Evaluation of In-Situ Solidification/Stabilization For Redevelopment of Manufactured Gas Plant Impacted Sites

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PRODUCT DESCRIPTION

Process byproducts produced at manufactured gas plants (MGP) pose concerns from an environmental standpoint. One treatment for the management of a broad range of contaminated media and wastes is solidification/stabilization (S/S). The U.S. Environmental Protection Agency (EPA) considers S/S an established treatment technology and it continues as a cornerstone treatment technology for the management of site remediation. The Electric Power Research Institute (EPRI) has been sponsoring research on the use of in-situ solidification/stabilization (ISS) at former MGP sites for several years (EPRI report 1010949). This report presents a uniform and consistent approach for documenting the assessment, implementation, and long-term monitoring of ISS at MGP sites for redevelopment purposes. The document also provides a list of example MGP sites that have undergone ISS treatment and been redeveloped.

Background

Efforts to remediate MGP sites are driven by corporate initiatives, the market value of the property, and regulatory enforcement (EPRI report 1007222). Application of S/S for remediating contaminated MGP properties has been used at several plant sites with promising results. Ample literature describing how to implement ISS exists. However, a standard approach for selecting and implementing the ISS technology with an objective to redevelop the MGP site is not adequately documented, which represents a barrier to the use of S/S technologies at MGP sites for redevelopment.

Objective

To identify and describe the important performance parameters associated with ISS treatment at an MGP site considered for redevelopment.

Approach

The project team reviewed publically available literature to evaluate the state of ISS technology, investigate reported ISS applications at MGP plant sites and determine the most appropriate methods for selecting and implementing ISS at MGP sites. The study also included discussions with site owners and regulatory agencies.

Results

The document provides guidance for the use of performance specifications during the design, testing, implementation and long term monitoring phases of ISS projects at MGP sites with the objective of redeveloping them for future use. A streamlined process for selecting performance parameters and methods of measurement will allow practitioners to apply a consistent assessment methodology that considers the physical (e.g., strength, permeability), and chemical (e.g., constituent retention) properties of the treated material to meet remedial action objectives.

The selection of performance parameters and methods of measurement will be contingent upon accurately characterizing the existing subsurface of the proposed redevelopment property. Proper characterization, when combined with appropriate long-term monitoring activities, aims to bolster the regulatory acceptance of this already-proven technology.

Applications, Values, and Use

Non-aqueous phase liquid (NAPL) and inorganic impacts to soil and groundwater at former MGP sites pose a potential risk to the environment that can be difficult and expensive to remediate. Traditionally, many sites have opted to excavate and treat NAPL-impacted soils off site, and backfill with clean soil. For sites where the impacts are shallow and easy to excavate, this may be a cost-effective approach. However, for sites with a high water table, limited working area, and/or deep contamination, excavation is often impractical and prohibitively expensive. Additionally, assessments of ISS at a handful of MGP sites have focused on the implementation stage. Further evaluation of the long-term monitoring considerations will help practitioners determine site-specific approaches that provide reliable measures of remedy success with regard to redevelopment.

This report will allow utility managers to evaluate and implement this technology in a systematic, cost-effective and timely manner. The development of a standardized process for selecting performance criteria also aims to streamline the regulatory approval process.

Keywords
In-situ solidification/stabilization (ISS)
Manufactured gas plants (MGP)
Coal tar
Cement
Polycyclic aromatic hydrocarbons (PAHs)
Non-aqueous phase liquid (NAPL)
Remediation

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1 INTRODUCTION

1.1 Background

From the early 1800s through the 1900s manufactured gas plants (MGP) were operated across the U.S. to supply homes and industry with fuel for heating, cooking, and lighting. Coal and oil was primarily used for generation of gas. As natural gas became widely available, MGPs closed leaving large areas of land contaminated with coal tar related MGP wastes. The gas manufacturing and purification processes conducted at the plants resulted in residues that included tars, sludge, lampblack, light oils, spent oxide wastes, and other hydrocarbon products (EPA 1999). The process byproducts produced at MGPs pose concerns from an environmental standpoint. Chemicals associated with MGP waste include volatile organic compounds (VOCs) like benzene and toluene, polycyclic aromatic hydrocarbons (PAHs) like naphthalene, tar acids like phenol and cresol, creosote, and coal tar pitch.

Efforts to remediate MGP sites are driven by corporate initiatives, the market value of the property, and regulatory enforcement. There may be greater financial incentive to cleanup and rehabilitate a site if it is located in a highly desirable urban area where property values are high and land scarce. With the creation of Environmental Protection Agency's (EPA) Land Revitalization Initiative, cleaning up previously contaminated properties for reuse has helped reinvigorate communities, preserve green-space, and prevent sprawl. Revitalized or redeveloped land can be used in many ways, including the creation of public parks, the restoration of wetlands, construction of commercial buildings, infra-structure, etc. Redevelopment of MGP sites using ISS is typically complicated by real or perceived environmental contaminations.

One treatment for the management of a broad range of contaminated media and wastes is solidification/stabilization (S/S). The U.S. EPA considers S/S an established treatment technology and S/S continues as a cornerstone treatment technology for the management of site remediation. Application of S/S for remediating contaminated MGP properties has been used at several plant sites with promising results. Ample literature describing how to implement in-situ solidification/stabilization (ISS) exists. However, a standard approach for selecting and implementing the ISS technology at MGP sites for redevelopment purposes are not adequately documented; this represents a barrier to the use of ISS technologies at MGP sites for redevelopment.

This report presents a systematic approach to implement in-situ solidification/stabilization (ISS) for remediation of former MGP sites for redevelopment purposes. The use of ISS for remediating former MGP sites containing PAHs is steadily increasing; however, the approach to redevelop and reuse the sites after the implementation of ISS has not been clearly and adequately documented. The document will assist professionals in developing a uniform and systematic approach for applying ISS for redevelopment and future use of the site. Very few MGP sites have been redeveloped after being remediated using ISS. One of the reasons for this is the presence of contaminants at the site after being treated by ISS – the contaminants are not destroyed or removed in ISS. As such, long-term stewardship of an ISS remediated site is required and may include monitoring environmental media, monitoring of institutional controls, and maintenance of engineering controls. With this inexpensive long-term stewardship, MGP sites can be economically redeveloped using ISS.

This report presents a uniform and consistent approach for documenting the assessment, implementation, and long-term monitoring of ISS at MGP sites for redevelopment purposes. It also provides a list of example MGP sites that have undergone ISS treatment and have been redeveloped.

1.2 Study Objectives

This document provides guidance for the use of performance specifications during the design, implementation and long term monitoring phases of ISS projects at MGP sites with the objective to redevelop them for future use. A streamlined process for selecting performance parameters and methods of measurement will allow practitioners to apply a consistent assessment methodology that considers the physical (e.g., strength, permeability), and chemical (e.g., constituent retention) of the treated material to meet remedial action objectives.

Once a remedy has been implemented, long-term stewardship programs are typically used to verify that the remedy remains effective as designed and therefore protective of human health and the environment. Long-term monitoring considerations are discussed in Section 7 to aid practitioners when determining site-specific approaches that provide relevant reliable measures of remedy success.

1.3 Scope of Work

A review of published literature was performed to evaluate the state of ISS technology, investigate reported ISS applications at MGP plant sites, and determine the most appropriate methods for selecting and implementing ISS at MGP sites. A number of MGP sites undergoing ISS remediation were also included in the review; Internet sources such as clu-in.org and regulatory sites provided up-to-date project status information. More information on these sites can be found below in Section 9 – Example Projects.

2
OVERVIEW OF ISS TECHNOLOGY

2.1 Technology Description

ISS is a treatment technology comprised of two distinct processes: solidification and stabilization. Solidification/stabilization together refers to a general category of physical chemical processes that are used to treat a variety of wastes, including solids and liquids. Solidification and stabilization are each distinct technologies, as described below (EPA, 2000 and EPRI, 2009):

Solidification refers to processes that encapsulate a waste to form a solid material and to restrict contaminant migration by decreasing the surface area exposed to leaching and/or by coating the waste with low-permeability materials. Solidification can be accomplished by a chemical reaction between a waste and binding (solidifying) reagents or by mechanical processes.

Stabilization refers to processes that involve chemical reactions that reduce the leachability of a waste. Stabilization chemically immobilizes hazardous materials or reduces their solubility through a chemical reaction. The physical nature of the waste may or may not be changed by this process.

Typical binding reagents for solidification include cement, pulverized fly ash, and clays, which are mixed with the contaminated media or waste. These techniques are done either in-situ, by injecting the reagent into the contaminated media or ex-situ, by excavating the materials and mechanically mixing them above ground (EPA, 2009). Inorganic cementitious/pozzolanic reagents are most commonly used to treat impacted material in ISS.

Stabilization of heavy metals is mainly achieved by converting the heavy metals into insoluble precipitates. Organic compounds are generally nonpolar and hydrophobic; they do not react with the inorganic binders and may interfere with the hydration reactions of the cement or pozzolanic materials and inhibit the curing of cement. Instead, organics are generally sorbed or encapsulated in the pores, and their leachability depends on their solubility in water and their diffusivity though the treated waste matrix (Paria, 2006).

Treatment of soils containing coal tar with organic contaminants typically found at MGP sites, have generally relied on the reagents' ability to solidify the soil containing contaminants. For example, with Portland cement, the solidification process may include: (a) binding of free water within soil matrix into cement hydration reaction products; (b) creation of a treated product with improved physical integrity, such as a granular solid or monolith; and (c) reduction in hydraulic conductivity of the soil (Wilk, 2007).

Bench-scale testing, followed by occasional confirmatory pilot testing, is commonly used to determine appropriate reagent materials and their dosages. The full-scale process involves mixing of selected reagents with impacted media using a mechanical mixing device. Reagents can be incorporated in the form of a liquid or a dry solid depending on the moisture content of the impacted media. Once mixing has been completed, the solidifying material typically forms a monolith with an increased compressive strength and lower hydraulic conductivity.

This document focuses on the approach for implementing ISS where reagents are mixed with impacted material and cured in-place, to create a solidified mass with increased strength and typically a lower hydraulic conductivity, to reduce the potential for leaching of contaminants. Therefore, the technology discussed in this document is focused on on-site, in-situ treatment of MGP impacted material.

2.2 Contaminants Treated by ISS

ISS has been shown to treat a range of contaminants, such as metals including lead, arsenic and chromium, and organic contaminants such as creosote and petroleum products. Of particular interest at MGP sites are non-halogenated semi-volatile organic compounds (SVOCs) such as the PAHs naphthalene and benzo(a)pyrene. Table 2-1 lists ISS effectiveness in treating general contaminant groups.

Table 2-1
Documented Effectiveness of S/S Treatment for Chemical Groups (ITRC, 2011)

Chemical groups	Citations for treatment effectiveness[a]		
	EPA 1993a[b]	EPA 2009b[b]	Other references[c]
Organic Chemicals			
HVOCs[d]	N	N	D, with pretreatment (Paria and Yuet 2006)
N-HVOCs[d]	N	N	D, with pretreatment (Paria and Yuet 2006)
HSVOCs[d]	D	D	
N-HSVOCs, N-VOCs[d]	D	D	
PCBs	P	D	
Pesticides	P	D	
Dioxins/furans	P	P	D (Bates, Akindele, and Sprinkle 2002, PASSiFy Project 2010)
Organic cyanides	P	P*	D (Wilk 2007)
Organic corrosives	P	P*	D (Wilk 2007)
Pentachlorophenol	–	–	D (Bates, Akindele, and Sprinkle 2002, Wilk 2007)
Creosotes, coal tar	–	–	D (Bates, Akindele, and Sprinkle 2002,Wilk 2007)
Heavy oils	–	–	D (Wilk 2002)
Inorganic Chemicals			
Volatile metals	D	D*	
Nonvolatile metals	D	D	
Asbestos	D	D*	
Radioactive materials	D	D	
Inorganic corrosives[d]	D	D*	
Inorganic cyanides[d]	D	D*	
Mercury	D	D*	EPA 2007b
Reactive Chemicals			
Oxidizers	D	D*	
Reducers	D	D*	

[a] Key:

- N = no expected effectiveness, P = potential effectiveness, D = demonstrated effectiveness.
- P*/D* = S/S effectiveness was specifically stated in EPA 1993a but not in EPA 2009b; effectiveness is assumed to be the same in 2009. EPA 2007b documents the selection and use of S/S at National Priorities List (NPL) sites, but EPA does not indicate the effectiveness of the remedy.
- = This chemical was not specifically discussed in EPA 1993a or 2009a, but effectiveness has been documented in other references (see rightmost column).

[b] See EPA references (EPA 1993a, 1993c, 2009b) on use of S/S for organics and inorganics and for site remediation.

[c] Other references provide S/S effectiveness for specific chemical groups for which EPA (1993a, 2009b) has not specifically stated S/S effectiveness as "D."

[d] Halogenated volatile chemicals (HVOCs) include solvents, gases; nonhalogenated volatile chemicals (N-HVOCs) include ketones/furans, aromatics; halogenated semivolatile chemicals (HSVOCs) include PCBs, pesticides, chlorinated benzenes, chlorinated phenols; nonhalogenated semivolatile chemicals (N-HSVOCs) include PAHs, nonchlorinated phenols; inorganic corrosives include hydrochloride (HCL), sulfuric acid, sodium hydroxide, potassium hydroxide; inorganic cyanides include salts of cyanide (CN^-).

2.3 ISS Advantages and Limitations

ISS has been used effectively at MGP sites across the United States, specifically where saturated subsurface contaminants could not be excavated. ISS has a proven track record of effectively remediating a broad range of contaminants and is an economical remediation method. In general, the advantages and limitations associated with implementation of ISS at a MGP sites are essentially applicable to a site planned for redevelopment.

More extensive use of ISS to treat impacted materials has resulted in collection of useful data for evaluation of effectiveness of the ISS technology. As a result, practitioners are able to focus on important and necessary data and eliminate irrelevant factors for implementation of ISS. Implementation of ISS requires that practitioners have sound knowledge of site conditions as well as understand the limitations of the technology. Some of the non-site specific challenges and advantages associated with implementation of ISS technology are identified in ITRC July 2011, Environment Agency 2004, and EPRI 2009.

ISS Technology Advantages:

- Effective in treating wide range of material impacted by inorganic chemicals
- Effective in treating material impacted by certain organic chemicals (e.g. PAHs)
- Effective in treating material impacted by low level NAPL
- Generally more economical than excavation and offsite disposal
- Almost always more economical than excavation/offsite disposal for materials classified as hazardous waste
- Onsite treatment and management does not require transportation of impacted material to offsite disposal facility
- Treated material has improved structural properties (strength) and lends itself positively to redevelopment of the site
- Impacted materials above and below water table can be treated in-situ without dewatering
- Generally uses readily available construction equipment

ISS Technology Challenges:

- Contaminants are neither destroyed nor removed – they are immobilized
- Not effective in treating materials impacted by certain highly mobile organics (e.g. VOCs)
- Long-term stewardship may be required
- Depending on the quantity of reagents mixed, an increase in volume takes place after ISS treatment
- Potential change in physical property (reduced permeability, formation of granular or monolith solid) is typical after treatment and may require additional assessment
- Underground obstructions or debris may need to be removed prior to treatment

2.4 ISS Cost

ISS treatment costs range from $80 to $200 per cubic yard (EPRI, 2004). Depending on factors identified below, the cost of ISS can be lower than $80 per cubic yard. Primary factors influencing the total project implementability costs include, but are not limited to:

- Depth of the contaminants below ground surface;
- Dewatering if site conditions warrant;
- Presence of subsurface obstructions such as foundations, utilities, or large cobbles;
- Compatibility of the contaminants with suitable reagents;
- Resulting bulk volume increase.

3
FACTORS AFFECTING ISS PERFORMANCE

3.1 Overview

ISS can be applied to unsaturated soils, saturated soils (within groundwater), sediments, and other impacted media in-place without removing the impacted media. With ISS the contaminants remain in-place, however they may change in form physically (i.e. solidified) and chemically (i.e. stabilized) resulting in reduced mobility in the environment. Soils and sediments are the two commonly found materials that are impacted by contaminants and therefore are primarily considered as the impacted media in this report.

This section describes the key factors that can impact the performance of SS-treated material in the subsurface. The term “performance” refers to the ability of the SS-treated material to meet the numerical values for the performance parameters, i.e. strength, permeability and leachability.

A number of physical and chemical factors must be carefully considered when designing ISS remediation. Some of the key factors are discussed below.

3.2 Contaminants of Concern

The toxic nature and relative abundance of PAHs at MGP sites places the focus of most remediation efforts on these SVOCs. However, early site characterization sampling should include testing for the possible presence of metals and VOCs onsite. If necessary, remediation of VOCs should precede ISS using other processes such as thermal or biological treatment [EPA, 2000]. Certain organic contaminants have a detrimental effect on the properties of cementitious materials and may not be immobilized by ISS treatment. As noted in Table 2-1, ISS is expected to have no effectiveness on VOCs. However, the Federal Remediation Technologies Roundtable reports that systems targeting VOCs are being developed (FRTR, 2012).

While metals have been effectively treated using ISS, metal chemistry should be evaluated during bench-scale testing to determine how metal chemistry affects the ISS performance. Therefore, chemical and physical factors of the contaminants of concern must be considered during the reagent selection process.

To design an effective ISS treatment process a thorough understanding of the physical and chemical properties of the impacted media, contaminants and the mechanism of interactions between these is important. PAHs are hydrophobic compounds and tend to accumulate in soils and sediments and are typically found in low concentrations in the water. The type of contaminants present at a MGP site may dictate if ISS treatment should be implemented in separate steps for stabilization and solidification. Treatability testing should be conducted to evaluate if treatment needs to be implemented in single step or two steps.

ISS is typically effective in treating the contaminants of concern (COCs) found at a MGP sites. As long as the performance criteria developed can be verified by treatability testing, the type of COCs at a MGP site should have little impact on the redevelopment of the site. However, VOCs present at the site may require additional evaluation for vapor intrusion (VI) and possibly engineering controls.

3.3 pH

Although many factors play a role in effectiveness of ISS, pH is arguably the most important factor. The pH of the SS-treated material influences both the leachability of contaminants as well as strength. Several reactions that occur during the mixing process are strongly dependent on pH. Retention mechanisms such as adsorption, desorption, precipitate dissolution and solubility of inorganic constituents rely on proper pH balance to maximize ISS performance. In a cement-based ISS, most metals form insoluble hydroxides. Inorganic chemicals may be incorporated within the mineral phase, adsorbed on the mineral surface or organic matter, precipitated as solids or dissolved within porewater. The porewater pH has an effect on leaching of many inorganic chemicals under equilibrium-based leaching conditions. Most heavy metals form metal hydroxides species in the SS-treated material and the solubility of these hydroxides are strongly influenced by pH of the treated material porewater. The formulation of low solubility metal hydroxides is an important phenomenon in cement-based SS. Figure 3-1 shows the solubility of metal hydroxides with respect to pH of the porewater. As shown on this figure metal hydroxides solubility decreases with increasing pH up to a pH value of about 10. The solubility starts to increase after about a pH value of 11 and the metals form soluble complex anions with excess hydroxide ions (Paria, 2006).

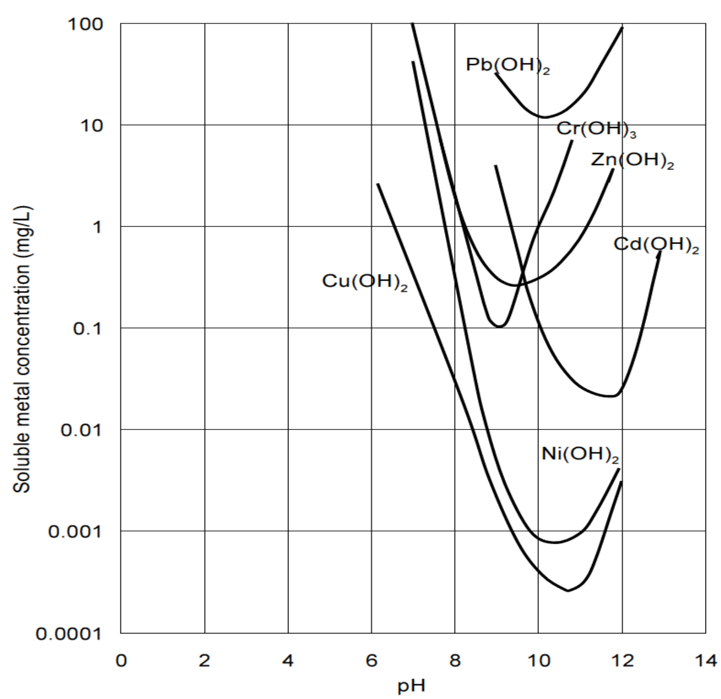

Figure 3-1
Calculated Solubilities of Metal Hydroxides at Different pH (from Cullinane et al. 1986; Shi and Spence 2004)

As detailed in the ITRC document, although pH does not have a direct influence on the solubility of organic contaminants such as PAHs, highly alkaline mixtures can result in greater dissolved concentrations of organic matter in pore water [2011]. PAHs tend to be concentrated or adsorbed on particular organic matter (for example, humic substances and other organic substances). Thus, the solubility of PAHs is not directly affected by change in pH; however at high pH, the organic matter tend to dissolve as dissolved organic carbon (DOC). The increased DOC in porewater results in increased concentration of PAHs in porewater (Butler 2009; Dijkstra, Meeussen, and Comans 2004; Roskam and Comans 2007). DOC can form aqueous complexes with PAHs, which in effect increase the PAHs concentration in porewater (EPRI 2009B).

Portland cement has been used extensively in ISS for impacted material containing metals. Typically, addition of Portland cement, improves the property of the treated material by increasing strength, reducing permeability and forming granular or monolithic structure. However, the increased pH from addition of Portland cement (high alkalinity material) may result in increased leaching of metals if the pH of the porewater increases past ten or eleven. Increase in porewater pH may also potentially solubilize some of the metals that may not have been leaching in the untreated material. Naturally occurring metals in soils may also be potentially solubilized and become mobile in the environment. As such, a thorough treatability testing is essential in evaluating the appropriate dosages of reagents for effectiveness and retention of inorganics and PAHs.

3.4 Hydraulic Conductivity

Hydraulic conductivity of the treated material/ monolith will determine the contact time of groundwater with the treated material. In general, after SS treatment the hydraulic conductivity is reduced and most of the groundwater tends to flow through a preferential pathway through the surrounding soils rather than through the stabilized mass, thus reducing the leaching potential of contaminants. The hydraulic conductivity difference between the monolith and undisturbed surrounding soil is potentially smallest with silty and clayey soil types. Additional discussion on hydraulic conductivity is provided in Section 4.2.

3.5 Homogeneity

During bench-scale testing, practitioner must evaluate the appropriate quantities of reagent material and quantity of water needed to achieve a homogenous mixture. Adding too much water results in more swelling, and a lack of water makes mixing difficult. Contaminants within the soil matrix must be mixed homogeneously with a stabilization reagent for the contaminants to come in contact with reagents. Such thorough contact between absorbed contaminants and the reagent reduces the leaching potential by changing the chemical form of metals and inorganic contaminants encapsulating the particles and through other mechanisms.

3.6 Environmental Factors

Long-term monolith integrity can be affected by external environmental factors. Acids, organic carbon, and chelants can alter the solubility of minerals and contaminants, which occurs most commonly near the surface of the monolith. Although ISS-treated monoliths are commonly found with micro- and macro-sized cracks, these do not equate to failure. A crack in monolith, essentially create two monoliths with the same performance characteristics.

4

KEY PERFORMANCE PARAMETERS

4.1 ISS Performance Assessment Approach

This document focuses on the technical approach and key performance parameters assessment for implementation of ISS at MGP sites with goals to redevelop the site. In assessing the performance of an ISS-treated material at MGP sites, several considerations should be taken into account; site remedial goals/objectives, risk associated with the contaminants, specific requirements of the regulatory agency, site land use, etc.

EPRI completed a study on the long-term effectiveness of cement-based ISS treatment implemented at a MGP site in Columbus, Georgia. The study evaluated structural integrity and solid phase geochemistry for identification of physical and chemical deterioration of the SS-treated material. The result of this evaluation indicates that ten years after treatment the structural integrity of the SS-treated solidified material continues to exceed the performance criteria established prior to implementation. All samples exceeded the geotechnical performance criteria (UCS and hydraulic conductivity) set for treated material. Groundwater monitoring shows that contaminant leaching has not occurred and results from modeling have shown that there is low potential for leaching in the future. The data revealed no evidence that the long-term future integrity of the site would be less stable than current site conditions. Therefore, the utilization of S/S at the site was concluded to be an appropriate long-term treatment method for contaminated MGP soils (EPRI, 2003).

Another study for evaluating the long-term performance was undertaken as part of extensive multinational project (PASSiFy, 2010) to investigate the long-term performance of SS-treated soils up to sixteen years old. Samples were collected for a total of eight sites – three Superfund and two private sites in the United States and three private sites in the United Kingdom were included in this study. The samples from these sites were analyzed using X-ray techniques, optical and electron microscopy and leaching tests. The results indicated that the SS-treated materials met their original acceptance physical performance criteria (strength and hydraulic conductivity). The study also concluded that release of contaminants from the SS-treated material was within the specified limits suggesting that contaminants are likely to be immobilized over extended period of time (Antemir, 2010).

Each site will need to develop its own remedial goals and thereby establish performance parameters based on site specific conditions. The following key performance parameters are considered the most important in evaluation of the ISS for redevelopment of a MGP sites based on a review of literature, ISS implementation experience at MGP and other sites, and evaluation for long-term performance:

- Hydraulic Conductivity
- Compressive Strength
- Contaminant Leachability
- Vapor Intrusion

4.2 Hydraulic Conductivity

Hydraulic conductivity[1] of soil or material expresses the ease with which water will pass through it and is defined by Darcy's Law. Hydraulic conductivity testing for SS-treated material measures the rate of water that passes through pores of the treated material. Physical performance criteria must be established prior to implementing the ISS program. Because a stabilized waste typically will have significantly lower hydraulic conductivity than the soil around it, most of the groundwater will naturally chose a preferential pathway other than through the stabilized mass, thus reducing the leaching potential of contaminants. It is therefore important to recognize that the groundwater flow path is dependent on relative hydraulic conductivities of SS-treated material and the surrounding soils. Since the flow of groundwater through the treated mass will be low, the dissolution (mass transfer of chemicals from soil to groundwater) of contaminants from soil particles to groundwater will also be very low. However, the outside surface area (within the saturated zone) of the treated monolith is the area that is directly exposed to the surrounding groundwater flow and may contribute to limited leaching (Figure 4-1). The leaching of contaminant is controlled by the rate of mass transfer.

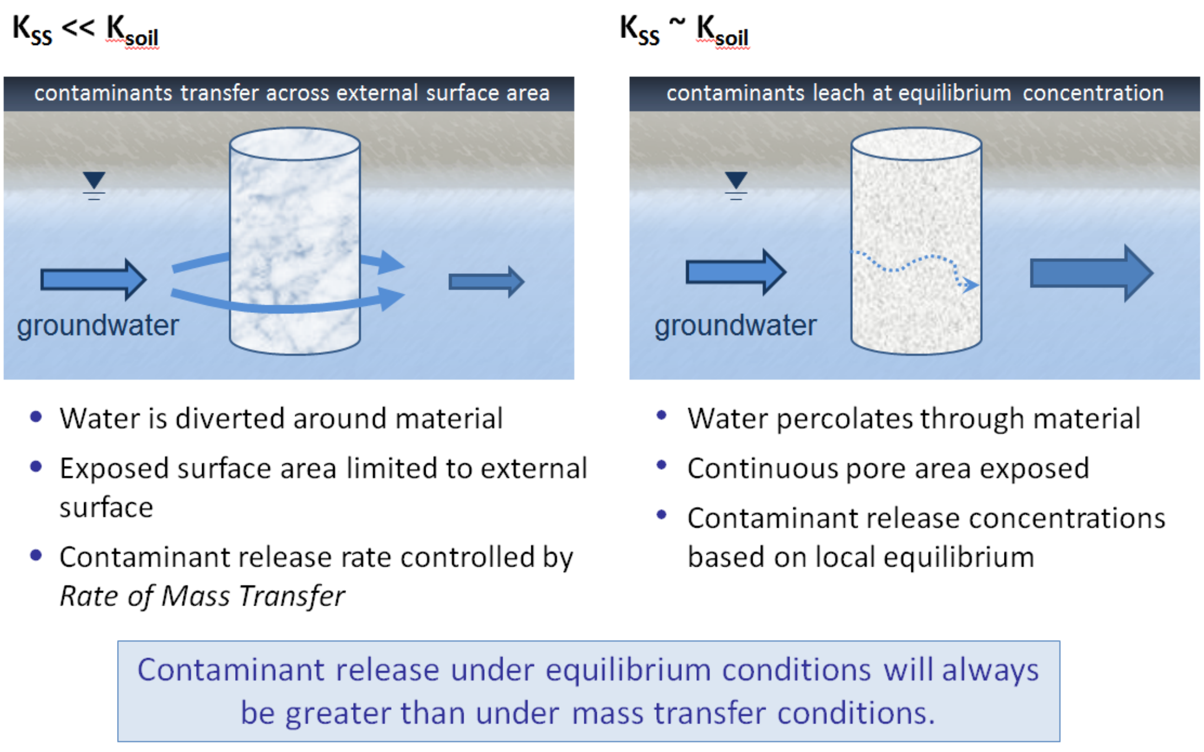

Figure 4-1
Relative Hydraulic Conductivity (Modified from ITRC, 2011)

In order to minimize the leaching, the SS-treated material should have a hydraulic conductivity less than surrounding soils. The hydraulic conductivity criteria of treated material should be selected based on the site's surrounding soil hydraulic conductivity. Permeability for soils vary

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[1] "Hydraulic conductivity" is often interchangeably referred as permeability. Permeability of a porous media expresses the ease with which fluid will pass through it. Although similar, permeability is defined in terms of porous media properties and independent of fluid properties such as viscosity and specific weight.

from 10^{-1} cm/sec for gravel/sand to 10^{-7} cm/sec for clay/rocks with silty clay and clay soils hydraulic conductivity ranging from 10^{-5} cm/sec to 10^{-6} cm/sec (Dagan 1989). Although site specific hydraulic conductivity should be developed, a commonly observed hydraulic conductivity for SS-treated material has ranged from 10^{-5} cm/sec to 10^{-6} cm/sec. These guidelines are also considered suitable for sites that will be redeveloped.

4.3 Compressive Strength

The compressive strength of a material reflects its ability to withstand mechanical force without incurring a structural damage and is a useful performance criterion in SS treatment. To estimate the long-term stability of any material the relationship between stress, strain, and time must be defined. Unconfined Compressive Strength (UCS) is used as a measure of the ability of a monolithic SS-treated material to resist mechanical stresses. It is one of the most commonly used tests and there are standard methods for its determination. UCS is commonly used to evaluate the physical performance of SS-treated soils for the following purposes:

- UCS is an indicator of the progress of hydration reactions in the material and durability of a monolithic SS material in a cement-based SS process (Perara, et al. 2004)
- Load bearing capacity for environmental covers/caps, for construction equipment access during in-situ mixing and thereafter, or for foundations for buildings;
- As an indicator of long-term durability.

As a minimum, the treated material should have a compressive strength equal to the surrounding soils. The EPA considers a SS material with a UCS of 50 psi as satisfactory (EPA 1989). This UCS guideline value is suggested by EPA to provide a stable foundation for material placed upon it, including construction equipment, impermeable cap or soil cover material. EPA also recommends that the minimum UCS for SS treated material be evaluated on a site specific basis and design loads to which the material will be subjected. The future land use of the site is an important consideration in developing the UCS criteria. SS-treated material with excessive UCS will be difficult to excavate (for the purpose of constructing a foundation), if the site is planned for redevelopment. As such, the UCS should be developed based on site specific conditions and future land use. A former MGP site in Wilmington, DE, which has undergone ISS treatment and redeveloped to house an IMAX theater, identified UCS of 50 psi and no greater 200 psi for redevelopment purposes (Section 9.6). Typical UCS values for sites identified for redevelopment may range from 25 psi to 200 psi depending on the future land-use.

4.4 Leachability

ITRC 2011 defines leaching to be the process of release of a constituent from a solid into contacting liquid. The term leachability may be used to describe either the percentage of total constituent leaching or rate of leaching (time-dependent release) from a material (ITRC 2011).

Two leaching procedures have historically been applied to test leaching from ISS material, neither of which accurately simulates typical environmental conditions encountered by ISS-treated granular or monolith materials. The Toxicity Characteristic Leaching Procedure (TCLP) simulates conditions in a landfill by extracting sample waste with an organic acid. Because ISS-treated materials are commonly left in place at MGP sites, the TCLP procedure is not the appropriate simulation of these disposal scenarios. Another process, the Synthetic Precipitation Leaching Procedure (SPLP), has been used in place of the TCLP to address these shortcomings.

The SPLP is designed to simulate waste exposure to acid rain; however, the SPLP process also involves breaking the monolith into many tiny particles for testing. The SPLP test protocol exposes specimens no larger than 1 centimeter to a pH of approximately 4.2 during the leaching test. Such total destruction of the ISS-treated monoliths is not likely to occur under typical conditions at a site following ISS. Many studies have concluded that the SPLP and the TCLP leaching tests are overly aggressive toward PAH releases and overestimate leachability of contaminants that would otherwise remain solidified within the monolith [EPRI, 2009].

The American Nuclear Society (ANS) has developed leaching test method ANS 16.1, *Measurement of the Leachability of Solidified Low-Level Radioactive Wastes by a Short-Term Test Procedure.* This test method was developed for cement-based low radioactive waste in the nuclear industry. Unlike TCLP or SPLP where samples are crushed into small particles, In ANS 16.1 an intact sample is used in the semi-dynamic leaching conditions. The procedure includes leachant replacement at certain time intervals and analyzing the water/liquid samples for cumulative fraction of contaminant release relative to total mass of the treated sample over a period of time. Typically the leachate solution used in this test is distilled water; however groundwater has also been used. Modifications (more frequent change of leachate) have been made to address the suppression of contaminant release rate to prevent the concentration from building up in the leachate. However, volatilization of VOCs or light PAHs from the container remains one of the major concerns of this test method.

Recently EPA has proposed non-destructive tests to model in-situ monolith leachability. These EPA Draft Methods are a combination of static, column, and semi-dynamic leach experiments that can be used to provide more detailed mechanistic information on material performance in comparison to the current standard leach methods, such as ANS 16.1, SPLP and TCLP. They are:

- Method 1313 "Liquid-Solid Partitioning as a Function of Extract pH for Constituents in Solid Materials using a Parallel Batch Extraction Procedure" – Method 1313 describes a leaching extraction procedure for a granular solid material at nine specified pH values used to assess how constituent leaching varies with leachant pH under equilibrium conditions.
- Method 1314 "Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials using an Up-flow Percolation Column Procedure" – This method is designed to provide the liquid-solid partitioning (LSP) of inorganic constituents (e.g., metals, radionuclides) and non-volatile organic constituents (e.g., polycyclic aromatic hydrocarbons (PAHs), dissolved organic carbon) in a granular solid material as a function of liquid-to-solid (LS) ratio under percolation conditions.
- Method 1315 "Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials using a Semi-dynamic Tank Leaching Procedure" – This method is designed to provide the mass transfer rates (release rates) of inorganic analytes contained in a monolithic or compacted granular material, under diffusion controlled release conditions, as a function of leaching time. Observed diffusivity and tortuosity may be estimated through analysis of the resulting leaching test data.
- Method 1316 "Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials using a Parallel Batch Extraction Procedure" – Method 1316 describes a leaching extraction procedure for a granular solid material at five specified liquid-to-solid ratio (L/S) values used to assess how constituent leaching varies with the relative leachant

volume in contact with a solid material under equilibrium conditions, and at the pH generated by the test material.

In ISS, leachability of a COC is normally established by site remedial goals and may not be necessarily driven by site redevelopment objectives. However, the site owner must identify the redevelopment goal prior to feasibility study to ensure that appropriate approach and methodologies are employed to develop the performance criteria. As an example, certain sites may not be required to meet a numerical leaching criterion for leaching of COC if the site is not slated for redevelopment. In this case, a percentage reduction in leaching has also been acceptable.

Table 4-1
Performance Parameters

Parameter	Units	Average Value	Test Method
Unconfined Compressive Strength	Pounds per Square Inch	>50[1]	ASTM D1633
Hydraulic Conductivity	Centimeters per Second	$<1x10^{-6}$	ASTM D5084
Leaching Tests	Milligrams per Liter	Site Specific	Proposed EPA Methods 1313, 1314, 1315 and 1316

[1] – EPA recommended value UCS value. UCS of 25 psi has been used at some sites; UCS value for a site can be average and can vary based on proposed redevelopment conditions.

4.5 Vapor Intrusion

Soil vapor intrusion (VI) is the process by which volatile chemicals move from a sub-surface source into the indoor air of overlying buildings. Because of a difference in pressure, soil vapor containing volatile chemicals can enter buildings through cracks in slabs or basement floors and walls, through openings around sump pumps, or where pipes and electrical conduits penetrate the foundation. In the last several years, VI from impacted sub-surface soil and/or groundwater into indoor air space in an overlying building has received considerable attention from regulatory agencies and has emerged as a major environmental issue. Vapor from MGP coal tar may contain a number of chemical constituents that maybe of potential concern to the environment and human health when left untreated. Benzene toluene ethyl-benzene and xylenes (BTEX) and some of the SVOCs are primary chemicals of concern at a MGP site. Of these, BTEX are the most volatile and most often considered in the assessment of vapor intrusion. PAHs are typically considered “semi-volatile”. Naphthalene, which is considered a PAH and is sometimes referred to as an SVOC, is sufficiently volatile and should be considered in the assessment of VI. VI is a concern for owners and developers that may become involved in redevelopment of the site.

EPRI conducted a study consisting of literature search for assessing vapor intrusion at MGP sites. This study indicated that there are very limited publicly available articles describing results of assessments of vapor intrusion of VOCs or SVOCs into buildings at former MGP sites. The EPRI literature search revealed that studies have not specifically addressed evaluation of natural attenuation or biodegradation of MGP chemicals within the vadose zone, which extends from the ground surface to the water table (EPRI 2009). The limited research conducted as part of the EPRI study did not provide specific information on migration of PAHs via vapor encroachment from MGP sites after implementation of ISS. While the lower permeability of ISS treated material may likely act like a vapor barrier and reduce the migration of PAHs via vapor encroachment, the long-term effects of ISS at reducing VI concerns from PAHs at MGP sites is not well documented. However, it is well-documented that during mixing of reagents, there is potential for VOCs and SVOCs to volatilize, as would also be expected during excavation or implementation of some other remediation alternatives. This volatilization of chemicals from MGP sites should be evaluated during treatability testing and more specifically during field pilot testing. Site-specific evaluation needs to be performed to assess if vapor laden with chemicals will emanate into the work zone or surrounding areas during mixing of reagents, and what mitigation measures are appropriate. Some sites have addressed the issue by installing a shroud around the mixing head devices to capture the vapor/chemicals during mixing of reagents. VI from ISS-treated material should be addressed on a site specific basis.

5
TREATABILITY TESTING CONSIDERATIONS

5.1 Bench-Scale Testing

A review of the ISS literature places specific emphasis on the benefits of bench-scale testing. Treatability testing provides valuable site-specific information is performed to evaluate the efficacy of ISS at a site and develop design basis information for full-scale implementation. A proper bench-scale testing considers the following parameters (ITRC, 2011):

- Chemical characteristics of impacted media
- Type of reagent to employ
- Quantities of the reagent and water
- Contaminant emission
- Scale-up considerations

The following steps are often considered when performing bench-scale testing:

- Preparing of a work plan
- Collecting test samples
- Characterizing test samples
- Performing treatability testing with reagents
- Analyzing, assessing, and validating data
- Writing a treatability study report

Bench-scale testing is an easy and cost-effective way to test several reagents, and develop design information over a short period of time. In a bench-scale testing a small quantity of impacted material is collected and mixed with previously identified reagents in the laboratory. Identification of reagent for bench-scale testing is mainly dependent on the type of COCs present at the site.

Once collected samples are characterized, bench-scale testing is performed in tiered approach and typically includes mixing previously identified reagents with impacted samples for assessing physical performance criteria of strength and permeability. Once the design basis for the physical performance criteria are developed, reagents are mixed with impacted material for assessing the leaching of chemicals. Leaching should be assessed not only for COCs, but also for other chemicals that may mobilize as result of reagent mixing and change in geo-chemistry of the impacted material. A bench-scale testing is an iterative process and the result of each tier is evaluated to determine the subsequent next steps and next set of parameters and conditions to be evaluated.

5.2 Sample Collection

Sample collection for bench-scale treatability testing is critical and requires technical expertise to determine the most appropriate locations based on previous sampling results, operation history of the site and visual survey. A sampling plan should be developed to identify sampling locations, number of samples, compositing of samples, analytical tests, analytical methods, sampling equipment, procedures, etc. Sampling plan should also consider how the full-scale ISS will be implemented. The main objective of sampling is to collect samples that are representative of entire site. Heterogeneity in contaminant distribution (vertically and horizontally) should be considered while collecting samples. Representative samples should also be considered from each geologic stratum that is to be involved in mixing. Proportional compositing can be performed by combining samples from each stratum according to the stratum thicknesses.

- Collect samples from several locations and select the sample with highest contaminant concentration for the bench-scale testing. Bench-scale testing performed using highly contaminated material provides assurance that these areas can be treated using ISS, however project cost developed from this information will be highly inflated.
- Perform bench-scale testing using samples which have been composited from a wide range of sampling locations, both vertically and horizontally to represent average site contaminant concentration.

Bench-scale testing should conceptually mimic full-scale implementation approach. If the site is complex containing number of contaminants, consideration should be given to how the full-scale will be implemented, such as full-scale will be implemented separately for each impacted area versus mixing and homogenizing all the material before adding reagents for ISS. If the site has single COC, compositing the samples for bench-scale testing will be appropriate. The depth of treatment is also an important consideration and samples should be collected to represent entire depth. In conclusion, not collecting representative samples for testing may potentially result in failure of performance criteria during full-scale implementation.

5.3 Reagent Selection

Selection of appropriate reagents for bench-scale testing is based on several factors including COCs, concentration of COCs, required performance criteria and geotechnical properties of the impacted material. While cementitious materials account for the majority of reagents used, the following additives may be considered based on site-specific conditions (Conner, 1998):

Table 5-1
Common Additives Used in ISS (from Conner, 1998)

Additive Class	Purpose
Concrete additives	Control leaching of heavy metals
Iron and aluminum compounds	Counters retarding effect of organic constituents in soil matrix
Organoclays	Control viscosity, reduce available water, sorb organics and metals
Sorbents, including activated carbon and ion-exchange resins	Immobilization of metals, especially complex species difficult to precipitate
Soluble silicates	Immobilize metals, reduce permeability, anti-inhibition agent for cement setting
Sorbents – fly ash, clays, minerals	Control free water content
Carbonates, sulfides, phosphates, and iron compounds	Speciate metals, or to co-precipitate them in less soluble forms
Buffers, including calcium carbonate and magnesium sulfate	Maintain pH within a desired range
Acids, alkalies, and salts (including lime, caustic soda, and ferrous sulfate)	pH control

5.4 Scale-up Considerations

The ease of mixing the selected soil and reagent combinations is one component to consider when progressing from the bench-scale testing to the next stages. Difficult mixing situations can add unwanted time, cost and potential failure of performance criteria. Excavating the unsaturated zone and surface obstructions prior to ISS implementation can minimize the volume treated and maximize operational time when ISS equipment is onsite.

Applying the proposed ISS techniques to full-scale implementation should address the following (ITRC (2011):

- Equipment sizing and selection
- Energy required for mixing
- Chemical storage and delivery methods
- Presence of debris and utilities
- Mixing and curing time
- Mixing grid design
- Quality assurance methods

6 IMPLEMENTATION CONSIDERATIONS

6.1 Reagent and Equipment

Reagent selection must consider availability, transport cost, and ease of pumping, injecting, and mixing into the soil. Successful use of grout with viscosities of less than 50 centipoise (cP) and densities of less than 95 pounds per cubic foot (pcf) have been reported (EPRI, 2004). Selecting equipment for mixing is based on depth of treatment and presence of debris. Mixing reagent homogenously with the impacted media is extremely important for reagents to come in contact with the contaminants. ISS mixing equipment is primarily selected based on the depth of treatment. For shallow treatment depth, a rotary type mixing device or excavator bucket is typically used. A high speed rotary type mixing device imparts high energy and mixes the reagents homogenously within a short period of time. An excavator bucket can also be used for mixing, however it typically requires more time to mix the reagent. Treatment depth greater than 15 feet typically requires an auger for mixing, if site conditions do not allow for a bench (platform) to be created. In both rotary and auger mixing devices, the reagents are delivered and injected through the mixing head, as slurry.

Sometimes stabilization is performed as a first step followed by solidification, depending on the contaminant type and the results of the bench-scale testing. This approach provides adequate contact of COCs with the stabilization reagent prior to mixing of solidification reagent (typically cement or pozzolanic material).

Monitoring mixing time, mixing speed of rotary mixer, auger penetration rate, reagent delivery rate, reagent slurry concentration, and reagent quantity are some of the items that should be incorporated into a quality assurance/quality control plan. In addition, the storage and delivery of reagents to the impacted areas need to be considered during mixing. In auger mixing, the overlap of treatment cells/zones is particularly important to ensure that all impacted materials are being treated.

6.2 Treated Material Performance

Evaluating ISS performance against specifications established at the outset of the remediation process and verified by the bench-scale testing, will determine the degree of success achieved by the remediation activities. Key parameters of ISS performance typically include strength, hydraulic conductivity, and leachability. ITRC presents detailed specifications of applicable performance testing methods (ITRC, 2011). Sometimes only strength and hydraulic conductivity are measured in the field during implementation when a robust treatability testing (bench and pilot) can demonstrate that leaching will not be a concern in the field. In addition, surrogate parameter such as pH of the treated material can be developed during bench-scale testing and can be measured in the field to correlate the leaching of the treated material. However, each site should develop its own performance parameter based on COCs and other site specific conditions. The performance tests are typically performed on samples that have been collected and cured for 7, 14 or 28 days.

The performance criteria should allow for some variability due to inherent differing conditions that may be encountered in the field. As part of the design, the practitioner should include a minimum acceptable value for each performance parameters and the minimum number of samples that will be acceptable with the minimum performance criteria values. With ISS, the goal should be to treat the impacted media and proactively meet the performance criteria after one treatment. Retreating the cells should be considered a last resort because the geo-chemistry of treated material has undergone a change and will not likely correlate to the pre-treatment bench-testing data and design.

6.3 Health and Safety

Due to the specialized nature of ISS, specific considerations warrant attention when considering the health and safety of workers and the public. These factors include:

- Use of reagents, such as cement, that pose respirable hazards
- Production of vapors during the mixing process
- Movement of heavy construction equipment
- Presence of subsurface utilities in the treatment area
- Creating unwanted chemical reactions in the subsurface

7
LONG-TERM STEWARDSHIP

7.1 Long-Term Durability

Durability studies indicate a properly designed and implemented ISS remediation should last decades or centuries (Environment Agency, 2004). Durability is maximized when the factors affecting ISS performance are considered in the design phase and addressed by the final implementation phase.

Two studies described in Section 4.1 of this report have concluded that durability of the SS-treated material has not been impacted for sites that were treated ten to sixteen years ago. Groundwater monitoring shows that contaminant leaching above acceptable levels has not occurred. The data revealed no evidence that the long-term future integrity of the site would be less stable than current site conditions.

7.2 Groundwater Monitoring

With ISS, the contaminants are left in-place and sometimes the treated material is below the water table. Groundwater monitoring is conducted to verify that treatment was successful and the contaminants from the treated mass are not migrating into the groundwater. Long-term groundwater monitoring plans consider baseline conditions prior to SS implementation and site redevelopment use when comparing routine groundwater concentrations to site cleanup objectives. If untreated impacted areas remain up-gradient of the ISS treatment area, these concentrations may be established as the baseline for samples collected down-gradient of the remediated area. Water table elevation may be one factor to monitor, as the ISS treatment area can change the infiltration rate of stormwater and change the groundwater flow regime.

In selecting locations for groundwater monitoring wells, the new groundwater flow regime, contaminant travel time & pathway, and locations of other potential impacts will need to be considered. Elevated groundwater concentrations of contaminants in some states, such as New Jersey, trigger indoor air monitoring based on the proximity of the well to a building. Proper placement of the groundwater monitoring well will aid in complying with these regulations.

Modeling data may help predict groundwater concentrations over time. These data can assist in establishing optimal locations for long-term groundwater monitoring wells and the frequency and duration of groundwater sampling.

7.3 Institutional and Engineering Controls

Administrative and/or legal controls to limit human exposure or disturbance of the monolith are known as institutional controls. Zoning restrictions, deed ordinances, and groundwater use controls are examples of institutional controls commonly used with ISS techniques.

Common ISS engineering controls include barriers or membranes; these structures limit the contact between the stabilized material and human activity, control infiltration, and could act to contain or remove potential vapors from the subsurface. Substances such as soil or asphalt can serve as the onsite covers, which are primarily used when the ISS treatment is performed at shallow depths.

7.4 Land Use

Institutional and engineering controls play a major role in acceptable site reuse. Post-ISS land use must consider the controls in place and, in the same turn, anticipated land use should help shape which controls are implemented at the subject property. Once ISS implementation is completed, land use should be managed through planning and zoning, ordinances, land use laws, etc. Future land use can be impacted by the existence of contamination as is the case with ISS. However, with appropriate institutional and engineering controls land can be redeveloped. It is important to know the future land use to develop the treatment program design and the institutional controls. A properly designed ISS improves the suitability of a site for redevelopment construction, not impede it. ISS can be designed to accommodate variety of land use with suitable selection of performance criteria (described in Section 4) based on the future land use.

7.5 Community Concerns

Implementing ISS requires significant equipment and site disturbance; community notification and public relations work may be necessary to allay concerns of the public and local officials if the project is one with high visibility. Public notification is required by some states and may require long-term performance monitoring updates.

Vapor intrusion has been a topic in question at developed MPG sites. The likelihood of vapor intrusion has not been the focus of many long-term studies and should be considered within the realm of possibility. However, as published in the Journal of Regulatory Toxicology and Pharmacology, “No increased public health risks were associated with occupied residential or commercial properties overlying or surrounding former MGPs” (2011). Development with no reported vapor intrusion issues has occurred at several of the example projects highlighted in Section 9.

8

SUMMARY AND CONCLUSIONS

ISS is a proven and established treatment technology for management of COCs detected at MGP sites. ISS has been used at several MGP sites with promising results. Ample literature describing how to implement ISS exist, however a standard approach for selecting and implementing the ISS technology at MGP sites for redevelopment purposes are not adequately documented. Redevelopment of an MGP site requires careful planning and designing the ISS using appropriate approach and consideration of factors that are important. This report presents an approach to develop and implement an ISS remedy for remediation of former MGP sites for redevelopment purposes.

- Although ISS has shown to be an effective remedy, few MGP sites have been redeveloped for future use.
- Recent studies conducted at several sites, with more than ten years from ISS implementation, have demonstrated that ISS is an effective remedy and continues to meet the performance criteria set during remediation.
- The key factors that influence the performance of ISS-treated material are:
  - pH of the treated material
  - Contaminant type
  - Relative hydraulic conductivity
  - Thorough homogeneous mixing of reagent with impacted material
- Collecting representative samples for bench-scale testing is critical in developing design basis for the full-scale ISS remedy.
- Although several performance criteria are used in the past, the key performance criteria are strength, hydraulic conductivity, leachability and VI.
- While lower permeability of ISS-treated material may influence VI, site-specific evaluation is required if VOCs are present at the site.
- The approach to assessing the effectiveness of ISS at MGP site has varied widely due to regulatory climate, lack of understanding of the technology, future land use of the site, lack of consistent assessment methodology, use of inconsistent performance criteria, etc. This has discouraged the owner/developers of MGP sites from choosing ISS for implementation where redevelopment of site is planned.
- Few MGP sites have been redeveloped after being remediated using ISS primarily due to the presence of contaminants at the site. In ISS the contaminants are not destroyed or removed – they are immobilized by physical mechanism and chemical reactions. A long-term stewardship of an ISS remediated site is required and may include monitoring of institutional controls and maintenance of engineering controls to address the concerns of site owners/developers. With this inexpensive long-term stewardship, MGP sites can be economically redeveloped using ISS.

9
EXAMPLE PROJECTS

9.1 Former MGP site, Macon, Georgia

ISS used to treat this former MGP site, which was redeveloped as a park and river walk to attract new businesses to the area. Strict performance criteria for UCS, permeability, and wet/dry durability were met for the 16,290 cubic yards of material mixed to a depth of 26 feet below grade. The reagent mixture included ground granulated blast furnace slag cement, Portland cement, and bentonite. Public health and safety and odor controls were top concerns during the development of this urban parcel (Geo-Con, 2012b).

Figure 9-1
Macon, Georgia work in progress (www.Geo-Con.net)

9.2 Former MGP Site, Exeter, New Hampshire

Nearby senior citizen housing and daycare facilities were prime concerns when ISS was used to successfully treat LNAPL and DNAPL contaminants at this former MGP site in Exeter, New Hampshire. Odors with the potential to migrate offsite were minimized with odor-reducing compounds as soil was disturbed. Reagents used in the stabilization of the approximately 7,900 cubic yards of material included municipal water, Portland cement, organophillic clay, and sodium bentonite (Geo-Con, 2012a). A portion of site has been redeveloped for senior citizen housing.

Figure 9-2
Exeter, New Hampshire Site (www.Geo-Con.net)

9.3 Former MGP Site Athens, Georgia

Cement-based grout was injected and mixed with saturated soils between 10 and 30 feet below grade during ISS remediation at this former MGP site in Athens, Georgia (Portland cement Association, 2004). Situated next to residential areas, a portion of this property is now part of the North Oconee River Greenway, a pathway used by pedestrians and bicyclers near the Oconee River. The rest of the site has been developed into a county transportation center consisting of buildings and parking lots. (Athens, 2013).

9.4 Former MGP Site Nyack, New York

A 4-acre former MGP site adjacent to the Hudson River and proximal to nearby commercial and residential properties in Nyack, New York was found to contain coal tar NAPL and BTEX compounds. ISS was implemented on a portion of the site with a mixture of water, Portland cement, and sodium bentonite used as the reagent. The reagent was manufactured in a custom onsite batch plant and mixed in soil columns to the bedrock depth of 21 feet below grade. The bedrock-ISS interface was sealed using a high-pressure jet grouting method. Approximately 11,711 cubic yards of material were treated using ISS (Geo-Con, 2012c). Design standards include a hydraulic conductivity of 1x10-6 cm/sec and USC between 50 and 500 psi (NYSDEC, 2011).

Figure 9-3
Nyack, New York work in progress (www.Geo-Con.net)

9.5 Former MGP Site Cambridge, Massachusetts

Approximately 103,000 cubic yards of material were stabilized at a former MGP site in Cambridge, Massachusetts. Obstructions present in the mixing area were removed or broken in place and then removed prior to ISS implementation. A foam suppressant was used to control odors generated during the excavation of the obstructions. Existing groundwater between 8 and 10 feet below grade and was combined with additional water, cement-kiln dust, and bentonite reagents. The site has been developed to include commercial office building (Geo-Con, 2012).

Figure 9-4
Cambridge, Massachusetts site (www.Geo-Con.net)

9.6 Former MGP Site Wilmington, Delaware

This industrial site was primarily used for a MGP since the late 1800s and was in operation till 1961. Site investigation indicated presence of metals, PAHs, VOCs SVOCs and PCBs in soils. The remedy consisted of hot-spot excavation for PCBs and NAPL impacted areas and ISS for the remaining area. Approximately 16,302 cubic yards of material were in-situ stabilized/solidified. Portland cement and slag were the reagents developed based on bench-scale treatability testing. The performance criteria were hydraulic conductivity less than 5×10^{-6} cm/sec, UCS greater than 50 psi and no more than 200 psi, wet/dry cycle less than 10%, and paint filter test. ANS16.1 leachability test was performed on ISS-treated samples for informational purposes only. To prevent access to the existing and SS-treated soils, a two feet thick soil cap was placed over the entire treated area. In addition, a vapor barrier for protection from VI is installed underneath buildings constructed at the site. Long-term stewardship consists of groundwater monitoring and institutional controls. An environmental covenant is placed for this site requiring notification to Delaware Natural Resources and Environmental Control (DNREC) prior to any intrusive activity and restriction on groundwater use. The site has been redeveloped and an IMAX theater has been constructed at the site.

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