Designation: E2435 − 05 (Reapproved 2020)

Standard Guide for Application of Engineering Controls to Facilitate Use or Redevelopment of Chemical-Affected Properties[1]

This standard is issued under the fixed designation E2435; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Environmental media, such as soil, groundwater, or air, are susceptible to impact by chemical releases associated with past property-use activities; or they may be affected by naturally occurring conditions. Previously developed properties may have been impacted by chemical releases associated with historical operations, chemical spill incidents, waste management practices, or other related sources of COCs. In some cases, such chemicals may remain in soil, groundwater, or other environmental media; and, depending on their toxicity, concentration, location, and migration potential in the environment, they can pose a potential health risk in the event of exposure of current or future property users. Similarly, in the absence of a chemical release caused by human activity, COCs that are naturally present in soils, groundwater, soil vapors, or other environmental media can pose an unacceptable risk to human health, depending on the chemical toxicity and exposure (e.g., radon gas emanation into indoor air space of overlying buildings). Under certain conditions, in the absence of exposure controls, human exposure to chemical-affected environmental media at residential, commercial, or industrial properties could occur via various exposure pathways, including but not limited to (*1*) surface soil direct contact, (*2*) ambient or indoor air vapor exposure, or (*3*) affected groundwater impact on subsurface structures or utilities. Other pathways or exposure mechanisms may exist, and if so, should be addressed in a similar manner to those addressed in the guide.

1. Scope

1.1 This guide presents general considerations for application of engineering controls to facilitate continued use or redevelopment of properties containing chemical-affected soil, groundwater, or other environmental media, due either to chemical releases or naturally-occurring conditions. This guide is not meant to be prescriptive but rather to present considerations for evaluating technologies capable of addressing potential human exposures associated with chemical-affected environmental media.

1.2 Table 1 lists the considerations that should be taken into account when developing an engineering control in accordance with this guide.

1.3 This guide is intended for use by real estate developers, civil/structural designers, environmental regulators, industrial parties, environmental consultants, and other persons concerned with residential, commercial, or industrial development of real properties where chemical-affected environmental media are present. The design process should involve the individuals and firms working on various aspects of the specifications for construction, operation, and maintenance. If the site is located on public property, then public participation should be considered during the design process.

1.4 This guide is directed toward properties where chemical-affected environmental media, associated with either human-influenced activities or naturally-occurring conditions, will remain in place and where active or passive engineering controls will be used to reduce or eliminate exposures that may otherwise pose an unacceptable risk to property users.

1.5 This guide identifies the exposure concerns associated with chemical-affected properties that may affect the property development plan, both in the construction phase and during the proposed use of the property; defines performance standards for control of applicable exposure pathways; and, for each exposure pathway, provides examples of engineering controls that may be applied for new or existing construction.

[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.04 on Corrective Action.

Current edition approved Nov. 1, 2020. Published November 2020. Originally approved in 2005. Last previous edition approved in 2015 as E2435 – 05(2015). DOI: 10.1520/E2435-05R20.

TABLE 1 Design Considerations for Engineering Controls[A]

Task/Description	Reference[B]	Check: When Complete	Check: If Not Applicable
SITE CHARACTERIZATION			
1. Regulatory Framework			
• *Regulations:* Identify federal, state, and local laws, rules, and ordinances applicable to site characterization and engineering controls. Ensure design and installation conform to technical standards specified in regulations.	6.3.9	☐	☐
• *Guidance:* Identify relevant guidance documents.	4.6,6.3.9	☐	☐
• *Risk Limits:* Define unacceptable risk per regulatory framework or other process.	5.2	☐	☐
• *Permitting:* Complete permitting, notification, and activity and use limitations per regulatory requirements.	6.3.9	☐	☐
2. Site Conceptual Model			
• *Delineation:* Define extent of chemical-affected environmental media: soil, groundwater, air, other.	5.2.1	☐	☐
• *Chemicals of Concern:* Identify COCs, toxicity, concentrations, locations, migration potential.	5.2.1	☐	☐
• *Receptors:* Identify potential receptors, complete exposure pathways, define anticipated property use during design life of engineering control.	5.2.1	☐	☐
SITE DEVELOPMENT PLAN			
1. Considerations for Site Development Plan			
• *Human Contact:* Reduce or eliminate human contact with chemical-affected environmental media.	5.3.1	☐	☐
• *Waste:* Limit generation of hazardous waste materials.	5.3.1	☐	☐
• *COC Migration:* Prevent off-site migration of COCs.	5.3.1	☐	☐
• *Plume Expansion:* Prevent expansion of affected soil and groundwater zones.	5.3.1	☐	☐
2. Limitations on Site Development Plan			
• *Subsurface Construction:* Consider locations of structures and subsurface penetrations, consider direct contact with chemical-affected groundwater during construction.	5.3.2	☐	☐
• *Existing Facilities:* Consider need to maintain existing engineering controls.	5.3.2	☐	☐
DESIGN OF ENGINEERING CONTROLS			
1. Achievement of Performance Standard			
• *Risk Limits:* Reduce or eliminate unacceptable risk by either or both of the following: a. By preventing direct contact with chemical-affected environmental media. b. By preventing migration of COCs from chemical-affected environmental media to point of exposure.	6.1.1	☐	☐
• *Design Life:* Set design life of engineering control equal to lesser of the following: a. Expected duration of the exposure hazard. b. Expected duration of the site or structure for the specified property use.	6.1.2	☐	☐
2. Application of Engineering Controls to Specific Exposure Pathways			
• *Direct Contact:* Prevent surface soil direct contact by either or both of the following a. Obstructing human contact with chemical-affected soil. b. Impeding the release of wind-driven soil particulates into the air.	6.2.1	☐	☐
• *Soil or Groundwater Vapors:* Prevent inhalation of vapors at concentrations exceeding unacceptable risk levels by inhibiting migration of vapors to ambient or indoor air.	6.2.2	☐	☐
• *Groundwater Impacts:* Prevent impact of affected groundwater on subsurface structures or utilities by installing a barrier to flow.	6.2.3	☐	☐
3. Design Specifications			
• *Qualifications:* Prepare design specification by qualified persons having required professional or regulatory certifications.	4.5,6.3	☐	☐
• *Participation:* Solicit, consider, and incorporate input from individuals and firms working on various aspects of the design, construction, operation, and maintenance specifications.	1.3	☐	☐
• *Documentation:* Document design specifications in sufficient detail to evaluate compliance with performance criteria.	6.3	☐	☐
• *Design Basis Information:* Develop design basis information sufficient to support engineering design of components of the engineering control.	6.3.1	☐	☐
• *Effective Area:* Define effective area to address the full area or volume, or both, of the chemical-affected environmental media requiring exposure control.	6.3.2	☐	☐
• *Defining Boundary:* Specify defining boundary to physically demarcate or document engineering control or area of chemical-affected media, or both.	6.3.2	☐	☐
• *Components:* Specify design components of engineering control, including details of design, installation, and operation and maintenance.	6.3.3	☐	☐
• *Dimensions and Material Specifications:* Evaluate the properties of each design component (e.g., material strength, durability, corrosion resistance, chemical compatibility) for capability to achieve the specified performance standard for the duration of the design life under anticipated site conditions.	6.3.4	☐	☐
• *Treatment System:* Specify design for construction or installation of treatment system for soil or groundwater, including removal efficiency or required concentrations after treatment.	6.3.5	☐	☐
• *Documentation:* Prepare record drawings, drawings conforming to construction records, or other written records to document installation of engineering control.	6.3.7	☐	☐
INSTALLATION OF ENGINEERING CONTROLS			
• *QA/QC Program:* Set up system of inspections, monitoring, or testing, or combination thereof, to confirm installation in accordance with design specifications.	7.1	☐	☐
• *Qualifications:* Specify installation by persons qualified to complete work by reason of professional or regulatory certifications.	7.2	☐	☐

TABLE 1 *Continued*

Task/Description	Reference[B]	Check: When Complete	Check: If Not Applicable
MONITORING AND MAINTENANCE OF ENGINEERING CONTROLS			
• *Obligatory Requirements:* Ensure monitoring requirements comply with enforcement instruments for site (e.g., consent agreement, consent order, order, permit, etc.).	8.1	☐	☐
• *Periodic Monitoring:* Specify type (e.g., visual inspection, physical measurements, sampling and testing) and frequency, of monitoring programs needed to assess performance of engineering control and fulfill regulatory requirements. Include triggers for non-routine monitoring.	8.2	☐	☐
• *Maintenance:* Describe schedule and procedures for conducting repairs or replacements indicated by periodic monitoring.	8.3	☐	☐
• *Assessment:* Describe procedures for assessing the performance of the engineering control and implementing changes as needed to address results of the periodic monitoring.	8.4	☐	☐
• *Re-Evaluation:* Describe procedures for re-evaluating the performance of the engineering control and implementing changes as needed to address (*1*) a change in land use, regulatory criteria, or site development plan; or (*2*) a newly identified risk.	4.4,5.4,8.4	☐	☐
USE OF ACTIVITY AND USE LIMITATIONS			
• *Need for Activity and Use Limitations:* Identify the activity and use limitations to be implemented along with engineering controls in order to control risk.	9.1	☐	☐
• *Recordation:* File activity and use limitations in real property records of governmental entities having jurisdiction over the site in order to notify future owners and users of the site about the presence of engineering controls.	9.2	☐	☐

[A] Table presents design issues to be considered to demonstrate that the design of an engineering control for chemical-affected property has been developed in accordance with this guide. Consideration of the issues should be documented in accordance with the identified regulatory framework for the site.
[B] References indicate sections of this guide.

1.6 This guide will assist in identification of the optimal property development plan for a property with chemical-affected environmental media. Such a plan will address both short-term construction issues and long-term exposures of property users.

1.7 This guide does not address the broader range of environmental concerns that are not directly affected by construction measures and engineering controls (e.g., protection of water resources or ecological receptors).

1.8 Detailed specifications for site-specific application of engineering controls are not addressed in this guide. The user is referred to other related ASTM standards and technical guidelines regarding the implementation of the site evaluation and corrective action process, as well as the detailed design, installation, operation, and maintenance of these engineering controls.

1.9 The overall strategy for addressing unacceptable risks may employ either remedial actions or activity and use limitations, or both. Engineering controls are a subset of remedial actions given that (*1*) remedial actions involve cutting off the exposure pathway or reducing the concentration of COCs, or both and (*2*) that engineering controls only involve cutting off the exposure pathway. Engineering controls are briefly described in Guide E2091, which describes a broad range of options for managing risk. This guide covers implementation of engineering controls in a detailed manner, thereby providing a needed complement to the information provided in Guide E2091.

1.10 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.12 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 The pertinent ASTM standards for development of engineering controls at chemical-affected properties are listed below. Additional standards and other non-ASTM references related to the development of engineering controls at chemical-affected properties are provided in Appendix X6.

2.2 *ASTM Standards:*[2]

C1193 Guide for Use of Joint Sealants

C1299 Guide for Use in Selection of Liquid-Applied Sealants (Withdrawn 2012)[3]

E1689 Guide for Developing Conceptual Site Models for Contaminated Sites

E1745 Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs

E1984 Guide for Brownfields Redevelopment (Withdrawn 2012)[3]

E2081 Guide for Risk-Based Corrective Action

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

E2091 Guide for Use of Activity and Use Limitations, Including Institutional and Engineering Controls
E2121 Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings

3. Terminology

3.1 *active engineering control*—active engineering control systems involve the input of energy (e.g., electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other energy source) to remove, treat, or control chemical-affected environmental media. Examples of active engineering controls include, but are not limited to, groundwater pumping, vapor extraction, in-situ chemical or biological treatment, active sub-slab ventilation systems.

3.2 *activity and use limitations*—legal or physical restrictions or limitations on the use of, or access to, a site or facility so as to eliminate or minimize potential exposures to COCs.

3.3 *chemical(s) of concern (COCs)*—the specific compounds and their breakdown products that are identified for evaluation in the Risk-Based Corrective Action (RBCA) process or redevelopment process, based upon their current or historical use at the property; detected concentrations in environmental media; and mobility, toxicity, and persistence in the environment. COCs may include, but are not limited to, methane, petroleum hydrocarbons, radon, organic chemicals, inorganic chemicals, metals, etc.

3.4 *chemical release*—any spill or leak of COC(s) to an environmental medium.

3.5 *chemical-affected environmental medium*—environmental medium which has been physically or chemically altered or otherwise adversely impacted by one or more COCs in excess of background levels or other applicable regulatory standard or beneficial use criterion.

3.6 *engineering controls*—physical modifications to a site or facility installed to reduce or eliminate the potential for exposure to COCs.

3.7 *environmental medium*—naturally-occurring physical material in the environment, including but not limited to ambient or indoor air, air in soil pore spaces, soils, groundwater, or surface water.

3.8 *exposure pathway*—the course that a COC takes from the source area(s) to a receptor. An exposure pathway describes the mechanism by which an individual or population is exposed to a COC originating from a site. Each exposure pathway includes a source from which a release of a COC occurs, an exposure route, and a point of exposure where a human receptor may come in contact with the COC. If the exposure point is not at the source, then a transport medium or exposure medium, or both (for example, air or water), are also included in the exposure pathway.

3.9 *exposure route*—the manner in which a COC comes in contact with a receptor (for example, ingestion, inhalation, dermal contact).

3.10 *passive engineering controls*—passive engineering control systems either require no energy or chemical input or take advantage of natural conditions (e.g., barometric pressure variations) to remove or control, or both, chemical-affected environmental media. Passive controls may include those involving only physical barriers or flow controls. Examples of passive controls include, but are not limited to, groundwater seepage barriers, surface soil covers, passive vapor controls, surface covers, and polymeric membrane liners.

3.11 *potentially complete exposure pathway*—a situation with a reasonably likely chance of occurrence in which a human receptor may become directly or indirectly exposed to the COC(s).

3.12 *property*—real property, including land and associated improvements, as well as all environmental media contained within the legal boundaries. The environmental media containing COCs may extend over all or a portion of one or more properties.

3.13 *property development*—the human-influenced alteration of a property, including but not limited to the construction of improvements such as buildings, roadways, utilities, landscaped areas, parking lots or structures, recreational areas, or other such features associated with residential, commercial, or industrial land use.

3.14 *property development plan*—the short-term and long-term strategies or schemes for implementing the human-influenced alteration of a property.

3.15 *risk*—the potential for, or probability of, an adverse effect, which may be expressed either quantitatively or qualitatively.

3.16 *surface soil*—the soil zone that a human receptor could reasonably come into contact with, currently or at some time in the future. The surface soil zone extends from ground surface to the shallower of the following: (*1*) the depth specified in applicable law, rule, or ordinance, depending upon the planned land use; or (*2*) a depth extending no deeper than the top of the uppermost groundwater-bearing unit or bedrock.

3.17 *unacceptable risk*—a risk which exceeds regulatory, published, or other criteria based on site-specific considerations and a human health-risk assessment.

4. Significance and Use

4.1 *Intended Application of Guide*—This guide is intended for use at properties that are presently developed or proposed for development for residential, commercial, or industrial purposes but which contain chemical-affected soil, groundwater, air, or other environmental media, which may pose an unacceptable risk to human health. This guide can be used as a tool for planning and implementation of property reuse or redevelopment activities at former commercial/industrial facilities, "brownfield" properties, or properties containing naturally occurring, chemical-affected environmental media so as to effectively manage potential human exposures to COCs which might otherwise limit productive use of the property.

4.2 *Situations Where This Guide May Be Applied*—An engineering control may be needed as part of the development plan when: (*1*) COCs are present in soil, groundwater, or other environmental media at concentrations posing unacceptable risk(s) to human health per applicable regulatory criteria or a risk-based evaluation; (*2*) a potentially complete exposure pathway for COCs is likely to exist in the absence of an engineering control or other response measure, and (*3*) installation and maintenance of the engineering control is determined to be an applicable and cost-effective response action relative to other options. A property should not be excluded from development or redevelopment solely on the basis of chemical-affected media, in general, and chemical-affected groundwater, in particular. If no affected environmental media are identified as having COC concentrations in excess of applicable regulatory standards or risk-based criteria, then engineering controls or other response measures are not required.

4.3 *Assumptions for Use of This Guide*—For use of this guide, it is assumed that (*1*) an environmental site assessment has been completed to characterize chemical-affected environmental media, (*2*) exposures to COCs posing an unacceptable risk to the health of current or future property users have been identified based upon a risk-based corrective action analysis or other evaluation consistent with applicable regulatory requirements, and (*3*) engineering controls are being considered as a potentially effective and acceptable measure to manage exposures to chemical-affected environmental media remaining in place at the property. This guide assumes that the property is served by a public water supply or other water source so that use of on-site groundwater or surface water resources as a water supply is not necessary.

4.4 *Presumptive Use of Engineering Controls*—The design basis for any engineering controls installed depends on the risk to be controlled, nevertheless, if no known risk has been identified, the guide may be implemented at the discretion of the site developer. As a conservative measure to reduce or eliminate potential unidentified exposures (e.g., migration of COCs from adjacent properties with known chemical-affected environmental media), the site developer may choose to install engineering controls in the absence of a detailed site characterization and associated risk-based corrective action analysis. Regardless, the site must be sufficiently characterized as to the types and concentrations of the COCs present in order to design and install engineering controls that will effectively mitigate the potentially complete exposure pathway(s) identified for the site. Upon change in land use, the potential for unacceptable risk should be evaluated and the engineering control modified, if so indicated by the results of the evaluation.

4.5 *Expected Qualifications for Persons Applying This Guide*—Persons applying this guide are expected to be sufficiently knowledgeable in various disciplines, including but not limited to environmental science, property development requirements, or engineering applications, or combination thereof. Such knowledge is required in order to (*1*) interpret the results of environmental site assessments and risk-based corrective action analyses and (*2*) identify applicable construction measures and engineering controls, as needed to reduce or eliminate unacceptable human exposures to chemical-affected environmental media while achieving property development goals. Persons implementing this guide are responsible for ensuring that the application of the guide, as well as design, installation, and monitoring and maintenance of engineering controls identified for a site by the guide, are performed, reviewed, or certified, or combination thereof, by persons qualified to complete work of this nature by reason of professional or regulatory certifications, or both.

4.6 *Intended Compatibility with Other ASTM Guides*—This guide is intended to be compatible with other ASTM guides related to the investigation and characterization of chemical-affected property and the management of associated human health risks. This guide is consistent with the practices set forth in these other guides but provides a more focused evaluation on engineering controls as measures to manage risk specifically associated with property development activities.

4.7 *Limitations on Use of This Guide*—This guide provides a general overview of the procedures for evaluation and selection of engineering controls for use in property development or reuse, but does not address the detailed design, installation, operation, or maintenance of these engineering controls. The user is referred to other, more detailed technical design guidelines for proper implementation of such controls on a site-specific basis.

4.8 *Situations Not Addressed*—This guide does not address other environmental issues or concerns that are not directly related to property development or reuse but which may be required under applicable laws or regulations. Such uses may include groundwater protection, surface water protection, or ecological concerns.

4.9 *Costs Associated with Engineering Controls*—The costs for engineering control systems will depend on numerous site specific factors (e.g., area and volume of chemical-affected environmental media, COCs, unacceptable risks to be reduced or eliminated). An exhaustive comparison of costs associated with various engineering control systems is beyond the scope of this guide; however, in order to illustrate the potential cost impact of site development using engineering controls, a case study example is presented in Appendix X4.

5. General Considerations for Use or Redevelopment of Chemical-Affected Property

5.1 *Overview*—Continued use or redevelopment of property containing chemical-affected environmental media may entail consideration of potential human exposure concerns, both during the construction phase and during the subsequent use of the property. To address these issues, the nature and extent of chemical-affected environmental media should first be characterized based on an environmental site assessment. Based upon this information, a risk-based corrective action analysis or other relevant evaluation should then be conducted by a competent individual to define potentially complete exposure pathways under the current or proposed land use. The site development plan should address design and construction constraints related to contact with or mobilization of chemical-affected environmental media, as well as waste production and related costs. Consideration of the following environmental factors in the planning process can facilitate safe and economical use or redevelopment, or both, of the property.

5.2 *Conceptual Exposure Model*—The conceptual exposure model is a representation of an environmental system which includes the biological, physical, and chemical processes that determine the fate and transport of COCs through environmental media to receptors within that system. The purpose of the conceptual exposure model is the characterization of exposure pathways which includes (*1*) delineation of zones of chemical-affected environmental media, (*2*) determination of fate and transport mechanisms, and (*3*) identification of potential human receptors. Procedures for development of the conceptual exposure model are provided in Guide E1689.

5.2.1 *Chemical-Affected Environmental Media*—The nature and extent of chemical-affected environmental media should be characterized sufficiently to support development of the conceptual exposure model and to support evaluation of applicable engineering control measures. Characterization may include delineation of chemical-affected environmental media; determination of unsaturated or saturated soil properties (e.g., grain size, soil type), or determination of groundwater-bearing unit properties (e.g., hydraulic conductivity, thickness, porosity), or combination thereof. This evaluation must also consider naturally occurring conditions having the potential to cause unacceptable risk to human health (e.g., radon, methane).

5.2.2 *Potentially Complete Exposure Pathways and Corrective Action Goals*—Based upon the characterization of chemical-affected environmental media, potentially complete pathways for human exposure should be defined on a site-specific basis. This information should then be used to establish corrective action goals as needed to reduce or eliminate unacceptable risks associated with chemical-affected environmental media during and after property development activities.

5.3 *Short-Term Construction Issues and Property Development Constraints*—Use and development of chemical-affected property may entail design and construction considerations not encountered at unaffected properties, including (*1*) exposure of construction workers to chemical-affected environmental media; (*2*) mobilization of chemical-affected environmental media or COCs during or after site development activities (e.g., dust, excavation, leaching to groundwater); (*3*) generation of chemical-affected environmental media classified as waste material requiring special handling, treatment, or disposal procedures; (*4*) preservation of engineering controls or activity and use limitations established in accordance with prior regulatory approval (e.g., soil leachate control systems or surface covers to control migration of chemicals via soil leaching to groundwater); or (*5*) other regulatory restrictions related to property use.

5.3.1 *Considerations for Site Development Plan*—Design and construction considerations may affect the site development plan as needed to (*1*) reduce or eliminate human contact with chemical-affected environmental media, (*2*) manage the generation, storage, and disposal of hazardous waste materials, if required, (*3*) prevent off-site migration of COCs in environmental media or the expansion of existing chemical-affected environmental media on the property, and (*4*) install new engineering controls, preserve previously installed engineering controls, or replace previously installed engineering controls. Previously installed engineering controls for reducing or eliminating potential exposure to human receptors at the property may be replaced if no longer effective, if no longer required, or if an alternative engineering control is determined to be advantageous with respect to reducing or eliminating risk, operation and maintenance, cost effectiveness, or other considerations. For projects where the community is involved in the property development, general guidelines for community outreach and input are described in Guide E1984.

5.3.2 *Limitations on Site Development Plan*—The property development plan may entail limitations on structure locations or subsurface penetrations (e.g., slab-on-grade foundations versus excavated basements, underground utilities, stormwater retention ponds); installation of engineering controls or maintenance of existing engineering controls (e.g., surface covers, vapor barriers, drainage controls); or other such measures which serve to achieve site development goals while reducing or eliminating environmental concerns and associated costs. Such constraints, if any, are site-specific in nature and depend in part upon the nature and extent of the chemical-affected environmental media, the presence and effectiveness of existing engineering controls, the applicable regulatory requirements, and the relative cost and feasibility of alternative site development measures.

5.4 *Re-Evaluation of Engineering Control for Change in Land Use*—The effectiveness of each engineering control should be re-evaluated upon a change in land use, regulatory criteria, or site development plan. Based on a proposed change in property use, the engineering control may require modification, and should be retooled or replaced in accordance with approved alternative corrective action(s) intended to continue to reduce or eliminate unacceptable risks of exposure to future property users.

6. Design of Engineering Controls

6.1 *Performance Standards for Engineering Controls*—Engineering controls serve to prevent unacceptable contact with chemical-affected environmental media by human receptors under the proposed property use. The conceptual design must therefore: (*1*) identify reasonable mechanisms whereby such exposure could occur under the proposed property use, and (*2*) define controls needed to reduce or eliminate unacceptable risk of exposure to property users and facilitate the proposed property use, if technically and economically feasible.

6.1.1 *Exposure Prevention*—Based on the Conceptual Exposure Model, the engineering control(s) should serve to reduce or eliminate exposure to COCs at concentrations exceeding unacceptable risk levels (*1*) preventing direct contact with the chemical-affected environmental media (e.g., dermal contact with affected soils) and (*2*) preventing migration of COCs from the affected medium to a point of exposure at a different location or in a different medium, or both (e.g., soil-to-air volatilization of chemical vapors). Depending on property conditions and the type of control selected, a single engineering control may serve to address one or more exposure pathways.

6.1.2 *Design Life*—While accounting for operation and maintenance, the engineering control should be designed for a time period equal to the lesser of (*1*) the expected duration of the unacceptable risk or (*2*) the expected duration of the site or structure for the specified land use. For presumptive remedies as described in 4.4, the engineering control should be designed for a time period equal to the lesser of (*1*) the expected duration of the potential unacceptable risk or (*2*) the expected duration of the use of the site or structure for the specified land use. Other considerations for determining a design lifetime will depend on the specific engineering controls evaluated for the site and may include regulatory requirements, properties of materials of construction, cost-benefit analyses, and expected or reasonable design lifetimes of the engineering control as a system.

6.2 *Application of Engineering Controls to Specific Exposure Pathways*—Performance criteria for control of selected exposure pathways and examples of applicable engineering control techniques are listed below. In all cases, existing engineering controls (e.g., pavement, soil cover) may be evaluated to assess effectiveness for exposure control and amended only as needed to achieve performance objectives. Appendix X5 provides a summary of the applicability, design considerations, and monitoring requirement for various engineering control technologies.

6.2.1 *Pathways Addressed*—The intent of this guide is to address potential exposures likely to be associated with property development or redevelopment. This guide is not a comprehensive manual for addressing every potential unacceptable risk, whether on-site or off-site. This guide describes engineering controls to address such potential unacceptable risks for three principal exposure pathways: (*1*) surface soil direct contact, (*2*) ambient or indoor air vapor exposure, and (*3*) affected groundwater impact on subsurface structures or utilities. Other exposure mechanisms may exist, and if so, should be addressed in a similar manner as described.

6.2.2 *Surface Soil Direct Contact*—In areas where chemical-affected soils are present at or near the ground surface, human exposure could occur via incidental ingestion, direct dermal contact, or inhalation of particulates. Chemical-affected soil particulates could potentially be released into the air as a result of erosion by the wind or as a result of shallow excavation for landscaping, construction, or maintenance activities. An effective engineering control would prevent surface soil direct contact by inhibiting (*1*) human contact with the chemical-affected soil and (*2*) the release of wind driven soil particulates into the air. Example technologies for controlling exposure due to surface soil direct contact include, but are not limited to, the following or combinations thereof:

Asphalt pavement,
Concrete pavement,
Flexible membrane liner (FML),
Clean soil cover,
Vegetative cover, and
Stone blankets.

Additional information regarding design, installation, and maintenance of engineering controls for chemical-affected soils is provided in Appendix X1.

6.2.3 *Ambient or Indoor Air Vapor Exposure*—In areas where chemical-affected soils or groundwater are present, human exposure could occur via inhalation of vapors released into the air as a result of volatilization of COCs from soils or groundwater. An effective engineering control would serve as a barrier to prevent COC concentrations exceeding unacceptable risk levels in ambient or indoor air. Such a barrier would prevent (*1*) migration of vapors to ambient air from chemical-affected soils or groundwater or (*2*) migration of vapors to indoor air through vapor entry routes such as basements, foundations, sumps, subsurface utility connections, or subsurface utility corridors, or both. Example technologies for controlling exposure due to inhalation of ambient or indoor air vapors include, but are not limited to, the following or combinations thereof:

Sealing soil gas entry routes,
Passive vapor barriers,
Building pressurization systems, and
Active soil depressurization.

Additional information regarding design, installation, and maintenance of engineering controls for soil or groundwater vapors is provided in Appendix X2.

6.2.4 *Affected Groundwater Impact on Subsurface Structures or Utilities*—In areas where chemical-affected groundwater is present, human exposure could occur via incidental ingestion or direct contact if groundwater enters subsurface structures, stormwater retention ponds, or utilities through cracks or leaks. In such a situation, property damage could also be sustained (e.g., fiber optic cable lines). An effective engineering control would prevent entry of groundwater to subsurface structures, stormwater retention ponds, or utilities. Example technologies for controlling exposure due to impact of chemical-affected groundwater on subsurface structures or utilities include, but are not limited to, the following or combinations thereof:

Seepage barriers.
Sealing utility lines, foundations, or utility joints,
Interceptor wells and trenches,
Slurry walls, and
Permeable reactive barriers.

Additional information regarding design, installation, and maintenance of engineering controls for chemical-affected groundwater is provided in Appendix X3.

6.3 *Development of Design Specifications*—Design specifications for the selected engineering controls should be documented in sufficient detail to ensure that the implemented control achieves the applicable performance criteria. The engineering control should be designed by persons qualified to complete work of this nature by reason of professional or regulatory certifications, or both. As applicable, design specifications may address general criteria for design, installation, and monitoring and maintenance, as summarized as follows.

6.3.1 *Design Basis Information*—Sufficient information regarding current and future site conditions should be compiled to support engineering design of all components of the proposed engineering control.

6.3.2 *Effective Area and Defining Boundary*—The engineering control must address the full area or volume, or both, of the chemical-affected environmental media requiring exposure control. As applicable, the engineering control should be equipped with a "defining boundary," serving to physically demarcate the engineering control or the area of chemical-affected environmental media, or both. Examples of such defining boundaries to be installed below grade include, but are not limited to, geofabric, horizontal plastic snow fencing, horizontal chain-link fencing, grids of warning tape, or other inert material. Signs may also be posted to delineate the defining boundary above grade. Record drawings or drawings conforming to construction records depicting the location and construction details of the engineering controls may also serve as a record of the effective area. If prepared, drawings should be available for reference, either at the site or at another location known and accessible to persons needing access to such information

6.3.3 *Design Components*—Each of the principal components of the engineering control should be defined, along with specifications for the design, installation, and operation and maintenance of each component included in the design.

6.3.4 *Dimensions and Material Specifications*—The material strength, durability, corrosion resistance, and chemical compatibility of each design component should be sufficient to achieve the specified performance standard for the design life of the control under the anticipated site conditions.

6.3.5 *Treatment System*—If an active engineering control such as a soil vapor or groundwater treatment system is to be included in the property development plan, the design specifications should address the design and operation of the equipment needed to treat the extracted soil vapor or groundwater so as to reduce concentrations of COCs to regulatory-mandated concentration levels prior to discharge. If a treatment system is already in place prior to property development or redevelopment, then the system should continue operating as needed for mitigation of chemical-affected environmental media as per applicable regulatory requirements, unless an engineering control proves to be more effective at preventing exposure to chemical-affected environmental media, subject to applicable regulatory requirements and approvals.

6.3.6 *Installation Specifications*—Requirements for installing the engineering control should specify methods, quality assurance/quality control (QA/QC) procedures, and personnel qualifications to ensure that the final installation is consistent with the design. The area to which the engineering control will be applied should be prepared as needed for an effective installation (e.g., clearing and grading for placement of surface cover).

6.3.7 *Documentation*—Record drawings, drawings conforming to construction records, or other written records, or combination thereof, should be prepared to document the installation details of the engineering control.

6.3.8 *Monitoring and Maintenance*—The design specifications should describe operations and maintenance requirements, if any, for the engineering control to ensure the best achievable effectiveness of the engineering control. The design should specify monitoring measures and monitoring frequency. The monitoring frequency will be a function of the timeframe for possible failure of the engineering control (i.e., more frequent for an active system, less frequent for a passive system) and the relative effect of such a failure on a potential receptor (more frequent for immediate impact, less frequent for a delayed impact). Design specifications may include (*1*) a monitoring frequency that varies over the operating period of the engineering control or (*2*) a provision to evaluate and modify the monitoring frequency based on data or information obtained during monitoring and maintenance. Non-routine inspections should be conducted to verify adequate and intended system performance after certain triggering events (e.g., floods, earthquakes). If applicable, the design specifications should provide for alarm of any expected condition harmful to potential receptors (e.g., percent lower explosive limit) as well as a response to the alarm.

6.3.9 *Regulatory Considerations*—Permitting, notification, and activity and use limitations should be completed per applicable regulatory requirements. The design should conform to applicable technical standards specified by regulations.

7. Installation of Engineering Controls

7.1 *QA/QC Program*—A quality assurance/quality control (QA/QC) program involving inspections, monitoring, and testing should be implemented to confirm that the engineering control has been completed in accordance with the design specifications.

7.2 *Qualifications*—The engineering control should be installed by persons qualified to complete work of this nature by reason of professional or regulatory certifications, or both.

8. Monitoring and Maintenance of Engineering Controls

8.1 *Overview of Monitoring Requirements*—Engineering controls may require routine monitoring to demonstrate the initial performance of the engineering control for the specified design objective and ensure continued performance for the duration of the property use activity. Note that monitoring requirements may be binding if they are included in an enforcement instrument (e.g., consent agreement, consent order, order, permit, no-further-action letter).

8.2 *Periodic Monitoring*—In order to assess key performance criteria of the engineering control, monitoring programs may involve one or more of the following: visual inspection, physical measurements, or sampling and testing. The nature and frequency of such monitoring will depend on the type of engineering control employed: active controls may, but not necessarily will, require more frequent and detailed inspections than passive controls. Municipal or state requirements will likely require monitoring to demonstrate that (*1*) related activity and use limitations remain in the active public record, and (*2*) post-installation construction or maintenance activities by other parties have not adversely impacted the engineering control.

8.3 *Maintenance*—Repairs or replacements (e.g., replacement of topsoil, sealing of asphalt cracks, vegetation type and cover) should be completed as indicated based on the results of periodic monitoring.

8.4 *Engineering Control Assessment and Modification*—The performance of the engineering control should be re-evaluated based on the results of periodic monitoring. Inadequate performance of the engineering control may require corrective actions or modification of the property development plan, as needed to reduce or eliminate unacceptable risk to human health via exposure to COCs. Regular inspections should include a provision to review the actual uses of the property with respect to the design of the engineering control to ensure the continued applicability of the control.

9. Use of Activity and Use Limitations

9.1 *Need for Activity and Use Limitations*—Guidelines for application of activity and use limitations are provided in Guide E2091. For some sites, activity and use limitations other than engineering controls may be the only type of control required to reduce or eliminate unacceptable exposure to COCs in chemical-affected environmental media. However, in many cases, it may be necessary to implement engineering controls along with other activity and use limitations at the site.

9.2 *Purpose for Activity and Use Limitations*—In order to notify future property owners and users of the presence of engineering control(s) on the property and to ensure the proper maintenance of the engineering control(s), it may be necessary to file institutional control(s) in the real property records of the governmental entity or entities having jurisdiction over the property.

9.3 *Types of Activity and Use Limitations*—Guide E2091 gives the following examples of activity and use limitations: (*1*) proprietary controls, such as deed restrictions or restrictive covenants; (*2*) state and local government controls, such as zoning restrictions, building permits, well drilling prohibitions, and water advisories; (*3*) statutory enforcement tools, such as orders and permits; (*4*) information devices such as deed notices, geographic information systems, Registry Act requirements, and Transfer Act requirements; and (*5*) environmental easements.

10. Keywords

10.1 activity and use limitations; Brownfields; chemical releases; corrective action; engineering controls; environment; environmental media ; exposure controls; human exposure; property development; site assessment

APPENDIXES

(Nonmandatory Information)

X1. ENGINEERING CONTROLS FOR CHEMICAL-AFFECTED SOILS: DESIGN, INSTALLATION, AND MAINTENANCE GUIDELINES

X1.1 *Introduction*— Engineering controls may be employed as part of the use or redevelopment of chemical-affected properties to reduce or eliminate potential exposure to COCs in surface and subsurface soils. The engineering controls discussed in this appendix focus on managing risks from chemical-affected soil that occur by direct dermal contact, incidental ingestion, or inhalation of particulates. Although not the focus of this appendix, such controls may also provide a secondary benefit of managing risks by (*1*) controlling vapors from surface soils, subsurface soils, or groundwater, or (*2*) controlling migration of residual COCs to groundwater. In addition to design and installation considerations, this appendix discusses monitoring and maintenance initiatives for engineering controls for chemical-affected soils.

X1.2 *Performance Objectives and Available Technologies*—An engineering control for chemical-affected soil should reduce or eliminate the potential for human health risk by (*1*) preventing direct contact with the chemical-affected soil, (*2*) preventing incidental ingestion of the soil, and by (*3*) preventing the release of soil particulates into the air. Typical soil engineering controls may include either structural elements or thickness elements, or both. Structural elements rely on inherent physical strength to minimize contact, and include, but are not limited to, asphalt pavement, concrete pavement, building slabs, and associated foundations. Thickness elements rely on the thickness, depth, or volume characteristics of the control to minimize contact. Thickness elements include, but are not limited to, compacted clay, landscaping, and non-differentiated "clean" soil. The literature refers to engineering controls for chemical-affected soils by various terms such as engineered barriers, caps or covers. Although the literature is not consistent in the use of these terms, the term "barrier" more commonly refers to structural elements such as asphalt and concrete. The terms "cap" and "cover" are more frequently used to refer to thickness elements.

X1.3 *Design and Construction Considerations:*

X1.3.1 *Design and Construction Overview*—Design and construction of engineering controls for chemical-affected soil should account for the end use of the property in addition to addressing risk management objectives. Engineering controls for chemical-affected soil are often associated with construction for the end use of the property, including, but not limited to, parking lots, floor slabs, park surfaces, and roadways. In these applications, engineering controls are either placed directly onto the ground surface or comprise a portion of the surface soils of the site. Additional project-specific considerations may be associated with a design requirement of the control or with regulatory requirements. For example, the design requirements for a high-traffic roadway are more extensive than for a parking lot, although each system may be sufficient to manage the risks from chemical-affected soils. Also, the design should account for requirements needed to conform to local customary practices or additional regulatory requirements (e.g., Massachusetts has a draft comprehensive design guidance document for engineering controls based on meeting minimum RCRA-like requirements for all sites, irrespective of whether the site is in the RCRA program).

X1.3.1.1 This appendix provides guidance on the risk-management aspect of the engineering controls for chemical-affected soils. A detailed discussion of additional project-specific considerations related to end uses is beyond the scope of this appendix.

X1.3.1.2 Professional services providers (e.g., professional engineers, landscape architects, state certified brownfield specialists, etc.) may be required for the actual design and oversight of the construction. The design effort should solicit, consider, and incorporate input from individuals and firms working on various aspects of the design, construction, operation, and maintenance specifications

X1.3.2 *Design Basis Information*—Studies should be conducted at the property to characterize the shallow soil as needed for the design of the engineering control. Design basis information should be obtained concerning site characteristics (e.g., soil types, existing structures, topography) and the concentration and nature of COCs present in chemical-affected soils. The site investigation should delineate the lateral and vertical extent of chemical-affected soil. Materials used in construction of the engineering control should be evaluated for chemical compatibility with the COCs present in soil to ensure that materials will not be susceptible to degradation or adverse reaction after installation.

X1.3.3 *Effective Areas and Defining Boundary*— Engineering controls for chemical-affected soil placed at the ground surface should cover an area containing COCs at concentrations exceeding unacceptable risk levels. The area of coverage for an engineering control should be based on a sufficient number of sampling points to ensure that the entire volume of chemical-affected soil is addressed by the engineering control. The total area to be addressed, the number of data points, and the variability of data should be considered in identifying the effective area.

X1.3.3.1 Record drawings or drawings conforming to construction records or project reports, or both, may also serve to document the demarcation of engineering controls. Physical demarcation of surface soil engineering controls by colored tapes, fabrics or membranes is not commonly employed given the surface visibility of design elements. However, application of demarcation techniques should be considered for future applications in order to document and identify engineering controls and to comply with regulatory requirements, if any.

X1.3.4 *Design Components*—Engineering controls for chemical-affected soils are physical elements of construction selected on the basis of existing site conditions, availability of materials, and anticipated function. As with any physical element of construction, the design of a specific soil engineering control is based on the following: (*1*) a minimum structural integrity, (*2*) reasonable design life, and (*3*) non-excessive maintenance. More than one engineering control may be used in concert to address additional exposure pathways. For example, if inhalation of soil vapor (see Appendix X2) was identified as a exposure pathway in addition to direct contact with chemical-affected soils, then a concrete floor slab could be combined with a flexible membrane liner, an underfloor vapor collection system, or a soil cover in order to reduce or eliminate risks via both exposure pathways. Commonly available soil engineering controls include:

X1.3.4.1 *Asphalt Pavement*—Asphalt pavement, or an asphaltic barrier, may also be referred to as "bituminous concrete" in many State Department of Transportation (DOT) specifications. Asphalt is a designed mix of graded sand and gravel combined with a bituminous asphalt liquid which is applied in layers using specially constructed machines. A thick layer placed in one pass is referred to as full-depth asphalt; full depth asphalt is sometimes placed directly on a prepared natural soil surface. Alternatively, asphalt may be applied in thin layers (e.g., 2.5 to 5 cm thick) referred to as courses (e.g., surface or binder) to achieve the desired thickness. Layers of asphalt are typically applied over a several-centimetres thick layer of aggregate, generally coarser than the aggregate for the top layer, with an asphalt binder (i.e., the base course) to transfer loads to the underlying soils.

X1.3.4.2 *Concrete Pavement*—Concrete is a designed mix of graded sand and gravel mixed with cement and water. Concrete is commonly used for building floor slabs and for many exterior pavements. Concrete is typically placed over a several-centimetres thick layer of sand or gravel (i.e., the base course) to transfer loads to underlying soils. Concrete usually has wire mesh, reinforcing steel, or other admixtures (e.g., synthetic fibers) to control cracks that may occur during initial curing or over the long-term as a result of plastic shrinking, drying shrinking, thermal cracking, or loss of support. Concrete slabs intended to support heavy loads also have steel reinforcing bars. Exterior concrete slabs should include an air-entrainment additive to minimize surface erosion (i.e., spalling), which can occur due to inclement weather and frost conditions.

X1.3.4.3 *Flexible Membrane Liner (FML)*—FMLs are thin, low-permeability membranes installed to minimize the migration of gases and liquids. FMLs are synthetic layers that are installed from rolls of manufactured materials, or sprayed onto a surface to harden to a semi-flexible layer. FMLs are hydrocarbon-based and have a wide range of chemical compatibility. Commonly used FMLs include: PVC (polyvinyl chloride), PCE (polychlorethylene), HDPE (high density polychlorethylene), and several others. FML rolls require special seaming equipment to seal edges; spray-applied FMLs form a seamless monolithic membrane. FLM rolls have a more consistent thickness. Application of any FML requires experienced qualified installers. FMLs are generally placed in conjunction with a structural element since they have no structural strength on their own. A cover sufficient to block UV radiation should be installed atop FMLs susceptible to degradation by exposure to UV radiation.

X1.3.4.4 *Clean Soil Cover*—Clean soil covers may be constructed of soils ranging from high-permeability gravels and sands to low-permeability clays. Permeability requirements, if any, should be evaluated early on in the design of the engineering control. The thickness of a clean soil cover is dependent on the performance objective for the engineering control. If the intent is primarily to minimize contact or ingestion of underlying materials, then the thickness of the control layer should be one that is difficult to hand excavate by a home owner, child, or gardener; the material type can be any clean soil available (i.e., non-differentiated). Establishment of a vegetative cover is important to minimize erosion; therefore, soils conducive to plant growth are typically placed as the top layer of an engineering control. Such soils are commonly referred to as "top soil" and should have a significant portion of natural organic matter to promote plant growth. Landscapers typically suggest a minimum of 6 in. of topsoil to promote adequate plant growth; however, the soil thickness should also consider performance objectives for an engineering control for chemical-affected soil.

X1.3.4.5 *Stone Blankets*—Stone blankets are a passive means of exposure control comprising a layer of small stones or recycled concrete installed to isolate chemical-affected soil from direct contact. Stone blankets may be particularly suited to preventing exposure and erosion in arid locations where establishment of a vegetative cover may be challenging due to the lack of precipitation.

X1.3.5 *Dimensions and Material Specifications*— The objective of minimizing soil contact can be achieved by providing a thickness that can not be easily excavated by hand (e.g., 0.6 to 0.9 m of soil), or by providing a structural element that can not be penetrated by hand excavation (e.g., asphalt or concrete). Additionally, the control should not have excessive openings, cracks, or non-uniformity, such that the control loses its integrity. The range of specifications provided in this document is solely intended to guide developers and constructors prior to design of soil engineering controls.

X1.3.5.1 *Dimensions*—Table X1.1 provides general design considerations and dimensions for engineering controls to reduce or eliminate risks from chemical-affected soil that occur via the direct contact pathway (i.e., dermal contact, incidental ingestion, or inhalation of soil particulates). Table X1.1 also notes which of the engineering controls may be effective for reducing or eliminating risks associated with (*1*) inhalation of vapors and (*2*) leaching of COCs from the soil to groundwater and subsequent groundwater ingestion.

X1.3.5.2 *Soil Properties*—The type of soil used for an engineering control can vary widely depending on the property use or reuse. Most soil covers, irrespective of the type of soil will provide risk mitigation from potential contact when placed in a thickness that restricts contact. Landscaping topsoils intended to support a vegetative cover; non-differentiated "clean" soils, and a "stone blanket' to provide structural stability, are suitable to restrict contact.

X1.3.5.3 *Layer Thicknesses*—A thickness that will minimize contact with chemical-affected soils is considered in several states to be 91.4 cm. This thickness is required since soil can be relatively easily moved (i.e., compared to concrete or asphalt) or penetrated (e.g., as in gardening or landscaping). For petroleum hydrocarbons in soil, a soil cover thickness of less than 91.4 cm may be adequate for minimizing vapor to outdoor air. Some regulatory agencies have accepted 76.2 cm or less. The minimum structural integrity of a design element must also be considered. For example, although a 5-cm thick concrete slab may restrict direct contact, a 5-cm thick concrete slab would likely be insufficient as a construction element to endure typical use throughout the design life. Therefore, concrete may need to be installed in a thickness of 7.6 cm or

TABLE X1.1 Engineering Controls for Chemical-Affected Soils: General Design Considerations

Soil Engineering Control	Exposure Pathway[A]			Thickness Required to Achieve Performance Objective[B]	Comments
	Direct Contact	Inhalation of Vapors	Soil Leaching to Groundwater		
1. *Asphalt*	P	S	S	2.5 to 7.6 cm asphalt atop 10 to 15 cm base course; or 10 to 15 cm full depth asphalt	Requires adequate subbase
2. *Concrete*	P	S	S	7.6 to 10 cm concrete atop 10 to 15 cm base course	Requires adequate base
3. *Flexible Membrane Liner (FLM)*	S	P	P	FML liner plus structural element	Must be installed with structural element
4. *Soil Material Covers*					
• Clay	P	P	P	45.7 to 91.4 cm	Low permeability (approx. 1E-06 cm/s or lower)
• Non-differentiated clean soil	P	S	—	45.7 to 91.4 cm	Soils range from clayey to sandy (approx. 1E-03 to 1E-06 cm/s)
• Non-differentiated clean soil	P	P	S	91.4 to 152.4 cm	Soils range from clayey to sandy (approx. 1E-03 to 1E-06 cm/s)
• Vegetative soil	P	S	—	45.7 to 91.4 cm	Soils likely include organic topsoil
• Vegetative soil	P	P	S	91.4 to 152.4 cm	Soils likely include organic topsoil
• Sand/Stone blanket	P	—	—	45.7 to 91.4 cm	Typically porous, higher permeability materials (<1E-03 cm/s)

[A] P = Primary intent of engineering control; S = Secondary intent of engineering control; — = Not an appropriate use of this engineering control.
[B] Values listed here represent reasonable dimensions in the absence of design constraints or regulations. Regulatory design criteria would apply, if available.

more upon considering the anticipated use, design life, and reasonable maintenance.

X1.3.5.4 *Other Considerations*—Other issues may also need to be considered in the selection of a soil engineering control, including, but not limited to, the following:

Settlement of the control layer due to underlying materials (e.g., landfill, soft soils),
Seismic conditions,
Frost depth,
Runoff and erosion control,
Steep slopes (i.e., greater than 3 horizontal to 1 vertical),
Compatibility with toxic underlying materials, and
Gas management emanating from underlying materials.

X1.3.6 *Treatment Systems*—Some soil engineering controls can be used for treatment of residual constituents (e.g., phytoremediation or wetland treatment systems). These treatment systems are advanced treatment techniques requiring specific technical experience and are beyond the scope of this appendix.

X1.3.7 *Installation Specifications*—Numerous industry standards directly applicable to construction of engineering controls for surface and subsurface soils have been developed to verify construction quality. Key aspects relating to the performance of engineering controls for chemical-affected soils include preparation of the subgrade, and the joining of two different barriers or covers.

X1.3.7.1 *Subgrade Preparation Requirements*—The grade on which the soil engineering control is placed must be capable of supporting the design elements. Prior to placing an engineering control, the area should be cleared and grubbed of vegetation. The surface of the subgrade should be graded to the lines and grades provided by the construction specifications. Surface grading must consider whether affected soils are present to prevent spreading contamination. A soft or wet subgrade should be proof-rolled after grading. The proof-rolled surface should be observed for signs of rutting or pumping. Soft or wet soils that excessively pump or rut should be removed, replaced, and compacted prior to approval of the subgrade.

X1.3.7.2 *Joining of Two Different Engineering Control Systems*—Consideration must be given to the joining of different barriers or covers in order to form an adequate seal between the two elements. For example, in locations where asphalt and concrete engineering controls will abut, the concrete barrier should be constructed first so that the asphalt has a stable, straight-edged feature to be formed against. Adjoining of soil covers to asphalt, concrete, or another soil barrier should be designed to minimize potential erosion and maintenance. Seeding, sodding, or other planting will help minimize erosion near the interface, as well as reduce maintenance activities. Gradual transitioning should be incorporated into construction between engineering control areas and adjacent areas. For example, the ground surface beyond the extent of a thick clean soil engineered cover could be sloped gradually to meet the original elevation.

X1.3.8 *Documentation*—Owners may be required to submit record drawings or drawings conforming to construction records for the soil engineering controls constructed under applicable regulatory programs. The documentation may include, but not be limited to, the following: surface grade surveys before and after engineering control placement; photographs of the control; soil, asphalt and concrete physical tests (as appropriate); or a plat of survey identifying the soil engineering control location and area, or combination thereof. Documentation and record keeping similar to that required for regulatory programs should be considered for projects not specifically under regulatory purview. This consideration is based on the likelihood that questions regarding the performance of designated soil engineering controls, especially if it is recorded on the deed, could arise during future a property transfer.

X1.4 *Performance Monitoring*—The integrity of a soil engineering control must be maintained throughout the design life of the control. Planned and scheduled inspection and maintenance should be anticipated and conducted as part of the documentation of the performance of the soil engineering control.

X1.5 *Maintenance Issues*—Soil engineering controls should undergo routine inspections as part of a general maintenance program. Large cracks or openings within the soil engineering control or at adjoining areas of two controls could compromise the integrity of the control's intended use. For these conditions, a joint sealer compatible with the soil engineering control (e.g., rubberized asphalt, grout, additional fill soil) should be used for improvements or repairs.

X1.5.1 If it is necessary to disrupt the engineering control (e.g., for utility line placement) various barrier or cover replacement materials should be considered for patching. The replacement materials should be similar to, or more rigorous than, the original materials. The replacement materials should be applied to the entire utility corridor. Adequate replacement of disrupted flexible membranes is especially important, because flexible membrane liners are thin and rely on full continuity for successful performance.

X1.5.2 Soil engineering control maintenance activities should be completed in accordance with Occupational Safety and Health Administration (OSHA) and site risk-related requirements. Site inspectors and utility construction workers should be the focus of safety-related maintenance programs.

X1.5.3 A summary of common frequencies of inspection, action levels and typical maintenance actions is provided in Table X1.2.