxygen deficiency, toxic combustion byproducts or poisonous gases volatilized from the treated materials, which may include heavy metals, hydrogen sulfide (H_2S), carbon monoxide (CO), methane, and vinyl chloride, engulfment by hot ash, and entanglement or electrocution.

Control. Controls for confined spaces include:

- Design the thermal desorption treatment unit and exhaust gas treatment systems to maximize easy operation and physical cleaning and maintenance, to include accessible adequately sized access doors and ports, to minimize the number of confined spaces designed into the system, and to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Develop a pre-entry confined space permit (see 29 CFR 1910.146).
- Test the atmosphere within the confined space prior to entry and monitor throughout the work (see 29 CFR 1910.146).
- Design air-handling systems to minimize or eliminate oxygen-deficient locations and rigorously ventilate prior to entry of personnel.
- Perform the manufacturer's shutdown procedures and lock-out/tag-out of electrically energized systems, such as for the ESP or bag house, prior to entry.

- Ash collection hoppers must be inspected internally from above to determine the buildup of ash in corners or valleys prior to opening hopper doors. The doors must be connected to the electrical interlock system for the ESP, bag house, or cyclone. Use hopper level indicators to ensure that no accumulation of ash is present behind hopper access doors. If the hopper must be entered, all ash must be dislodged and discharged prior to entry, e.g., use a mechanical vibrator, poke, prod or air lance followed by washing with high-pressure water hose. Hoppers must never be opened during operation of the collection unit because of ash temperature and fluidity.
- Use penetrating temperature probes to measure internal temperatures of ash buildup or piles, such as in dust collection unit hoppers, prior to opening or entering the units. Otherwise identify the locations of all accumulations of ash or vitrified ash in the units through soundings, measuring concentrations of background radioactive contaminants, or other means prior to entry.
- Use air-supplied respirators to control inhalation exposures to toxic chemicals and prevent any potential for asphyxiation where only constant mechanical ventilation prevents the build up of a toxic or inert gas environment.

CONTROL POINT: Design, Operations, Maintenance

(20) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, which results in creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:
- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(21) D*esign Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological, soil gas, and geophysical surveys, trenching, drilling, stockpiling, and contaminated groundwater sampling. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.

- Prior to starting work, complete a walk-through inspection of each work zone with the intent of identifying and communicating site-specific hazards and controls.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Waste Material Exposure (Excavation and Transport).*
Description. Workers may be exposed to chemicals during excavation, transport, or handling of contaminated materials. Dry soils may generate airborne dusts contaminated with toxic materials, including and in addition to those contaminants being treated (e.g., respirable quartz, pesticides, etc.).

Control. Controls for waste material exposure include:

- Train the workers in the hazards, engineering controls, personal protective equipment, and good personal hygiene practices to reduce potential exposure.
- Routinely wet material and dirt/gravel travel routes to prevent airborne dust generation. Cover all excavated material during transport.
- Use appropriate respiratory protective equipment as determined from the result of adequate air monitoring, e.g., air-purifying respirators with N, R or P100 filters for particulates; organic vapor cartridges for organic vapors and some acid gases, or combination filter/cartridges for dual protection.

CONTROL POINT: Operations

(2) *Process and Waste Products*.
Description. During operation of the thermal desorption unit, workers may be exposed to contaminants or thermal desorption chemicals and other byproducts or conditions such as oxygen deficient inerting gases, methane, H_2S, CO, airborne toxic metals, metal acetates, mercury, lead, and chlorine. Subunits within the system that utilize bulk chemical or sludge additives in conjunction with exhaust gas wet scrubbers, pre-clarifier mixing tanks, filter press pre-coat tanks, or surge tanks, may present significant exposure potentials, both when replenishing the chemicals and when performing routine maintenance on the units.

Control. Controls for waste products include:

- Train all workers involved in both the operation and maintenance of the thermal desorption system. Training shall include hazards related to the generation, transport, and treatment of byproducts, and bulk chemical additives.
- Characterize and classify wastes to be treated prior to desorption. Feed only those waste materials compatible with the process into the unit.
- Design off-gas treatment to control generation and release of toxic materials. Design engineering controls for the system to prevent or minimize the gen-

eration or release of toxic materials into the breathing zone of the workers. Engineering controls could include negative air throughout the treatment system, dust misting systems at strategic points throughout the system, real-time monitors with alarms, and contaminant-specific monitoring badges.
- Locate, install, and maintain emergency fire fighting equipment, and eye-wash and emergency showers at critical points throughout the system. (See ANSI Z358.1 – 1998.)
- Assess workplace and identify appropriate personal protective equipment (PPE) that includes an evaluation of contaminants, treatment byproducts, and process-related hazards. Use approved PPE, such as thermal protective gear, safety glasses, face shields, protective gloves, air-supplied respirators or air-purifying respirators with appropriate filters/cartridges and air emissions controls.

CONTROL POINT: Design, Operations

(3) *Exhaust Vapors*.
Description. Workers may be exposed via inhalation during the thermal desorption process. Because some chemical contaminants, such as fuel oils, are not completely destroyed in the process, they may be discharged via the exhaust stack and in certain atmospheric conditions may affect the work area.

Control. Controls for exhaust vapors include:
- Gather exhaust vapors for further processing in an off-gas treatment unit (e.g., vapor carbon beds, incinerators, thermal oxidizers, or gas scrubbing towers). Fugitive emissions are possible if systems are not designed to address these issues.
- Verify that systems are operating at designed operating pressures, less than atmospheric pressures, to eliminate fugitive emissions.

CONTROL POINT: Design, Operations

(4) *Toxic Dust/Respirable Quartz Hazard*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard during the excavation and soil-handling phase of the process. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 – 2002: "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline quartz content.

Control. Controls for respirable quartz include:
- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.

- Use respiratory protection, such as an air-purifying respirator equipped with N, R or P100 particulate air filters.
- Train workers in the potential inhalation hazards associated with crystalline silica exposures.

CONTROL POINT: Design, Construction, Operations

c. Radiological Hazards.

Radioactive Devices.
Description. Fire and smoke detection devices and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Controls of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 23
Incineration

23-1. General

The process and applications of incineration are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

23-2. Technology Description

a. Process.

Incineration is a treatment process for contaminated soil, sludges, sediments, and liquids using extreme heat to oxidize organic materials (incineration of vapor streams is discussed in Chapter 24). Materials are heated to a specified temperature, usually at least 1800°F, for a specified time, usually at least 1 second at temperature, to oxidize the contaminants. The appropriate temperature and residence time depends on the nature of the waste stream and contaminants. A gaseous or liquid fuel provides the energy for the oxidation. Oxygen is supplied from air or pure oxygen feeds. The products of combustion are carbon dioxide, water, and depending on the feed, acid gases, metal oxides, and noncombustible ash.

While the treatment process is simple and reliable, there are stringent requirements for controlling vapor emissions from the incinerator that significantly increase the complexity of the process. Each additional treatment step also introduces unique hazards to the overall process. The exhaust from the treatment usually includes controls for particulates, ash, and combustion products (carbon monoxide, halogens released during combustion, and hydrocarbons). The ash usually requires handling and disposal as a hazardous waste material and is sent to special landfills for this purpose. The particulates are removed using either bag houses or electrostatic precipitators, but can also be removed by wet scrubbers. Dust is usually handled in the same fashion as ash. In addition, acid gases that form when oxidizing halogenated compounds must be removed in acid gas scrubbers. Uncontrolled acid gases can cause serious physical damage to equipment and pose significant hazards to workers. In addition, owing to the acid nature of the gasses, the water stream generated by the scrubber becomes acidic and must be handled and disposed of safely. See Figure 23-1.

b. Applications.

The incineration process is applicable to a wide range of waste streams, including volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), pesticides, solvents, polychlorinated biphenyls (PCBs), virtually all fuel and tar streams, and combinations of these compounds. It is very effective in terms of percentage of destruction of the compounds of concern. The feed to the incinerator is usually a liquid or a solid but can be a combination. Sludges, semi-solids, and cakes may be effectively treated, provided the feed handling system can convey these materials to the unit. Oversized solids (rocks, large chunks) may be removed by screening devices before the material is fed into the combustion chamber.

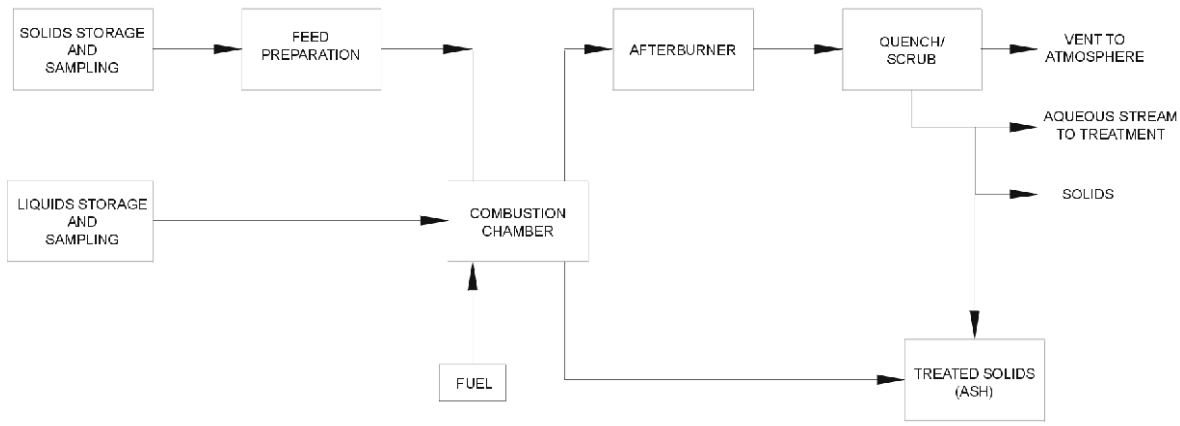


FIGURE 23-1. TYPICAL PROCESS FLOW FOR INCINERATION

23-3. Hazard Analysis

Principal unique hazards associated with incineration, methods for control, and control points are described below

a. Physical Hazards.

(1) *Noise Hazards*.
Description. Incineration may cause elevated noise levels in the work area because of the operation of air blowers, pumps, induced draft and exhaust fans, high energy venturi scrubbers, fuel injection ports, and the ignition of fuels within the combustion chamber. The noise level can interfere with safe and effective communications.

Control. Controls for noise hazards include:
- Refer to UFGS 02180A, "Remediation of Contaminated Soils and Sludges by Incineration" for noise control.
- Train workers in the use of hearing protection and establish a hearing conservation program (see 29 CFR 1910.95).
- Use personal electronic communications devices, such as a dual ear headset with speaker microphone, to overcome ambient noise where communication is critical in high noise areas. Hearing protection/headset combinations are commercially available and should be used where needed.
- Establish vibration and noise-free areas during operations to provide breaks from the vibration and noise, which can cause fatigue and inattention.

CONTROL POINT: Design, Operations

(2) *Heat and Pressure Buildup*.
Description. The incineration process may cause solid waste material to vitrify into a large, hot mass within the unit. The resulting heat and pressure buildup may exceed design specifications of the unit, damage the unit, and result in explosive release of waste materials and expose personnel and the public to chemical and physical hazards. Both heated or cooled vitrified material in the units may break away and seriously injure or kill workers who enter the units.

Control. Controls for heat and pressure buildup include:

- Prepare a Design Safety Analysis Plan. Follow operating instructions in UFGS 02180A, “Remediation of Contaminated Soils and Sludges by Incineration” (Section 1.2.2.3 of the standard addresses slagging control requirements). The standard also requires the following plans:
- A Mobilization Plan containing the specific procedures and requirements for on-site placement of the incineration system and subsystems.
- A Startup Plan providing a sequence of detailed procedures, calibrations, tolerances and schedules, control system functions, actions, reactions (both mechanical and chemical) occurring manually or automatically, as the system components are engaged to test the system with uncontaminated materials (a trial burn or mini burn) or used to begin a new sequence of operation.
- Utilize a System Safety Record of Documentation during the trial burn plan required by the Startup Plan. The System Safety Documentation Record shall present optimal operating conditions and allowable variances that shall be continuously monitored and recorded along with required sampling and analysis to support the record.
- A Permit-Required Confined-Space Entry Plan including pre-entry unit cool down procedures and shutdown verification prior to doing maintenance on the unit openings or interiors.
- Operate the unit within the design and control parameters.
- Design controls that prevent unit entry until all material has cooled.
- Train the operators in standard operation and emergency procedures in the event of a catastrophic failure, in life saving first aid procedures including halting reactions, extracting, extinguishing, decontaminating and stabilizing victims, and in emergency system isolation and shutdown procedures.
- Locate emergency fire fighting equipment, eyewashes, and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1998.)
- Perform a Process Hazard Analysis (PHA) prior to initial startup and correct all deficiencies found.
- A Demobilization Plan, including decontamination and disassembly requirements.

CONTROL POINT: Design, Operations, Maintenance

(3) *Flammable/Combustible Fuels.*

Description. Incinerators usually require storage of flammable or combustible fuels (e.g., kerosene, waste fuels) used to fire the incinerator. Hazards associated with fuels include the potential for an on-site spill or release of material. The release may cause worker exposure to the liquid state or vaporized fuels, or a fire hazard may exist if the material is ignited.

Control. Controls for flammable/combustible fuels include:

- Use appropriate tanks, bermed and equipped with pressure-relief devices to help prevent release of material.
- Use electrical equipment and fixtures that comply with NFPA 70.
- Meet mandatory requirements of NFPA 30, "Flammable and Combustible Liquids Code," NFPA 31, "Installation of Oil Burning Equipment," NFPA 54, "National Fuel Gas Code," or NFPA 58, "Standard for the Storage and Handling of Liquefied Petroleum Gases" for fuel system installation, storage, and testing.
- Ventilate the storage area adequately to help prevent the accumulation of flammable vapors.
- Permit only trained and experienced workers to work on the incinerator.
- Use lock-out and tag-out procedures on all electrical systems during repair or maintenance in the storage area.

CONTROL POINT: Design, Operations, and Maintenance

(4) *Ignition of Saturated Soils*.
Description. During excavation of waste materials with low flash points, saturated soils may be ignited by sparks generated when the blade of the dozer or crawler contacts rocks or other objects under unusual or extraordinary conditions. If the soil will be crushed prior to feeding into the incinerator, waste materials with high Btu values may ignite during the crushing/sorting process.

Control. Controls for ignition of saturated soils include:

- Apply water periodically to the soil (before and during crushing).
- Use professional judgment on evaluating the site, work equipment, soil, and ambient work conditions, and, if necessary, equip soil-handling equipment with non-sparking buckets or blades when highly flammable incineration feed soils or materials are suspected.

CONTROL POINT: Operations

(5) *Electrocution*.
Description. As incinerators operate electrical systems outdoors, workers may be exposed to electrocution hazards if the electrical equipment contacts water, or any of the subunits are not properly grounded.

Control. Controls for electrocution include:

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70, 500-1 through 500-10.

- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Use adequate ground-fault protection.
- Never allow the use of ungrounded temporary wiring for minor maintenance work on the units, nor wiring not approved for contact with water or on wet or damp surfaces.

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) *Incinerator Operation*.
Description. Workers may be exposed to toxic waste chemicals or combustion gases via inhalation if high-Btu waste material is fed into the incinerator at a rate that exceeds its design capacity. This may over-pressurize the system, resulting in a release of both combustion gases and unburned or partially burned waste material vapors into worker areas.

Control. Controls for incinerator operation include:
- Use experienced operators and supervisors.
- Audit and apply proper quality assurance/quality control (QA/QC) to assure work is done as designed.
- Operate the system and waste material within design parameters.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.

CONTROL POINT: Design, Operations

(7) *Incineration System Design*.
Description. The incineration process can use one piece of equipment with two or more additional waste processing units attached. Most waste incinerators include equipment similar to thermal desorption units for handling materials at the inlet and outlet of the unit. There may be exhaust gas conditioning equipment, such as electrostatic precipitators, bag houses, vapor scrubbers, or catalytic converters, added to incinerators. Each piece of equipment has its own hazards, such as confined space. The Environmental Protection Agency (EPA) regulates design requirements for incinerators. Process requirements are specified to eliminate contaminant releases that can cause exposure to site workers and the public. In addition, each manufacturer also publishes guidelines for assuring safe operation and maintenance.

Control. Controls for the incineration system include:
- Include the subject of hazard control in design to address all the individual sub-systems in the overall system.
- Perform a Process Hazard Analysis (PHA) prior to initial startup and correct all deficiencies found.
- Design the incineration process according to EPA and manufacturer requirements. Consult OSHA 29CFR 1910.146 “Permit-required Confined Spaces” and minimize the use of confined spaces in design. Design

requirements should meet UFGS 02180A, "Remediation of Contaminated Soils and Sludges by Incineration."

CONTROL POINT: Design

(8) *Transfer Equipment Design*.
Description. Improperly designed systems can corrode or dissolve to a point of failure and cause damage to the facilities or exposure to workers.

Control. Controls for transfer equipment design include:

- Consult EM 1110-1-4008, "Liquid Process Piping," and UFGS 15200A, "Liquid Process Piping," for appropriate materials for pumping various fluids.
- Use equipment fabricated from materials that are chemically inert to the waste chemicals and materials being transferred.
- Install spill leak detection instruments, including alarms if necessary.
- Include containment drip pans or receivers for potential leaks and spills.
- Implement preventive maintenance program and complete periodic inspections.

CONTROL POINT: Design, Construction, Maintenance

(9) *Burn Hazards*.
Description. Workers may be exposed to burn hazards to the skin from hot ash during operation and maintenance of the incinerator.

Control. Controls for burn hazards include:

- Design the incinerator and post-incineration exhaust gas treatment units to maximize ease of operation, physical cleaning, and maintenance to include adequately sized and easy access doors and ports where entry is required.
- Perform manufacturer's shutdown and cool down procedures prior to working on, around, or entering incinerator or post-incineration treatment units.
- Use penetrating temperature probes to measure internal temperatures of ash accumulations prior to incinerator or treatment unit entries. Verify that internal ash temperatures are ambient prior to entry into units to work.
- Develop confined space entry permit and rigorously apply requirements.
- Verify function, and use manufacturer's temperature safety control systems.
- Design the incinerator ash handling system to efficiently transport solid waste and ash materials exiting the system so as to avoid creating buildup of hot waste materials within the system.
- Install safety barriers to isolate critical sections of the equipment.
- Post signs warning of high temperatures.
- Train workers in hazards; use heat-resistant gloves, eye and skin protective gear, and permit system maintenance only after process equipment has cooled to the manufacturer's stated safe temperature.

CONTROL POINT: Design, Operations, Maintenance

(10) *Transfer Systems*.
Description. Transfer systems, such as feed belts, augers, screw conveyors, etc., expose workers to injury if limbs or clothing are caught in the system.

Control. Controls for transfer systems include:

- Enclose or otherwise guard transfer system pinch points, such as belts, pulleys, and conveyor end points, or material transfer points to the maximum extent possible.
- Install color coded labeled emergency shutoff controls at multiple critical locations. Train workers on the shutoff control locations and operation. Post signs if necessary.
- Train workers in acceptable use of hand tools. Lock-up or otherwise remove unnecessary shovels, poles, or hand tools that may be used by workers as dislodging tools.
- Enforce lock-out/tag-out procedures rigorously.
- Train workers to identify pinch points in the system.

CONTROL POINT: Design, Operations, Maintenance

(11) *Piping System Leaks*.
Description. Workers may be exposed via inhalation to components of waste fuels such as VOCs, e.g., toluene, if leaks occur in the pressurized section of the piping system.

Control. Controls for leaks in the piping system include:

- Design the system to operate under a negative pressure (e.g., ducts and piping) for the maximum operating pressure expected.
- Avoid or minimize fugitive emission hazards by designing pressure control mechanisms and appropriate relief systems.
- Install and test fuel systems according to requirements of NFPA 30, “Flammable and Combustible Liquids Code,” NFPA 31, “Installation of Oil Burning Equipment,” NFPA 54, National Fuel Gas Code,” or NFPA 58, “Standard for the Storage and Handling of Liquefied Petroleum Gases.”

CONTROL POINT: Design, Operations, Maintenance

(12) *Heated Surfaces*.
Description. Workers may be exposed to infrared radiation hazards associated with working in the vicinity of incinerators. The exposure, depending on the temperature of the equipment, length of exposure, and other variables may increase the risk of cataracts or heat stress.

Control. Controls for heated surfaces include:

- Minimize worker exposure time on or near hot equipment surfaces.

- Use eye protection with the appropriate shade safety glass and reflective radiant heat protective suits if prolonged work near the radiant heat surface or source is required to control both eye and body exposure.
- Shield affected work areas.

CONTROL POINT: Operations, Maintenance

(13) *Sunlight/UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight. Even short-term exposure to sunlight can cause dermal damage and burns. Hot and humid conditions can increase the risk of heat-related injury as heat exhaustion, cramps, or heat stroke.

Control. Controls for Sunlight, UV radiation and heat stress include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length unbloused pants, and by applying UV barrier sunscreen to exposed skin. Loose clothing and sun hats should not be worn around moving parts that may snag the worker and draw him into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.
- Shade work and break areas, if possible.
- Minimize exposure to heat stress by training the workers in the symptoms of heat stress, practicing the Buddy System, taking frequent breaks, drinking adequate fluids, and working during the cooler part of the day.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) “TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices.”

CONTROL POINT: Construction, Operations, Maintenance

(13) *Respirable Quartz*.
Description. If soil is the material incinerated, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of quartz in feed materials. To determine respirable quartz exposure potential, sample and analyze site soils and ash for fines content by ASTM D422 (R2002) “Standard Test Method for Particle Size Analysis of Soils” followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Eliminate dust generation or escape of dust from equipment into worker’s air spaces and breathing zones. Install water mist systems on the equipment at dust escape points. Wet the soil periodically with water or amended water to minimize dust generation and worker exposure.

- Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Where engineering controls fail, use respiratory protection such as air-purifying respirators equipped with an N, R or P100 particulate filter and train workers in respirator use.
- Train workers in potential inhalation hazards from crystalline silica quartz laden dust.

CONTROL POINT: Operations, Maintenance

(14) *Confined Spaces.*

Description. Workers may be exposed to confined-space hazards when entering the process equipment for inspection, maintenance or repair. Incineration systems typically have multiple treatments subunits to treat the exhaust combustion gases that range in physical and operational complexity, such as the incinerator itself, dust/gas collection/ventilation duct work, electrostatic precipitators (ESP), cyclones, high energy wet scrubbers and bag houses, which can be operated under high temperature, oxygen deficient, toxic, inert, and negative air conditions. All treatment units that require periodic entry for maintenance present significant confined space hazards. The treatment train dust collection units typically operate at high temperatures generated in the incinerator. Ash and dust suctioned from the incinerator can accumulate in the ESP, bag house, or cyclone feed duct and collection hoppers. Hot ash can retain its fluid and thermal properties for an extended period of time, even many days after shutdown. Confined space hazards may include death or injury by sudden release of hot or vitrified waste ash or material in the units during maintenance, such as caused by prematurely opening hopper doors. Before entry, assurance must be made that no accumulations of ash are impounded behind the doors. Death or injury can be caused by inhalation exposure to inert gas, severe oxygen deficiency, toxic combustion byproducts, or poisonous gases volatilized from the treated materials, including heavy metals, H_2S, CO, methane, vinyl chloride, etc., and entanglement or electrocution.

Control. Controls for confined spaces include:

- Design the incinerator and exhaust gas treatment systems to maximize easy operation, and physical cleaning and maintenance to include accessible, adequately sized access doors and ports; and to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Develop a pre-entry confined space permit (see 29 CFR 1910.146).
- Test the atmosphere within the confined space prior to entry and monitor throughout the work (see 29 CFR 1910.146).
- Design air-handling systems to minimize or eliminate oxygen-deficient locations and rigorously ventilate prior to entry of personnel.
- Perform the manufacturer’s shutdown procedures and lock-out/tag-out of electrically energized systems, such as for the ESP or bag house, prior to entry.

- Ash collection hoppers must be inspected internally from above to determine the buildup of ash in corners or valleys prior to opening hopper doors. The doors should be connected to the electrical interlock system for the ESP, bag house, or cyclone. If the hopper must be entered, all ash must be dislodged and discharged prior to entry, i.e., use a mechanical vibrator, or poke, prod or air lance followed by washing with high-pressure water hose. Hoppers must never be opened during operation of the collection unit because of ash temperature and fluidity.
- Use penetrating temperature probes to measure internal temperatures of ash buildup or piles, such as in the dust collection unit hoppers, prior to opening or entering the units. Identify the locations of all accumulations of ash or vitrified ash in the units through soundings, measuring concentrations of background radioactive contaminants, or other methods prior to entry.
- Use air-supplied respirators to control inhalation exposures to toxic chemicals and prevent any potential for asphyxiation in situations where only constant mechanical ventilation prevents the buildup of a toxic or inert gas environment.

CONTROL POINT: Design, Operations, Maintenance

(15) *Emergency Wash Equipment*.
Description. Emergency shower/eyewash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: “Emergency Eyewash and Shower Equipment” for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(16) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Waste Material Exposure (Excavation and Transport).*
Description. Worker exposure may occur during excavation, transport, or handling of waste materials. Dry soils may generate airborne dusts contaminated with toxic materials, including and in addition to those contaminants being treated (e.g., respirable quartz, pesticides, etc.).

Control. Controls for waste material exposure include:

- Train the workers in the hazards, engineering controls, personal protective equipment, and good personal hygiene practices effective in protecting against exposure to the contaminants of the materials being transported.
- Routinely wet waste material and dirt/gravel travel routes to prevent airborne dust generation.
- Use respiratory personal protection equipment (PPE) such as air supplied, or air-purifying respirators with appropriate filter/cartridges such as N, R or P100 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.

CONTROL POINT: Operations

(2) *Toxic Material Exposure (Feed or Byproducts).*
Description. During operation of the incinerator, workers may be exposed to toxic materials in the feed, byproducts of combustion, oxygen deficient atmospheres, high levels of carbon dioxide, carbon monoxide, or to airborne toxic materials, including heavy metals, metal acetates, mercury, and halogens such as chlorine from halogenated hydrocarbons in wastes being incinerated. In addition, toxins such as dibenzofurans and dioxins may also be generated during the process. Post-incineration units within the system that utilize bulk chemical additives or sludge additives in conjunction with exhaust gas wet scrubbers, preclarifier mixing tanks, filter press pre-coat tanks, or surge tanks may present significant exposure potentials, both when the chemicals are replenished and when routine maintenance is performed on the units.

Control. Controls for exposure to toxic material include:

- Train all workers involved in both the operation and maintenance of the incinerator in all chemical hazards related to the generation, transport, and treatment of the contaminants, contaminant byproducts within the system, and the bulk chemical additives used to treat the contaminants.
- Characterize and classify wastes to be treated prior to incineration.
- Use only those waste materials compatible with the process managed in the unit.

- Note design parameters on feed characteristics and meet the requirements of UFGS 02180A "Remediation of Contaminated Soils and Sludges by Incineration."
- Design engineering controls for the system to prevent or minimize the generation or release of toxic materials or gases into the breathing zone of the workers, both during operation and maintenance. The engineering controls could include negative air throughout the treatment system, dust misting systems at strategic points throughout the system, real time monitors with alarms, and contaminant exposure badges.
- Select the appropriate technology for the known or anticipated wastes.
- Use appropriate ventilation controls.
- Install, locate, and maintain emergency fire fighting and eyewash and emergency showers at critical points throughout the system. (See ANSI Z 358.1 – 1998.)
- Use PPE appropriate to the contaminants and treatment byproducts, such as thermal protective gear, safety glasses, face shields, protective gloves, air-supplied respirators or air-purifying respirators equipped with filters/cartridges appropriate for the contaminants of concern and air emission controls.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

Radioactive Devices.
Description. Fire and smoke detection devices and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:
- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Controls of opportunistic insect and animals include:
- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evi-

dence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.

- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 24
Off-Gas Oxidation (Thermal/Catalytic)

24-1. General

The process of off-gas oxidation is described in the first section of the chapter. The chapter's second portion is a hazard analysis with controls and control points listed.

24-2. Technology Description

a. Process.

Off-gas oxidation is the incineration of contaminated air or other vapor streams to destroy the contaminants before discharge to the atmosphere. A vapor stream laden with volatile organic compounds (VOCs), produced by a soil vapor extraction (SVE) system or a landfill vent system, is blown through a duct system that contains an ignited natural gas or propane burner. The heat from the fuel combustion oxidizes the combustible components of the VOC stream and the exhaust is stack discharged. The system is designed to meet specified temperature and residence times, depending on the waste stream characteristics, ambient condition, and air permit requirements.

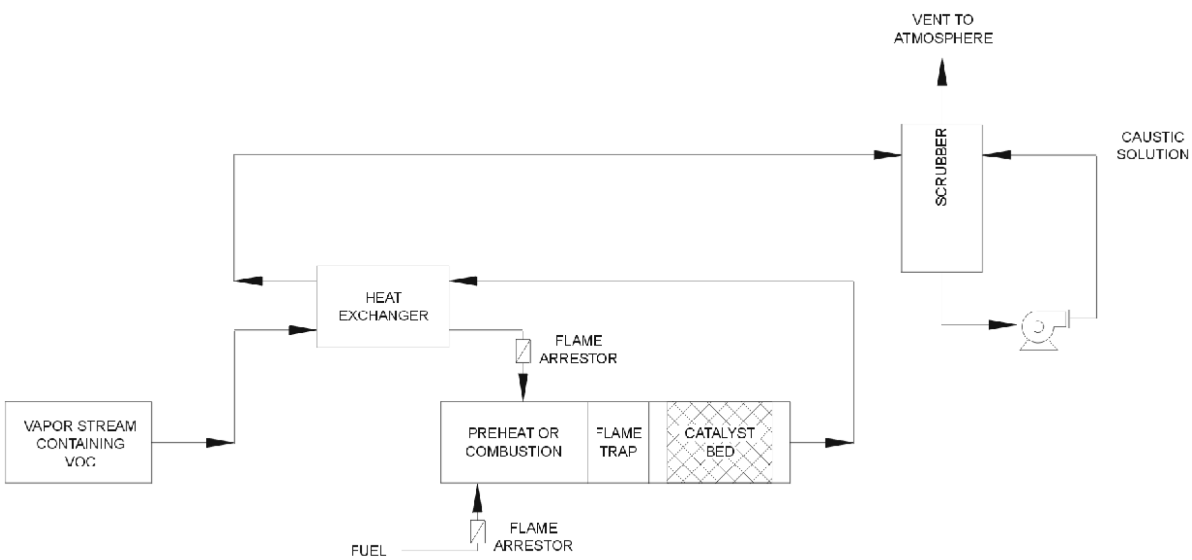


FIGURE 24-1. OFF-GAS OXIDATION (THERMAL/CATALYTIC)

In addition to the burner unit, the treatment system often incorporates catalytic oxidizer units. The unit uses a catalyst on a support, such as alumina, similar to catalytic converters in automobiles. The catalyst lowers the required treatment temperature, thereby reducing the amount of fuel and off-gas treatment required. However, the catalyst can be fouled or poisoned with chemicals such as lead, coke, and tar compounds that can be present in the waste stream. If high concentrations of chlorinated solvents are present, the catalyst support and the duct work may require special construction to cope with the hydrogen chloride gas and hydrochloric acid generated. Scrubbers may be required to remove the acid before the stream can be exhausted. See Figure 24-1.

24-3. Hazard Analysis

Principal unique hazards associated with off-gas oxidation (thermal/catalytic), methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire*.
Description. If the Btu value of the waste feed gas is not controlled and is higher than the Btu value of the feed gas for which the unit was designed, the temperature of the unit may exceed its design specifications, resulting in damage to the unit and increase the probability of releasing untreated waste gasses. Operating off-gas oxidizer systems above the design waste gas concentrations or temperature may cause auto-ignition with a resultant flashback of the flame through the waste gas feed piping system to the source.

Control. Controls for fire include:

- Use experienced operators and supervisors and train them in both the flammability characteristics of the waste feed gas, the exposure hazards of the waste feed, and design operating parameters of the off-gas oxidizer.
- Audit and apply proper quality assurance/quality control (QA/QC) to assure work is done as designed.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct deficiencies found.
- Operate the system and waste feed within design parameters.
- Do not allow airflow to exceed the capacity of the system for efficient removal of any solids present in the waste material being treated.
- Do not allow temperatures in the primary combustion chamber to exceed 95% of the ash fusion temperature (as determined by ASTM E953 (R1998) “Standard Test Method for Fusibility of Refuse-Derived Fuel (RFD) Ash”) of the solids, if any, in the waste material being treated.
- Monitor and control the catalyst bed temperatures continuously.
- Incorporate flame traps and control valves into the design to prevent source ignition.

CONTROL POINT: Design, Operations, Maintenance

(2) *Noise Hazards*.
Description. Off-gas oxidation units may cause elevated noise levels in the work area from the operation of air blowers, pumps, induced draft and exhaust

fans, high-energy venturi scrubbers, fuel injection ports, and the ignition of fuels within the combustion chamber.

Control. Controls for noise include:

- Refer to UFGS 02180A, "Remediation of Contaminated Soils and Sludges by Incineration," for noise control.
- Establish a hearing conservation program to determine necessary controls and use adequate hearing protection (see 29 CFR 1910.95).
- Train workers in the use of hearing protection and enroll them in the hearing conservation program (see 29 CFR 1910.95).
- Use personal electronic communications devices, such as a duel ear headset with microphone, to overcome ambient noise where communication is critical in high noise areas. The hearing protection/headset combinations are available commercially and should be used where needed.
- Establish vibration and noise-free areas to provide breaks from the vibration and noise, which can cause fatigue and inattention.

CONTROL POINT: Design, Operations

(3) *Flammable/Combustible Fuels*.
Description. Off-gas oxidation usually requires storage of flammable fuels (e.g., propane or natural gas, waste fuels collected from the treatment process) used to fire the off-gas oxidizer. Hazards associated with flammable/combustible fuels are usually associated with a fuel spill or release resulting in worker exposure to liquid state fuels or vaporized fuels, or a fire/explosion hazard.

Control. Controls for flammable/combustible fuels include:

- Use appropriate tanks (equipped with pressure-relief devices and bermed) to help prevent release of material (see 29 CFR 1910.106).
- Locate tanks in an appropriate location on the site.
- Ventilate the storage area adequately to help prevent the accumulation of flammable vapors.
- Use electrical equipment and fixtures that comply with NFPA 70.
- Meet mandatory requirements of NFPA 30, "Flammable and Combustible Liquids Code," NFPA 31, "Installation of Oil Burning Equipment," NFPA 54, "National Fuel Gas Code," or NFPA 58, "Standard for the Storage and Handling of Liquefied Petroleum Gases," for fuel system installation, storage, and testing.
- Permit only trained and experienced workers to work on the off-gas oxidation units.
- Use lock-out and tag-out procedures on all electrical systems during repair or maintenance in the storage area.

CONTROL POINT: Design, Construction, Maintenance

(4) *Electrocution*.
Description. Since off-gas oxidation units operate electrical systems outdoors, workers may be exposed to electrocution hazards if the electrical equipment contacts water, or any of the subunits are not properly wired or grounded.

Control. Controls for electrocution include:

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70, Chapter 5, section 500.1 through 500.10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11, and NFPA 70.
- All electrical work shall be performed in accordance with applicable electrical codes and under the supervision of a state licensed master electrician.
- Use grounded ground-fault protected equipment (equipment wiring equipped with ground fault circuit interrupters (GFCI)).
- Never allow the use of ungrounded temporary wiring during minor maintenance. In addition, use only electrical cords approved for water contact when wet and damp conditions exist.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) *Transfer Equipment Design*.
Description. Improperly designed systems can corrode or dissolve to a point of failure and cause damage to the facilities or create inhalation exposures or safety hazards.

Control. Controls for transfer equipment design include:

- Use equipment fabricated from materials that are chemically unreactive to the waste gases, fuels, and materials being transferred. Use EM 1110-1-4008, "Liquid Process Piping," and UFGS 15200A, "Liquid Process Piping," for materials selection.
- Install spill or leak detection instruments including alarms if necessary.
- Include containment drip pans or receivers where leaks may occur.

CONTROL POINT:

(6) *Burn Hazards*.
Description. Thermal/catalytic off-gas oxidizers operate at high temperatures, which may result in thermal burns to workers.

Control. Controls for burns include:

- Design the off-gas oxidizer to maximize ease of operation, physical cleaning, and maintenance to include adequately sized and easy access doors and ports where entry is required.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct deficiencies found.

- Perform manufacturer's shutdown and cool down procedures prior to working on, around, or entering oxidizer.
- Develop confined space entry permit and rigorously apply requirements.
- Verify functioning of the manufacturer's temperature safety controls and use according to instructions.
- Use safety barriers to isolate critical sections of the equipment.
- Post signs warning of high temperatures.
- Train workers in the hazards, use heat resistant gloves and protective gear, and permit worker maintenance only after process equipment has cooled.

CONTROL POINT: Design, Operations, Maintenance

(7) *Heated Surfaces*.
Description. Workers may be exposed to infrared radiation hazards associated with working in the vicinity of incinerators. The exposure, depending on the temperature of the equipment, length of exposure, and other variables may increase the risk of cataracts or heat injury.

Control. Controls for heated surfaces include:
- Minimize worker exposure time on or near hot surfaces.
- Use eye protection with the appropriate shade safety glass and reflective radiant heat protective suits if prolonged work near the radiant heat surface or source is required to control both eye and body exposure.
- Install protective barriers to shield work areas.

CONTROL POINT: Operations, Maintenance

(8) *Sunlight/UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and ultraviolet (UV) radiation. Even short-term exposure to sunlight can cause dermal damage and burns. In hot and humid conditions, sunlight can significantly contribute to the heat load, thereby increasing the risk of heat injury such as heat exhaustion, cramps, and heat stroke.

Control. Controls for Sunlight, UV radiation and heat stress include:
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length unbloused pants, and by applying UV barrier sunscreen to exposed skin. Loose clothing and sun hats should not be worn around moving parts that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.
- Shade work and break areas, if possible.
- Minimize exposure to heat stress by training the workers in the symptoms of heat stress, practicing the Buddy System, taking frequent breaks, drinking adequate fluids, and working during the cooler part of the day.

- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Operations, Maintenance

(9) *Confined Spaces*.
Description. Workers may be exposed to confined-space hazards when entering the off-gas oxidizer for inspection, maintenance, or repair. Off-gas oxidizers may have additional units to treat the exhaust combustion gases that range in physical and operational complexity, such as the off-gas oxidizer itself, exhaust gas collection/ventilation duct work, and high energy wet scrubbers to remove contaminants such as hydrochloric acid (HCl). Entry can expose workers to high concentrations of chemicals such as heavy metals, CO, H_2S, methane, and vinyl chloride. In addition to chemical exposure, treatment units that require confined space entry may also present significant physical hazards, including high temperatures, engulfment, entanglement, pinch points, oxygen deficiency, electrical, and negative pressure. Death or serious injury can result.

Control. Controls for confined spaces include:

- Design the incinerator and exhaust gas treatment systems to maximize ease of operation, physical cleaning, and preventative maintenance tasks to include accessible, adequately sized access doors and ports; and design to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Develop a pre-entry confined space permit (see 29 CFR 1910.146).
- Rigorously train workers in confined space program requirements, hazards and controls.
- Test the atmosphere within the confined space prior to entry and monitor throughout the work (see 29 CFR 1910.146).
- Design air-handling systems to minimize or eliminate oxygen-deficient locations and rigorously ventilate prior to entry of personnel.
- Perform the manufacturer's shutdown procedures and lock-out/tag-out of electrically energized systems prior to entry.
- Use temperature probes to measure internal temperatures of units prior to opening the units for entry.
- Use air-supplied respirators to control exposure hazards that are immediately dangerous to life or health (IDLH), such as potential exposure to high air concentrations of toxic compounds or asphyxiation where constant mechanical ventilation of the space alone is not sufficient to prevent the buildup of an oxygen deficient or toxic environment.

CONTROL POINT: Design, Operations, Maintenance

(9) *Emergency Wash Equipment*.

Description. Emergency shower/eyewash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eyewash equipment with functional floor drains to isolate and collect the shower/eyewash water from electrical and slip hazards.

CONTROL POINT: Design

(10) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, biological, or radiological hazards.

Control. Control for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Equipment Entry*.
Description. During maintenance or repair, workers entering the unit for cleaning, inspection, or repair of equipment may be exposed to waste materials or incomplete combustion byproducts.

Control. Controls for equipment entry include:

- Assess hazards at the time of confined-space entry (see 29 CFR 1910.146).
- Wear appropriate personal protective equipment (PPE) such as air-supplied respirator and disposable protective coveralls along with the confined space retrieval lifelines. See confined space hazards.

CONTROL POINT: Operations, Maintenance

(2) *Toxic Material Exposure (Feed or Byproducts).*
Description. During operation of the off-gas oxidation unit, workers may be exposed to waste components/toxic materials in the feed vapor and byproducts of combustion, such as carbon monoxide chlorine, hydrochloric acid, dioxin,

dibenzofurans, PCBs, lead, and mercury. Post-off-gas oxidizing units, such as wet scrubbers, often use bulk chemical or sludge additives in conjunction with the scrubbers or pre-clarifier mixing, filter press pre-coat and surge tanks, and may present significant exposure potentials, both when replenishing the chemicals and when performing routine maintenance on the units.

Control. Controls for exposure to toxic materials include:

- Train all workers involved in both the operation and maintenance of the off-gas oxidizer system and in all chemical hazards related to the generation, transport, and treatment of the contaminants, and contaminant byproducts within the system, and the bulk chemical additives used to treat the contaminants.
- Characterize and classify the gaseous waste components prior to and following oxidation.
- Feed only gaseous waste streams compatible with the process into the unit.
- Note design parameters on feed characteristics. Refer to UFGS 02180A, "Remediation of Contaminated Soils and Sludges by Incineration." Select technologies appropriate for the known or anticipated wastes.
- Design engineering controls for the system to prevent or minimize the generation or release of toxic materials/gases into the breathing zone of the workers, both during operation and maintenance. The engineering controls could include real time monitors with alarms and appropriate ventilation controls.
- Install, locate, and maintain emergency eyewash and shower units at critical points throughout the system (see ANSI Z 358.1 – 1998).
- Use PPE appropriate to the work task, to the contaminants to be treated, and to the gaseous oxidation byproducts such as thermal protective gear, acid protective gear, chemical safety goggles, safety glasses, face shields, air-supplied respirators etc. Train workers in the use of the PPE.

CONTROL POINT: Design, Operations

(3) *Transfer Equipment Design*.
Description. Highly chlorinated feed streams may generate corrosive conditions, resulting from HCL gas within the off-gas oxidation exhaust stream, causing leaks in the system. The leaks may result in worker exposure via the inhalation/ingestion/dermal exposure routes.

Control. Controls for transfer systems include:

- Use transfer equipment fabricated from materials that are chemically resistent to the chemical being transferred.
- Consult EM 11101-14008, "Liquid Process Piping," and UFGS 15200A, "Liquid Process Piping," for appropriate materials for pumping various fluids.
- Train workers in potential acid exposure hazards and associated hazard controls.

- Implement preventive maintenance program and complete periodic inspections.

CONTROL POINT: Design, Construction, Maintenance

(4) *Toxic Discharge (Catalytic Oxidation Inefficiency).*
Description. Poisoning/blinding of the catalyst with high metal or particulate loadings in the gas stream may decrease the catalytic oxidation efficiency of the system and increase the discharge of toxic wastes into the work and surrounding areas.

Control. Controls for toxic discharge include:
- Monitor and control ash content of the waste feed to prevent excessive particulates from that source.
- Pre-treat air streams adequately to remove particulates using filtration, quiescent zone separation, or washing to prevent excessive particulates.
- Consider the metals content of the air stream in the design to avoid heavy metal poisoning of the catalyst.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

Radioactive Devices.
Description. Fire ands smoke detection devices and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:
- Workers should be prevented from and warned against tampering with the devices.
- The locations of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:
- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence

of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.

- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance

Chapter 25
Open Burn/Open Detonation

25-1. General

The process, applications, and possible toxic effects of open burn/detonation are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

25-2. Technology Description

a. Process.

Explosives may be encountered as a part of remedial actions, particularly at military and industrial sites. In many circumstances, the safest or only method for the safe disposal of these materials is by burning or detonation in open pits.

Open burning/detonation uses an excavated and usually bermed burn/detonation pit in which explosives of various classes can be burned or detonated. The pit, usually excavated to a depth of 6 to 10 feet, is typically ramped on one side to permit entry. Berms provide added containment while burning or detonating. Pits with vertical walls tend to contain blasts, forcing the released energy to be expelled vertically. However, some open burn/detonation are more pan-like in their design, with wide flat shallow sides, and blast energy radiates evenly outward on all sides. Pan-styles are better suited to open burning to enhance oxygen support to the waste material. Pan-style open burning/detonation pits are less suited to detonation in areas where space in limited, owing to the wider safety zone needed around the pit's circumference. Some pan-type detonation designs include half lids or hinged sides designed to contain blasts. The material for burning (including burnable explosives) or detonation is pumped or placed into the pit. Then material is ignited or detonated from a distance by electrical or ignitable fuses or detonators, signal fuses, torch, or other ignition/initiator sources. Good safety practices dictate electrical ignition whenever possible. In the case of burning explosives, an accelerant fuel, such as fuel oil or other readily combustible material, may be poured onto the explosives to easily initiate the burn. Also included for detonations may be a primary explosive to make the explosion more efficient and complete. The contents of the pit are allowed to burn in the confined space until the burning/detonation is complete. See Figure 25-1 for an illustration of the process in simple form.

The pit may be emptied of residue between burnings/detonations or after a sequence of burnings/detonations. Burning or detonating batches of material in sequence can be highly dangerous as the operator must be certain that all burning/detonation is complete, and no premature ignition sources remain in the pit during reloading of the flammable/explosive wastes.

The operator needs a complete understanding of the age, state, and nature of the explosives or other materials to be destroyed, as well as other chemicals present. Many explosive material properties are radically different when burned or detonated in large masses versus small (e.g., large, burning masses of TNT may self-detonate while small amounts burn safely). An operator should be able to recognize certain metals, oxidizers, or reducers, know when material is partially melted, recognize aged or partially decomposed substances (e.g., picric acid), or a variety of other conditions.

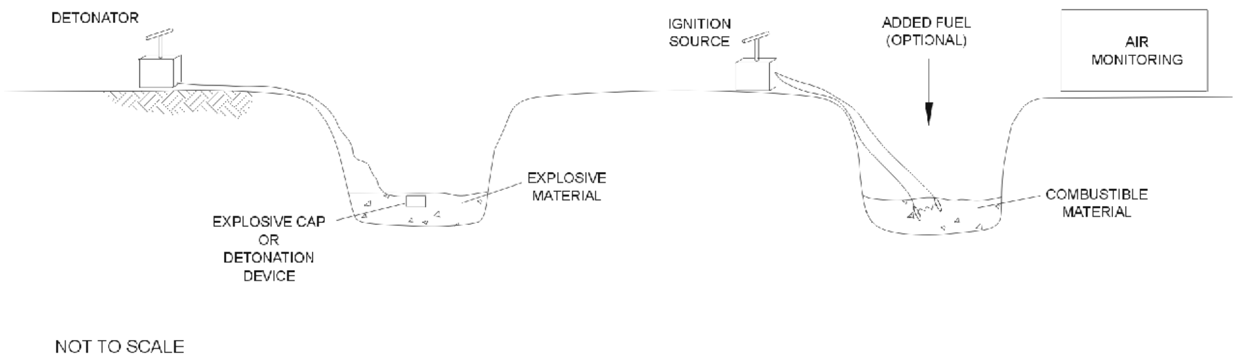


FIGURE 25-1. OPEN BURN/OPEN DETONATION

b. Applications.

Explosives include propellants, high and low explosives, many of which will burn or explode, and various initiators, ignitors, detonators, and accelerants. Included in these categories are dynamite, nitroglycerin, HMX, RDX, TNT, PETN, and Tetryl, mercury and other metal fulminates, styphnates, lead and other metal azides, ammonium nitrate, black powder, picric acid, and derivatives (such as salts) of the above.

c. Toxic Effects.

Most explosives such as TNT, RDX, picrates, HMX, tetryl, dynamite, and lead azides can have toxic effects or produce materials with toxic effects when burned or exploded. Examples of materials released or produced include unreacted explosives such as nitroglycerin and TNT, heavy metals such as mercury, lead or silver, cadmium, salt products, nitrogen oxide, and other nitrogenous residues with potential toxicity.

25-3. Hazard Analysis

Principal unique hazards associated with open burn/open detonation, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Ignition Systems*.
Description. Burning ignition systems may not reliably ignite the waste material. The wick or flame used to ignite the waste material may be temporarily extinguished by moisture or wind, only to reignite shortly thereafter. The delay in ignition may cause workers to believe the burning ignition system has failed. As they approach the burn area to investigate, detonation may occur.

Control. Controls for ignition systems include:

- Provide proper training and experience for personnel. This is critical.
- Design and construct reliable, remote, intrinsically safe ignition systems as a requirement for operation.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) *Quantity, Type of Explosives*.
Description. An explosion may damage the pit construction and injure any workers in the vicinity if more than the design quantity or type of explosives is detonated in one charge.

Control.. Controls for quantity and type of explosives include:

- Know quantities and types of explosives for the open burn/detonation pit design type and never exceed limits.
- Follow control procedures rigorously.
- Evenly distribute explosive wastes. Uneven distribution can create an excessive density of explosive material, resulting in uncontrolled explosive conditions.

CONTROL POINT: Operations

(3) *Pit Entry*.
Description. Sharp and hot fragments and residue may be present when entering the pit after prior burns or detonations. Workers may also be exposed to potential wall collapse or confined-space entry hazards.

Control. Controls for pit entry include:

- Wear appropriate personal protective equipment (PPE).
- Shore walls to prevent collapse.
- Require a structural inspection by a competent person prior to each pit entry.

CONTROL POINT: Design, Construction, Operations

(4) *Handling Waste Materials*.
Description. Hazards inherent in open burn and open detonation techniques may involve the handling of unstable waste materials, such as unusable munitions and explosive materials. Workers handling these materials face the risk of

these materials auto-detonating, especially if the explosives have become unstable because of age or other factors.

Control. Controls for handling waste materials include:

- Use only persons specifically trained in detonation and disposal techniques to transport and handle materials.
- Consult the Ordnance and Explosive Waste (OE) Center of Expertise (CX), Huntsville, Alabama, prior to any handling or movement of explosive items or of soils/materials significantly contaminated with explosives.

CONTROL POINT: Operations

(5) *Structures at or Near Detonation*.
Description. One or repeated explosions may cause mortar deterioration or fragmentation of concrete or cinder block walls of buildings or structures at or near the detonation area, particularly if large quantities of explosive materials are detonated.

Control. Controls for damage to structures nearby include:

- Limit the amount of waste materials detonated at any one time based on the known effects of the explosives.
- Consider using seismic monitoring of critical structures during the controlled detonation of the explosives.
- Divide large volumes of wastes and detonate in a series of smaller explosions.
- Locate the treatment facility carefully so that sensitive structures are not present or nearby.
- Design structures for shelter or containment of the explosions or burnings to adequately withstand the expected use of the system.

CONTROL POINT: Design, Operations

(6) *UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and the corresponding ultraviolet (UV) radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.
- Shade work and break areas, if possible.

- Minimize exposure to heat stress conditions by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(7) *Blast Noise Pressure.*
Description. Workers may be exposed to high impact noise pressure from the detonation. Even short-term exposure to high impact or explosion noise pressure can cause permanent hearing loss.

Control. Controls for high noise pressure include:

- Provide adequate distance from the explosion noise source in the burn/detonation pit based on the formula for Sound Pressure Level (SPL) as a function of distance from a point source, such that the distance will reduce impulse/impact sound pressure "at the ear" to levels preventing hearing loss or damage without the use of engineering controls (<140 dB impact noise (Peak)).
- Install noise pressure impact reducing barriers. Allow detonation only after workers are moved to safe zones or barriers proximate to the impact noise detonation sources.
- Use personal protective hearing devices including use of duel protection of plugs plus muffs.
- Establish and adhere to a hearing conservation program for the detonation workers. See DoD 6055.12 - 1996: "DoD Hearing Conservation Program".
- Train workers in the noise hazards of detonation.

CONTROL POINT: Design, operations

(8) *Continuous Noise Pressure.*
Description. Workers may be exposed to high continuous noise pressure from heavy equipment operations related to construction of the detonation pits. Unprotected, workers can suffer permanent hearing loss from the equipment noise.

Control. Controls for high noise pressure include:

- Allow only workers essential to the operation of the heavy equipment in the operation areas. Distance other on-site workers from the noise sources based on the formula for Sound Pressure Level (SPL) as a function of distance from a point source, such that the distance will reduce sound pressure "at the ear" to levels preventing hearing loss or damage without the use of engineering controls.

- Use personal protective hearing devices with total allowable NRR ratings to reduce the A-weighted sound pressure levels to within acceptable levels based on federal regulations while maintaining personal communication abilities (avoid significant over protection and consider using hearing protection with integrated communication devices for the equipment operators and ground spotters).
- Establish and adhere to a hearing conservation program for the detonation workers. See 29 CFR 1910.95, 29 CFR 1926.101 and DoD 6055.12.
- Train workers in the noise hazards of heavy equipment operation.

CONTROL POINT: Design, operations

(9) *Design Field Activities.*
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, geophysical surveys, trenching, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, biological, or radiological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Residual Cadmium, Crystalline Silica or Other Material*.
Description. Significant exposures to residual soil cadmium or crystalline silica among heavy equipment operators is possible during trench excavations at the demolition location, especially during high heat and dry ambient conditions that greatly increase the creation of fugitive dust. Cadmium, used as a plating to prevent corrosion of steel bomb casings, can accumulate as an explosion byproduct in the soil. On rare occasions some bombs may contain an asbestos-tar matrix used as an internal coating. Repeated use of the same location for bomb detonation tends over time to pulverize the soil particles, including naturally occurring crystalline silica (sand) into fine dust, creating a respirable dust hazard to the equipment operators.

Control. Controls for residual cadmium, respirable crystalline silica or other materials:

- Train the site workers in the hazards associated with inhalation of cadmium or respirable crystalline silica or asbestos.
- Do not operate multiple pieces of heavy trenching equipment down wind of each other.
- Whenever possible, take advantage of ambient moisture and wind conditions to minimize the creation and stagnation of fugitive dust during trenching operations.
- Use water spray or other wetting agents from tank trucks to treat the detonation location before and during trenching to reduce fugitive dust emissions.
- Equip heavy equipment operators with appropriate N, R or P 100 particulate filter air purifying respirators (APRs) or air-supplied respirators to control the inhalation hazard created by the fugitive dust. Institute a respiratory protection program that accounts for the characteristics of the fugitive dust.
- Use laundered work clothing or permeable disposable work clothing that minimizes the risk of heat stress, in conjunction with work-site shower and clean changing facilities for all site workers.

CONTROL POINT: Operations

(2) *Residual or Untreated Material*.
Description. If detonation or burning fails to fully neutralize the material, workers entering the burn pit may be exposed to it. Unreacted material may be carried downwind, exposing workers in the area. Heavy metal primer materials (metal azides and lead, mercury or silver compounds) and residual explosive components (e.g., nitroglycerin) may cause heart arrhythmias, headaches, and other physical effects.

Control. Controls for residual or untreated material include:
- Remain upwind of the pit during burning and detonations.
- Use PPE, as determined by a qualified health and safety professional, when entering the pit after burning and explosions. Examples of appropriate PPE include steel shank boots, coveralls to protect from dermal contact, nitrile or butyl gloves if soil handling is expected, and an appropriate air-purifying respirator if fumes or smoke are present.
- Use experts in detonations and burning, including accelerants or fuels or initiator explosives, to assure the maximum explosive/waste consumption.

CONTROL POINT: Design, Operations

(3) *Pit Atmospheric Conditions*.
Description. Workers who enter the pit may be exposed to an oxygen deficient atmosphere, to airborne toxic materials or carbon monoxide from the persistence of gases generated from subsurface blasting operations. A special

case involves the presence of liquid fuel storage facilities at the site that could contribute to confined space toxic atmospheres.

Control. Controls for pit atmospheric conditions include:

- Test the atmosphere within the trench to determine the level of airborne toxins, carbon monoxide, and oxygen level prior to entry (see 29 CFR 1910.146).
- Follow confined-space entry protocols, which may necessitate the use of PPE such as an air-purifying respirator equipped with an organic vapor cartridge, a supplied-air respirator or self-contained breathing apparatus (SCBA).

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

Description. If used infrequently or located in wooded or remote areas, snakes, including poisonous snakes, may use the open pan-type burn-detonation areas for sun bathing. This occurs particularly in spring and fall when there are significant temperatures variations between day and night. Care must be taken on first walking up to remote, infrequently used open pan-type burn areas.

Control. Controls for open burn pit/detonation biological hazards include:

- Visually inspect pit area for wildlife prior to bringing material, particularly shock sensitive materials, to the open burn/detonation area.
- Prepare to chase wildlife out of the open burn/detonation area from a distance using loud noises, stomping, or tossing non-hazardous debris in their area.
- Do not attempt to manually remove any wildlife without proper training and equipment. Call for specialized assistance from departments of natural resources or similar wildlife specialists.
- Do not burn or detonate wildlife.

CONTROL POINT: Operations, Maintenance

APPENDIX A
REFERENCES

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58	Liquefied Petroleum Gas Code, 2001.
70	National Electrical Code, 2002.

GLOSSARY

Annular Space: The space around the outside of the well pipe or casing between the native soil and the well pipe.

Aquifer: An underground body of water capable of producing fresh water at a sufficient rate to be considered a water source. While most aquifers are unconfined (on the sides), they have identifiable floors of impermeable material that define their thickness.

Attrition: Mechanical wear process in which particles rub and abrade against each other removing adhered surface contaminants and contaminated soils.

BTEX: Benzene, toluene, ethylbenzene and xylenes; a group of aromatic hydrocarbons that are present in gasoline and to a lesser extent in diesel fuel. They may also be used individually as solvents. Benzene is a known human carcinogen.

Control Point: The phase of the operation where worker exposure may occur.

DMSO: Dimethyl Sulfoxide; a clear, colorless, odorless liquid that is miscible in water and most organic solvents.

DNAPL: Dense Non-Aqueous Phase Liquids; organic and inorganic liquids denser than water and high enough in concentration to exceed their solubility in water, thus able to flow down the pores of the soil and sink through groundwater to form a discrete pool or phase beneath the surface of the groundwater.

Ex-Situ: "Out of Place"; remediation technologies that require excavation of solids or pumping of groundwater to effectively solve the contamination problem.

Flocculent: A chemical that can bind two or more molecules or complexes so as to form increasingly larger complexes of molecules until the complexes float or sink as large masses.

GCL: Geosynthetic Clay used as a bottom liner in landfills.

HDPE: High Density Polyethylene; an inexpensive, readily available plastic liner material for landfills and landfarms. The plastic has good mechanical strength and toughness but is subject to corrosive attack from some organic materials.

Hollow Stem Auger: A drilling method where a series of hollow shafts with a screw-type flight are assembled, typically in 5-foot-long sections, and turned in a borehole to drill by lifting soil up the flights. The hollow center may be used to drive sampling devices into the soil ahead of the auger to collect undisturbed environmental soil samples.

In-Situ: "In Place"; refers to remediation methods that do not require the soil or water to be brought to the surface and hence do not require excavation or pumping.

Leachate: Liquid material that drains from the bottom or sides of a landfill or other waste storage area.

LNAPL : Light Non-Aqueous Phase Liquids; organic and inorganic liquids less dense than water and high enough in concentration to exceed their solubility in water, thus able to sink through the open pores of the soil to the groundwater and to float on the groundwater to form a discrete pool or phase at the surface of the groundwater.

Mast: The elevated portion of a drill rig that shrouds and protects the drilling flights and drive mechanisms. On most drill rigs, the mast is kept in a horizontal (lowered) position during traveling and when not in use. It is raised into vertical position after the rig has been located at the appropriate drilling spot.

Mud (Drilling Mud): A slurry prepared from bentonite or other fine-grained solid material that may be used as a lubricant for the drilling bits used in borings or well installations or to seal the edges of the boring. Muds are most commonly used in petroleum or other deep drilling. When mud drilling is used in environmental well installations, the mud should be removed to the extent practical before sampling, or a biodegradable mud should be used to prevent the mud from sealing the borehole.

NAPL: Non-Aqueous Phase Liquid; any organic or inorganic liquid sufficiently high in concentration to exceed its solubility in water and thus exist in the environment as a discrete phase, usually beneath or on groundwater.

Neutron Density Gauge: A measurement device used to determine moisture content in clays and other soil materials. The device contains a radioactive source as part of the measurement mechanism.

NORM: Naturally Occurring Radioactive Materials.

Pathogen: A microorganism that is known to cause diseases in plants, animals, or humans.

POTW: Publicly Owned Treatment Works; a municipal or county water treatment works.

PPE: Personal Protection Equipment; the various pieces of clothing (steel-toed shoes, gloves, coveralls, etc.) and respirator equipment used by personnel for their personal protection from a variety of chemical, physical, radiological, and biological hazards.

Pug Mill: A type of mixing equipment that utilizes a rugged mixing blade configuration to mix high-solid slurries. It may be used to add solids to slurries as a means of thickening.

Pump-and-Treat: A treatment process whereby groundwater is extracted from a contaminated aquifer and treated by some appropriate technology on the surface before reinjection, infiltration, or discharge to a surface water.

PVC: Polyvinyl Chloride; an inexpensive, resilient plastic that has good resistance to many chemicals, frequently used in piping systems and sometimes used as a flexible liner for landfilling and landfarm applications.

RBC: Rotating Biological Contactor; a biological reactor consisting of a series of closely placed rotating disks with a very high total surface area capable of being colonized by a thin film of microbes. The rotating disks are half-immersed in the wastewater stream as it flows through the disks housing, allowing the fixed film microbes to be repeatedly soaked in the wastewater while emerging repeatedly into the air, thus allowing the microbes to aerobically degrade the contaminants in the wastewater.

Surfactants: “Surface Active Agents”; chemicals of a large range of types (ionic, non-ionic, zwitterionic) that contain both polar and non-polar molecule regions.

SVE: Soil Vapor Extraction; the process of removing volatile and some semivolatile contaminants by the combined effects of vacuum-increased volatility and vacuum-enhanced mass flow of air into, through, and out of a contaminated unsaturated subsurface zone, thus removing an increased mass of the volatilized contaminants.

SVOC: Semivolatile Organic Compounds; any of a large group of compounds including the polynuclear aromatic compounds (PNAs) and the polyaromatic hydrocarbons (PAHs) that are low in volatility under normal atmospheric conditions.

TCLP: Toxicity Characteristic Leaching Procedure; an EPA-defined analytical procedure used to classify waste for disposal purposes.

Vadose Zone: The region in the subsurface between the ground surface and the top of the capillary fringe above the water table. This region is characterized by the presence of some liquid water but also some open (vapor-filled) pore spaces.

VOC: Volatile Organic Compounds; any of a large group of compounds including the monoaromatic (BTEX) and ketones (MEK, acetone, MIBK) that are readily volatile under normal atmospheric conditions.