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Office of
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Emergency Response

EPA

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TITLE: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites

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2. Originator Information

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3. Title

Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites

4. Summary of Directive (include brief statement of purpose)

The purpose of this Directive is to clarify EPA's policy regarding the use of monitored natural attenuation for the remediation of contaminated soil and groundwater at sites regulated under Office of Solid Waste and Emergency Response (OSWER) programs.

5. Keywords

natural attenuation, remediation, soil, groundwater, contamination

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9. Signature of Lead Office Directives Coordinator	Date
Hal White	11/19/97
10. Name and Title of Approving Official	**Date**
Timothy Fields, Jr.	12/1/97

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 18 1997

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

MEMORANDUM

SUBJECT: Draft Interim Final OSWER Monitored Natural Attenuation Policy (OSWER Directive 9200.4-17)

FROM: Elizabeth Cotsworth, Acting Director
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TO: Addressees

Purpose

This memorandum accompanies a draft Interim Final Policy (OSWER Directive 9200.4-17) regarding the use of monitored natural attenuation for the remediation of contaminated soil and groundwater at sites regulated under all programs administered by EPA's Office of Solid Waste and Emergency Response (OSWER), including Superfund, RCRA Corrective Action, and Underground Storage Tanks. The Directive incorporates extensive comments received from EPA Regional and Headquarters reviewers (including the Office of General Counsel), as well as state agencies and federal facility representatives.

Summary of the Directive

This Directive clarifies the U.S. Environmental Protection Agency's (EPA) policy regarding the use of Monitored Natural Attenuation for the remediation of contaminated soil and groundwater at sites regulated under Office of Solid Waste and Emergency Response (OSWER) programs. These include programs administered under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund"), the Resource Conservation and Recovery Act (RCRA), the Office of Underground Storage Tanks (OUST), and the Federal Facilities Restoration and Reuse Office (FFRRO). The Directive is intended to promote consistency in how monitored natural attenuation remedies are proposed, evaluated, and approved. As a policy document, it does not provide technical guidance on evaluating Monitored Natural Attenuation remedies. This Directive is being issued as Interim Final and may be used immediately. It provides guidance to EPA staff, to the public, and to the regulated community on how EPA intends to exercise its discretion in implementing national policy on the use of Monitored Natural Attenuation. The document does not, however, substitute for EPA's statutes or regulations, nor is it a regulation itself and, thus, it does not impose legally-binding requirements on EPA, States, or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA may change this guidance in the future, as appropriate.

Implementation

This Directive is being issued in Interim Final form and should be used immediately as guidance for proposing, evaluating, and approving Monitored Natural Attenuation remedies. This Interim Final Directive will be available from the Superfund, RCRA, and OUST dockets and through the RCRA, Superfund & EPCRA Hotline (800-424-9346 or 703-412-9810). The directive will also be available in electronic format from EPA's home page on the Internet (the address is http://www.epa.gov/swerust1/directiv/d9200417.htm). EPA will review and evaluate additional comments received on this Interim Final version before issuing the Final Directive.

Questions/Comments

If you need more information about the Directive please feel free to contact any of the appropriate EPA staff listed on the attachment.

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State LUST Program Managers
UST/LUST Regional Program Managers
UST/LUST Regional Branch Chiefs
State Superfund Program Managers
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attachment

Attachment
EPA Contacts
December 3, 1997

If you have any questions regarding this policy, please first call the RCRA/Superfund Hotline at (800) 424-9346. If you require further assistance, please contact the appropriate staff from the list below:

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USE OF MONITORED NATURAL ATTENUATION AT SUPERFUND, RCRA CORRECTIVE ACTION, AND UNDERGROUND STORAGE TANK SITES

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Directive 9200.4-17

November, 1997

USE OF MONITORED NATURAL ATTENUATION AT SUPERFUND, RCRA CORRECTIVE ACTION, AND UNDERGROUND STORAGE TANK SITES

Contents

NOTICE: This document provides guidance to EPA staff. It also provides guidance to the public and to the regulated community on how EPA intends to exercise its discretion in implementing its regulations. The guidance is designed to implement national policy on these issues. The document does not, however, substitute for EPA's statutes or regulations, nor is it a regulation itself. Thus, it does not impose legally-binding requirements on EPA, States, or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA may change this guidance in the future, as appropriate.

PURPOSE AND OVERVIEW

The purpose of this Directive is to clarify EPA's policy regarding the use of monitored natural attenuation for the remediation of contaminated soil and groundwater at sites regulated under Office of Solid Waste and Emergency Response (OSWER) programs. These include programs administered under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund), the Resource Conservation and Recovery Act (RCRA), the Office of Underground Storage Tanks (OUST), and the Federal Facilities Restoration and Reuse Office (FFRRO).

EPA remains fully committed to its goals of protecting human health and the environment, remediating contaminated soils and groundwater, and protecting uncontaminated groundwaters and other environmental resources[1] at all sites being remediated under OSWER programs. EPA does not consider monitored natural attenuation to be a "presumptive" or "default" remedy—it is merely one option that should be evaluated with other applicable remedies. EPA advocates using the most appropriate technology for a given site. EPA does not view monitored natural attenuation to be a "no action" or "walk-away" approach, but rather considers it to be an alternative means of achieving remediation objectives that may be appropriate for a limited set of site circumstances where its use meets the applicable statutory and regulatory requirements. As there is often a variety of methods available for achieving a given site's remediation objectives[2], monitored natural attenuation may be evaluated and compared to other viable remediation methods (including innovative technologies) during the study phases leading to the selection of a remedy. As with any other remedial alternative, monitored natural attenuation should be selected only where it meets all relevant remedy selection criteria, where it will be fully protective of human health and the environment, and where it will meet site remediation objectives, within a time frame that is reasonable compared to that offered by other methods. In the majority of cases where monitored natural attenuation is proposed as a remedy, its use may be appropriate as one component of the total remedy, that is, either in conjunction with active remediation or as a follow-up measure. Monitored natural attenuation should be used very cautiously as the sole remedy at contaminated sites. Furthermore, the availability of monitored natural attenuation as a potential remediation tool does not imply any lessening of EPA's longstanding commitment to pollution prevention. Waste minimization, pollution prevention programs, and minimal technical requirements to prevent and detect releases remain fundamental parts of EPA waste management and remediation programs.

[1] Environmental resources to be protected include groundwater, drinking water supplies, surface waters, ecosystems and other media (air, soil and sediments) that could be impacted from site contamination.

[2] In this Directive, remediation objectives are the overall objectives that remedial actions are intended to accomplish and are not the same as chemical-specific cleanup levels. Remediation objectives could include preventing exposure to contaminants, minimizing further migration of contaminants from source areas, minimizing further migration of the groundwater contaminant plume, reducing contamination in soil or groundwater to specified cleanup levels appropriate for current or potential future uses, or other objectives.

Use of monitored natural attenuation does not signify a change in OSWER's remediation objectives, including the control of source materials and restoration of contaminated groundwaters, where appropriate (see Section 1, under "Implementation"). Thus, EPA expects that source control measures will be evaluated for all sites under consideration for any proposed remedy. As with other remediation methods, selection of monitored natural attenuation as a remediation method should be supported by detailed site-specific information that demonstrates the efficacy of this remediation approach. In addition, the progress of monitored natural attenuation toward a site's remediation objectives should be carefully monitored and compared with expectations. Where monitored natural attenuation's ability to meet these expectations is uncertain and based predominantly on predictive analyses, decision makers should incorporate contingency measures into the remedy.

The scientific understanding of natural attenuation processes continues to evolve rapidly. EPA recognizes that significant advances have been made in recent years, but there is still a great deal to be learned regarding the mechanisms governing natural attenuation processes and their ability to address different types of contamination problems. Therefore, while EPA believes monitored natural attenuation may be used where circumstances are appropriate, it should be used with caution commensurate with the uncertainties associated with the particular application. Furthermore, largely due to the uncertainty associated with the potential effectiveness of monitored natural attenuation to meet remedial objectives that are protective of human health and the environment, **source control and performance monitoring are fundamental components of any monitored natural attenuation remedy**.

This Directive is not intended to provide detailed technical guidance on evaluating monitored natural attenuation remedies. At present, there is a relative lack of EPA guidance concerning appropriate implementation of monitored natural attenuation remedies. With the exception of Chapter IX in OUST's guidance manual (USEPA, 1995a), EPA has not yet completed and published specific technical guidance to support the evaluation of monitored natural attenuation for OSWER sites. However, technical resource documents for evaluating monitored natural attenuation in groundwater, soils, and sediments are currently being developed by EPA's Office of Research and Development (ORD). In addition, technical information regarding the evaluation of monitored natural attenuation as a remediation alternative is available from a variety of sources, including those listed at the end of this Directive. "References Cited" lists those EPA documents that were specifically cited within this Directive. The list of "Additional References" includes documents produced by EPA as well as non-EPA entities. Finally, "Other Sources of Information" lists sites on the World Wide Web (Internet) where information can be obtained. Although non-EPA documents may provide regional and state site managers, as well as the regulated community, with useful technical information, these non-EPA guidances are not officially endorsed by EPA, and all parties involved should clearly understand that such guidances do not in any way replace current EPA or OSWER guidances or policies addressing the remedy selection process in the Superfund, RCRA, or UST programs.

BACKGROUND

The term "monitored natural attenuation", as used in this Directive, refers to the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remedial objectives within a time frame that is reasonable compared to that offered by other more active methods. The "natural attenuation processes" that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; and chemical or biological stabilization, transformation, or destruction of contaminants. When relying on natural attenuation processes for site remediation, EPA prefers those processes that degrade contaminants, and for this reason, EPA expects that monitored natural attenuation will be most appropriate at sites that have a low potential for plume generation and migration (see Section 3 under "Implementation"). Other terms associated with natural attenuation in the literature include "intrinsic remediation", "intrinsic bioremediation", "passive bioremediation", "natural recovery", and "natural assimilation". While some of these terms are synonymous with "natural attenuation," others refer strictly to biological processes, excluding chemical and physical processes. Therefore, it is recommended that for clarity and consistency, the term "monitored natural attenuation" be used throughout OSWER remediation programs unless a specific process (*e.g.*, reductive dehalogenation) is being referenced.

Natural attenuation processes are typically occurring at all sites, but to varying degrees of effectiveness depending on the types and concentrations of contaminants present and the physical, chemical, and biological characteristics of the soil and groundwater. Natural attenuation processes may reduce the potential risk posed by site contaminants in three ways:

(1) The contaminant may be converted to a less toxic form through destructive processes such as biodegradation or abiotic transformations;

(2) Potential exposure levels may be reduced by lowering of concentration levels (through destructive processes, or by dilution or dispersion); and

(3) Contaminant mobility and bioavailability may be reduced by sorption to the soil or rock matrix.

Where conditions are favorable, natural attenuation processes may reduce contaminant mass or concentration at sufficiently rapid rates to be integrated into a site's soil or groundwater remedy (see Section 3 under "Implementation" for a discussion of favorable site conditions). Following source control measures, natural attenuation may be sufficiently effective to achieve remediation objectives at some sites without the aid of other (active) remedial measures. Typically, however, monitored natural attenuation will be used in conjunction with active remediation measures. For example, monitored natural attenuation could be employed in lower concentration areas of the dissolved plume and as a follow-up to active remediation in areas of higher concentration. EPA also encourages the consideration of innovative approaches which may offer greater confidence and reduced remediation time frames at a modest additional cost.

While monitored natural attenuation is often dubbed "passive" remediation because it occurs without human intervention, its use at a site does **not** preclude the use of "active" remediation or the application of enhancers of biological activity (*e.g.*, electron acceptors, nutrients, and electron donors). However, by definition, a remedy that includes the introduction of an enhancer of any type is no longer considered to be "natural" attenuation. Use of monitored natural attenuation does not imply that activities (and costs) associated with investigating the site or selecting the remedy (*e.g.*, site characterization, risk assessment, comparison of remedial alternatives, performance monitoring, and contingency measures) have been eliminated. These elements of the investigation and cleanup must still be addressed as required under the particular OSWER program, regardless of the remedial approach selected.

Transformation Products

It also should be noted that some natural attenuation processes may result in the creation of transformation products[3] that are more toxic than the parent contaminant (*e.g.*, degradation of trichloroethylene to vinyl chloride). The potential for creation of toxic transformation products is more likely to occur at non-petroleum release sites (*e.g.*, chlorinated solvents or other volatile organic spill sites) and should be evaluated to determine if implementation of a monitored natural attenuation remedy is appropriate and protective in the long term. Additionally, some natural attenuation processes may result in transfer of some contaminants from one medium to another (*e.g.*, from soil to groundwater, from soil to air or surface water, and from groundwater to surface water). Such cross-media transfer is not desirable, and generally not acceptable except under certain site-specific circumstances, and would likely require an evaluation of the potential risk posed by the contaminant(s) once transferred to that medium.

Petroleum-Related Contaminants

Natural attenuation processes, particularly biological degradation, are currently best documented at petroleum fuel spill sites. Under appropriate field conditions, the regulated compounds benzene, toluene, ethyl benzene, and xylene (BTEX) may naturally degrade through microbial activity and ultimately produce non-toxic end products (*e.g.*, carbon dioxide and water). Where microbial activity is sufficiently rapid, the dissolved BTEX contaminant plume may stabilize (*i.e.*, stop expanding), and contaminant concentrations may eventually decrease to levels below regulatory standards. Following degradation of a dissolved BTEX plume, a residue

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[3]The term "transformation products" in the Directive includes biotically and abiotically formed products described above (*e.g.*, TCE, DCE, vinyl chloride), decay chain daughter products from radioactive decay, and inorganic elements that become methylated compounds (*e.g.*, methyl mercury) in soil and sediment.

consisting of heavier petroleum hydrocarbons of relatively low solubility and volatility will typically be left behind in the original source (spill) area. Although this residual contamination may have relatively low potential for further migration, it still may pose a threat to human health or the environment either from direct contact with soils in the source area or by continuing to slowly leach contaminants to groundwater. For these reasons, monitored natural attenuation alone is generally not sufficient to remediate even a petroleum release site. Implementation of source control measures in conjunction with monitored natural attenuation is almost always necessary. Other controls (*e.g.*, institutional controls[4]), in accordance with applicable state and federal requirements, may also be necessary to ensure protection of human health and the environment. Furthermore, while BTEX contaminants tend to biodegrade with relative ease, other chemicals (*e.g.*, methyl tertiary-butyl ether [MTBE]) that are more resistant to biological or other degradation processes may also be present in petroleum fuels. In general, monitored natural attenuation is not appropriate as a sole remediation option at sites where non-degradable and nonattenuated contaminants are present at levels that pose an unacceptable risk to human health or the environment. Where non-degradable contaminants are present, all processes (listed on page 4) which contribute to natural attenuation should be evaluated to ensure protection of human health and the environment.

Chlorinated Solvents

Chlorinated solvents, such as trichloroethylene, represent another class of common contaminants that may also biodegrade under certain environmental conditions. Recent research has identified some of the mechanisms potentially responsible for degrading these solvents, furthering the development of methods for estimating biodegradation rates of these chlorinated compounds. However, the hydrologic and geochemical conditions favoring significant biodegradation of chlorinated solvents may not often occur. Because of the nature and the distribution of these compounds, natural attenuation may not be effective as a remedial option. If they are not adquately addressed through removal or containment measures, source materials can continue to contaminate groundwater for decades or even centuries. Cleanup of solvent spills is also complicated by the fact that a typical spill includes multiple contaminants, including some that are essentially non-degradable.[5] Extremely long dissolved solvent plumes have been documented that may be due to the existence of subsurface conditions that are not conducive to natural attenuation.

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[4] The term “institutional controls” refers to non-engineering measures—usually, but not always, legal controls—intended to affect human activities in such a way as to prevent or reduce exposure to hazardous substances. Examples of institutional controls cited in the National Contingency Plan (USEPA, 1990a, p.8706) include land and resource (*e.g.*, water) use and deed restrictions, well-drilling prohibitions, building permits, well use advisories, and deed notices.

[5] For example, 1,4-dioxane, which is used as a stabilizer for some chlorinated solvents, is more highly toxic, less likely to sorb to aquifer solids, and less biodegradable than are other solvents under the same environmental conditions .

Inorganics

Monitored natural attenuation may, under certain conditions (*e.g.*, through sorption or oxidation-reduction reactions), effectively reduce the dissolved concentrations and/or toxic forms of inorganic contaminants in groundwater and soil. Both metals and non-metals (including radionuclides) may be attenuated by sorption[6] reactions such as precipitation, adsorption on the surfaces of soil minerals, absorption into the matrix of soil minerals, or partitioning into organic matter. Oxidation-reduction (redox) reactions can transform the valence states of some inorganic contaminants to less soluble and thus less mobile forms (*e.g.*, hexavalent uranium to tetravalent uranium) and/or to less toxic forms (*e.g.*, hexavalent chromium to trivalent chromium). Sorption and redox reactions are the dominant mechanisms responsible for the reduction of mobility, toxicity, or bioavailability of inorganic contaminants. It is necessary to know what specific mechanism (type of sorption or redox reaction) is responsible for the attenuation of inorganics because some mechanisms are more desirable than others. For example, precipitation reactions and absorption into a soil's solid structure (*e.g.*, cesium into specific clay minerals) are generally stable, whereas surface adsorption (*e.g.*, uranium on iron-oxide minerals) and organic partitioning (complexation reactions) are more reversible. Complexation of metals or radionuclides with carrier (chelating) agents (*e.g.*, trivalent chromium with EDTA) may increase their concentrations in water and thus enhance their mobility. Changes in a contaminant's concentration, pH, redox potential, and chemical speciation may reduce a contaminant's stability at a site and release it into the environment. Determining the existence and demonstrating the irreversibility of these mechanisms are key components of a sufficiently protective monitored natural attenuation remedy.

In addition to sorption and redox reactions, radionuclides exhibit radioactive decay and, for some, a parent-daughter radioactive decay series. For example, the dominant attenuating mechanism of tritium (a radioactive isotopic form of hydrogen with a short half-life) is radioactive decay rather than sorption. Although tritium does not generate radioactive daughter products, those generated by some radionulides (*e.g.*, Am-241 and Np-237 from Pu-241) may be more toxic, have longer half-lives, and/or be more mobile than the parent in the decay series. It is critical that the near surface or surface soil pathways be carefully evaluated and eliminated as potential sources of radiation exposure.

Inorganic contaminants persist in the subsurface because, except for radioactive decay, they are not degraded by the other natural attenuation processes. Often, however, they may exist in forms that are less mobile, not bioavailable, and/or non-toxic. Therefore, natural attenuation

[6]When a contaminant is associated with a solid phase, it is usually not known if the contaminant is precipitated as a three-dimensional molecular coating on the surface of the solid, adsorbed onto the surface of the solid, absorbed into the structure of the solid, or partitioned into organic matter. "Sorption" will be used in this Directive to describe, in a generic sense (*i.e.*, without regard to the precise mechanism) the partitioning of aqueous phase constituents to a solid phase.

of inorganic contaminants is most applicable to sites where immobilization or radioactive decay is demonstrated to be in effect and the process/mechanism is irreversible.

Advantages and Disadvantages of Monitored Natural Attenuation

Monitored natural attenuation has several potential advantages and disadvantages, and its use should be carefully considered during site characterization and evaluation of remediation alternatives. **Potential advantages** of monitored natural attenuation include:

- As with any *in situ* process, generation of lesser volume of remediation wastes, reduced potential for cross-media transfer of contaminants commonly associated with *ex situ* treatment, and reduced risk of human exposure to contaminated media;
- Less intrusion as few surface structures are required;
- Potential for application to all or part of a given site, depending on site conditions and cleanup objectives;
- Use in conjunction with, or as a follow-up to, other (active) remedial measures; and
- Lower overall remediation costs than those associated with active remediation.

The **potential disadvantages** of monitored natural attenuation include:

- Longer time frames may be required to achieve remediation objectives, compared to active remediation;
- Site characterization may be more complex and costly;
- Toxicity of transformation products may exceed that of the parent compound;
- Long term monitoring will generally be necessary;
- Institutional controls may be necessary to ensure long term protectiveness;
- Potential exists for continued contamination migration, and/or cross-media transfer of contaminants;

- Hydrologic and geochemical conditions amenable to natural attenuation are likely to change over time and could result in renewed mobility of previously stabilized contaminants, adversely impacting remedial effectiveness; and

- More extensive education and outreach efforts may be required in order to gain public acceptance of monitored natural attenuation.

IMPLEMENTATION

The use of monitored natural attenuation is not new in OSWER programs. For example, in the Superfund program, selection of natural attenuation as an element in a site's groundwater remedy goes as far back as 1985. Use of monitored natural attenuation in OSWER programs has continued since that time, slowly increasing with greater program experience and scientific understanding of the processes involved. Recent advances in the scientific understanding of the processes contributing to natural attenuation have resulted in a heightened interest in this approach as a potential means of achieving soil and groundwater cleanup objectives. However, complete reliance on monitored natural attenuation is appropriate only in a limited set of circumstances at contaminated sites. The sections which follow seek to clarify OSWER program policies regarding the use of monitored natural attenuation. Topics addressed include site characterization; the types of sites where monitored natural attenuation may be appropriate; reasonable remediation time frames; the importance of source control; performance monitoring; and contingency remedies where monitored natural attenuation will be employed.

Role of Monitored Natural Attenuation in OSWER Remediation Programs

Under OSWER programs, remedies selected for contaminated media (such as contaminated soil and groundwater) must protect human health and the environment. Remedies may achieve this level of protection using a variety of methods, including treatment, containment, engineering controls, and other means identified during the remedy selection process.

The regulatory and policy frameworks for corrective actions under the UST, RCRA, and Superfund programs have been established to implement their respective statutory mandates and to promote the selection of technically defensible, nationally consistent, and cost effective solutions for the cleanup of contaminated media. EPA recognizes that monitored natural attenuation may be an appropriate remediation option for contaminated soil and groundwater under certain circumstances. However, determining the appropriate mix of remediation methods at a given site, including when and how to use monitored natural attenuation, can be a complex process. Therefore, monitored natural attenuation should be carefully evaluated along with other viable remedial approaches or technologies (including innovative technologies) within the applicable remedy selection framework. **Monitored natural attenuation should not be considered a default or presumptive remedy at any contaminated site.**

Each OSWER program has developed regulations and policies to address the particular types of contaminants and facilities within its purview[7]. Although there are differences among these programs, they share several key principles that should generally be considered during selection of remedial measures, including:

- Source control actions should use treatment to address "principal threat" wastes (or products) wherever practicable, and engineering controls such as containment for waste (or products) that pose a relatively low long-term threat, or where treatment is impracticable.[8]

- Contaminated groundwaters should be returned to "their beneficial uses[9] wherever practicable, within a time frame that is reasonable given the particular circumstances of the site." When restoration of groundwater is not practicable, EPA "expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction" (which may be appropriate).[10]

- Contaminated soil should be remediated to achieve an acceptable level of risk to human and environmental receptors, and to prevent any transfer of

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[7]Existing program guidance and policy regarding monitored natural attenuation can be obtained from the following sources: For Superfund, see "Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites," (USEPA, 1988a; pp. 5-7 and 5-8); the Preamble to the 1990 National Contingency Plan (USEPA, 1990a, pp.8733-34); and "Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites, Final Guidance" (USEPA, 1996a; p. 18). For the RCRA program, see the Subpart S Proposed Rule (USEPA, 1990b, pp.30825 and 30829), and the Advance Notice of Proposed Rulemaking (USEPA, 1996b, pp.19451-52). For the UST program, refer to Chapter IX in "How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers;" (USEPA, 1995a).

[8]Principal threat wastes are those source materials (*e.g.*, non-aqueous phase liquids [NAPL], saturated soils) that are highly toxic or highly mobile that generally cannot be reliably contained (USEPA, 1991). Low level threat wastes are source materials that can be reliably contained or that would pose only a low risk in the event of exposure. Contaminated groundwater is neither a principal nor a low-level threat waste.

[9] Beneficial uses of groundwater could include uses for which water quality standards have been promulgated, such as a drinking water supply, or as a source of recharge to surface water, or other uses. These or other types of beneficial uses may be identified as part of a Comprehensive State Groundwater Protection Program (CSGWPP). For more information on CSGWPPs, see USEPA, 1992a and 1997b, or contact your state implementing agency .

[10] This is a general expectation for remedy selection in the Superfund program, as stated in the National Contingency Plan (USEPA, 1990a, §300.430 (a)(1)(iii)(F)). The NCP Preamble also specifies that cleanup levels appropriate for the expected beneficial use (e.g., MCLs for drinking water) "should generally be attained throughout the contaminated plume, or at and beyond the edge of the waste management area when waste is left in place."

contaminants to other media (*e.g.*, surface or groundwater, air, sediments) that would result in an unacceptable risk or exceed required cleanup levels.

Consideration or selection of monitored natural attenuation as a remedy or remedy component does not in any way change or displace these (or other) remedy selection principles. Nor does use of monitored natural attenuation diminish EPA's or the regulated party's responsibility to achieve protectiveness or to satisfy long-term site cleanup objectives. **Monitored natural attenuation is an appropriate remediation method only where its use will be protective of human health and the environment and it will be capable of achieving site-specific remediation objectives within a time frame that is reasonable compared to other alternatives.** The effectiveness of monitored natural attenuation in both near-term and long-term time frames should be demonstrated to EPA (or other regulatory authority) through: 1) sound technical analysis which provides confidence in natural attenuation's ability to achieve remediation objectives; 2) performance monitoring; and 3) backup or contingency remedies where appropriate. **In summary, use of monitored natural attenuation does not imply that EPA or the responsible parties are "walking away" from the cleanup or financial responsibility obligations at a site.**

It also should be emphasized that the selection of monitored natural attenuation as a remedy does not imply that active remediation measures are infeasible, or are "technically impracticable." Technical impracticability (TI) determinations, which EPA makes based on the inability to achieve required cleanup levels using available remedial technologies and approaches, are used to justify a change in the remediation objectives at Superfund and RCRA sites (USEPA, 1993a). A TI determination does not imply that there will be no active remediation at the site, nor that monitored natural attenuation will be used at the site. Rather, a TI determination simply indicates that the cleanup levels and objectives which would otherwise be required cannot practicably be attained within a reasonable time frame using available remediation technologies. In such cases, an alternative cleanup strategy that is fully protective of human health and the environment must be identified. Such an alternative strategy may still include engineered remediation components, such as containment for an area contaminated with dense non-aqueous phase liquids (DNAPL), in addition to approaches intended to restore to beneficial uses the portion of the plume with dissolved contaminants. Several remedial approaches could be appropriate to address the dissolved plume, one of which could be monitored natural attenuation under suitable conditions. However, the evaluation of natural attenuation processes and the decision to rely upon monitored natural attenuation for the dissolved plume should be distinct from the recognition that restoration of a portion of the plume is technically impracticable (*i.e.*, monitored natural attenuation should not be viewed as a direct or presumptive outcome of a technical impracticability determination.)

<u>Demonstrating the Efficacy of Natural Attenuation through Site Characterization</u>

Decisions to employ monitored natural attenuation as a remedy or remedy component should be thoroughly and adequately supported with site-specific

characterization data and analysis. In general, the level of site characterization necessary to support a comprehensive evaluation of natural attenuation is more detailed than that needed to support active remediation. Site characterizations for natural attenuation generally warrant a quantitative understanding of source mass; groundwater flow; contaminant phase distribution and partitioning between soil, groundwater, and soil gas; rates of biological and non-biological transformation; and an understanding of how all of these factors are likely to vary with time. This information is generally necessary since contaminant behavior is governed by dynamic processes which must be well understood before natural attenuation can be appropriately applied at a site. Demonstrating the efficacy of this remediation approach likely will require analytical or numerical simulation of complex attenuation processes. Such analyses, which are critical to demonstrate natural attenuation's ability to meet remedial action objectives, generally require a detailed conceptual site model as a foundation[11].

Site characterization should include collecting data to define (in three spatial dimensions over time) the nature and distribution of contamination sources as well as the extent of the groundwater plume and its potential impacts on receptors. However, where monitored natural attenuation will be considered as a remedial approach, certain aspects of site characterization may require more detail or additional elements. For example, to assess the contributions of sorption, dilution, and dispersion to natural attenuation of contaminated groundwater, a very detailed understanding of aquifer hydraulics, recharge and discharge areas and volumes, and chemical properties is required. Where biodegradation will be assessed, characterization also should include evaluation of the nutrients and electron donors and acceptors present in the groundwater, the concentrations of co-metabolites and metabolic by-products, and perhaps specific analyses to identify the microbial populations present. The findings of these, and any other analyses pertinent to characterizing natural attenuation processes, should be incorporated into the conceptual model of contaminant fate and transport developed for the site.

Monitored natural attenuation may not be appropriate as a remedial option at many sites for technological or economic reasons. For example, in some complex geologic systems, technological limitations may preclude adequate monitoring of a natural attenuation remedy to

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[11] A conceptual site model is a three-dimensional representation that conveys what is known or suspected about contamination sources, release mechanisms, and the transport and fate of those contaminants. The conceptual model provides the basis for assessing potential remedial technologies at the site. "Conceptual site model" is **not** synonymous with "computer model;" however, a computer model may be helpful for understanding and visualizing current site conditions or for predictive simulations of potential future conditions. Computer models, which simulate site processes mathematically, should in turn be based upon sound conceptual site models to provide meaningful information. Computer models typically require a lot of data, and the quality of the output from computer models is directly related to the quality of the input data. Because of the complexity of natural systems, models necessarily rely on simplifying assumptions that may or may not accurately represent the dynamics of the natural system. Calibration and sensitivity analyses are important steps in appropriate use of models. Even so, the results of computer models should be carefully interpreted and continuously verified with adequate field data. Numerous EPA references on models are listed in the "Additional References" section at the end of this Directive.

ensure with a high degree of certainty that potential receptors will not be impacted. This situation typically occurs in many karstic, structured, and/or fractured rock aquifers where groundwater moves preferentially through discrete channels (*e.g.*, solution channels, foliations, fractures, joints). The direction of groundwater flow through such heterogeneous (and often anisotropic) materials can not be predicted directly from the hydraulic gradient, and existing techniques may not be capable of identifying the channels that carry contaminated groundwater through the subsurface. Monitored natural attenuation will not generally be appropriate where site complexities preclude adequate monitoring. Although in some situations it may be technically feasible to monitor the progress of natural attenuation, the cost of site characterization and long-term monitoring required for the implementation of monitored natural attenuation is high compared to the cost of other remedial alternatives. Under such circumstances, natural attenuation would not necessarily be the low-cost alternative.

A related consideration for site characterization is how other remedial activities at the site could affect natural attenuation. For example, the capping of contaminated soil could alter both the type of contaminants leached to groundwater, as well as their rate of transport and degradation. Therefore, the impacts of any ongoing or proposed remedial actions should be factored into the analysis of natural attenuation's effectiveness. When considering source containment/treatment together with natural attenuation of chlorinated solvents, the potential for cutting off sources of organic carbon (which are critical to biodegradation of the solvents) should be carefully evaluated.

Once the site characterization data have been collected and a conceptual model developed, the next step is to evaluate the efficacy of monitored natural attenuation as a remedial approach. Three types of site-specific information or "evidence" should be used in such an evaluation:

(1) Historical groundwater and/or soil chemistry data that demonstrate a clear and meaningful trend[12] of decreasing contaminant mass and/or concentration over time at appropriate monitoring or sampling points. (In the case of a groundwater plume, decreasing concentrations should not be solely the result of plume migration. In the case of inorganic contaminants, the primary attenuating mechanism should also be understood.);

(2) Hydrogeologic and geochemical data that can be used to demonstrate indirectly the type(s) of natural attenuation processes active at the site, and the rate at which such processes will reduce contaminant concentrations to required levels. For example, characterization data may be used to quantify the rates of contaminant sorption, dilution, or volatilization, or to

[12] For guidance on the statistical analysis of environmental data, please see USEPA, 1989 and 1992b, listed in the "References Cited" section at the end of this Directive.

demonstrate and quantify the rates of biological degradation processes occurring at the site;

(3) Data from field or microcosm studies (conducted in or with actual contaminated site media) which directly demonstrate the occurrence of a particular natural attenuation process at the site and its ability to degrade the contaminants of concern (typically used to demonstrate biological degradation processes only).

Unless EPA or the implementing state agency determines that historical data (Number 1 above) are of sufficient quality and duration to support a decision to use monitored natural attenuation, EPA expects that data characterizing the nature and rates of natural attenuation processes at the site (Number 2 above) should be provided. Where the latter are also inadequate or inconclusive, data from microcosm studies (Number 3 above) may also be necessary. In general, more supporting information may be required to demonstrate the efficacy of monitored natural attenuation at those sites with contaminants which do not readily degrade through biological processes (*e.g.*, most non-petroleum compounds, inorganics), at sites with contaminants that transform into more toxic and/or mobile forms than the parent contaminant, or at sites where monitoring has been performed for a relatively short period of time. The amount and type of information needed for such a demonstration will depend upon a number of site-specific factors, such as the size and nature of the contamination problem, the proximity of receptors and the potential risk to those receptors, and other physical characteristics of the environmental setting (*e.g.*, hydrogeology, ground cover, or climatic conditions).

Note that those parties responsible for site characterization and remediation should ensure that all data and analyses needed to demonstrate the efficacy of monitored natural attenuation are collected and evaluated by capable technical specialists with expertise in the relevant sciences. Further, EPA expects that the results will be provided in a timely manner to EPA or to the state implementing agency for evaluation and approval.

Sites Where Monitored Natural Attenuation May Be Appropriate

Monitored natural attenuation is appropriate as a remedial approach only where it can be demonstrated capable of achieving a site's remedial objectives within a time frame that is reasonable compared to that offered by other methods and where it meets the applicable remedy selection criteria for the particular OSWER program. **EPA expects that monitored natural attenuation will be most appropriate when used in conjunction with active remediation measures (*e.g.*, source control), or as a follow-up to active remediation measures that have already been implemented**.

In determining whether monitored natural attenuation is an appropriate remedy for soil or groundwater at given site, EPA or other regulatory authorities should consider the following:

- Whether the contaminants present in soil or groundwater can be effectively remediated by natural attenuation processes;

- Whether the resulting transformation products present a greater risk than do the parent contaminants;

- The nature and distribution of sources of contamination and whether these sources have been or can be adequately controlled;

- Whether the plume is relatively stable or is still migrating and the potential for environmental conditions to change over time;

- The impact of existing and proposed active remediation measures upon the monitored natural attenuation component of the remedy;

- Whether drinking water supplies, other groundwaters, surface waters, ecosystems, sediments, air, or other environmental resources could be adversely impacted as a consequence of selecting monitored natural attenuation as the remediation option;

- Whether the estimated time frame of remediation is reasonable (see below) compared to time frames required for other more active methods (including the anticipated effectiveness of various remedial approaches on different portions of the contaminated soil and/or groundwater);

- Current and projected demand for the affected aquifer over the time period that the remedy will remain in effect (including the availability of other water supplies and the loss of availability of other groundwater resources due to contamination from other sources); and

- Whether reliable site-specific vehicles for implementing institutional controls (*i.e.*, zoning ordinances) are available, and if an institution responsible for their monitoring and enforcement can be identified.

For example, evaluation of a given site may determine that, once the source area and higher concentration portions of the plume are effectively contained or remediated, lower concentration portions of the plume could achieve cleanup standards within a few decades through monitored natural attenuation, if this time frame is comparable to those of the more aggressive methods evaluated for this site. Also, monitored natural attenuation would more likely be appropriate if the plume is not expanding, nor threatening downgradient wells or surface water bodies, and where ample potable water supplies are available. The remedy for this site could include source control, a pump-and-treat system to mitigate only the highly-contaminated plume areas, and monitored natural attenuation in the lower concentration portions of the plume. In combination, these methods would maximize groundwater restored to beneficial use in a time frame consistent with future demand on the aquifer, while utilizing natural attenuation processes to reduce the reliance on active remediation methods (and reduce cost).

Of the above factors, the most important considerations regarding the suitability of monitored natural attenuation as a remedy include whether the groundwater contaminant plume is growing, stable, or shrinking, and any risks posed to human and environmental receptors by the contamination. **Monitored natural attenuation should not be used where such an approach would result in significant contaminant migration or unacceptable impacts to receptors.** Therefore, sites where the contaminant plumes are no longer increasing in size, or are shrinking in size, would be the most appropriate candidates for monitored natural attenuation remedies.

<u>Reasonableness of Remediation Time Frame</u>

The longer remediation time frames typically associated with monitored natural attenuation should be compatible with site-specific land and groundwater use scenarios. Remediation time frames generally should be estimated for **all** remedy alternatives undergoing detailed analysis, including monitored natural attenuation[13]. Decisions regarding the "reasonableness" of the remediation time frame for any given remedy alternative should then be evaluated on a site-specific basis. While it is expected that monitored natural attenuation may require somewhat longer to achieve remediation objectives than would active remediation, the overall remediation time frame for a remedy which relies in whole or in part on monitored natural attenuation should not be excessive compared to the other remedies considered. Furthermore, subsurface conditions and plume stability can change over the extended timeframes that are necessary for monitored natural attenuation.

Defining a **reasonable time frame** is a complex and site-specific decision. Factors that should be considered when evaluating the length of time appropriate for remediation include:

- Classification of the affected resource (*e.g.*, drinking water source, agricultural water source) and value of the resource[14];

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[13] EPA recognizes that predictions of remediation time frames may involve significant uncertainty; however, such predictions are very useful when comparing two or more remedy alternatives.

[14] In determining whether an extended remediation time frame may be appropriate for the site, EPA and other regulatory authorities should consider state groundwater resource classifications, priorities and/or valuations where available, in addition to relevant federal guidelines.

- Relative time frame in which the affected portions of the aquifer might be needed for future water supply (including the availability of alternate supplies);

- **Uncertainties** regarding the mass of contaminants in the subsurface and predictive analyses (*e.g.*, remediation time frame, timing of future demand, and travel time for contaminants to reach points of exposure appropriate for the site);

- Reliability of monitoring and of institutional controls over long time periods;

- Public acceptance of the extended time for remediation; and

- Provisions by the responsible party for adequate funding of monitoring and performance evaluation over the period required for remediation.

Finally, individual states may provide information and guidance relevant to many of the factors discussed above as part of a Comprehensive State Groundwater Protection Program (CSGWPP). (See USEPA, 1992a) Where a CSGWPP has been developed, it should be consulted for groundwater resource classification and other information relevant to determining required cleanup levels and the urgency of the need for the groundwater. Also, EPA remediation programs generally should defer to state determinations of current and future groundwater uses, when based on an EPA-endorsed CSGWPP that has provisions for site-specific decisions (USEPA, 1997b).

Thus, EPA or other regulatory authorities should consider a number of factors when evaluating reasonable time frames for monitored natural attenuation at a given site. These factors, on the whole, should allow the regulatory agency to determine whether a natural attenuation remedy (including institutional controls where applicable) will fully protect potential human and environmental receptors, and whether the site remediation objectives and the time needed to meet them are consistent with the regulatory expectation that contaminated groundwaters will be returned to beneficial uses within a reasonable time frame. When these conditions cannot be met using monitored natural attenuation, a remedial alternative that does meet these expectations should be selected instead.

<u>Remediation of Contamination Sources and Highly Contaminated Areas</u>

The need for control measures for contamination sources and other highly contaminated areas should be evaluated as part of the remedy decision process at all sites, particularly where monitored natural attenuation is under consideration as the remedy or as a remedy component. Source control measures include removal, treatment, or containment measures (*e.g.*, physical or hydraulic control of areas of the plume in which NAPLs are present in the subsurface). EPA prefers remedial options which remove or treat contaminant sources when such options are technically feasible.

Contaminant sources which are not adequately addressed complicate the long-term cleanup effort. For example, following free product recovery, residual contamination from a petroleum fuel spill may continue to leach significant quantities of contaminants into the groundwater. Such a lingering source can unacceptably extend the time necessary to reach remedial objectives. This leaching can occur even while contaminants are being naturally attenuated in other parts of the plume. If the rate of attenuation is lower than the rate of replenishment of contaminants to the groundwater, the plume can continue to expand and threaten downgradient receptors.

Control of source materials is the most effective means of ensuring the timely attainment of remediation objectives. EPA, therefore, expects that source control measures will be evaluated for **all** contaminated sites and that source control measures will be taken at most sites where practicable.

Performance Monitoring

Performance monitoring to evaluate remedy effectiveness and to ensure protection of human health and the environment is a critical element of all response actions. Performance monitoring is of even greater importance for monitored natural attenuation than for other types of remedies due to the longer remediation time frames, potential for ongoing contaminant migration, and other uncertainties associated with using monitored natural attenuation. This emphasis is underscored by EPA's reference to "monitored natural attenuation".

The monitoring program developed for each site should specify the location, frequency, and type of samples and measurements necessary to evaluate remedy performance as well as define the anticipated performance objectives of the remedy. In addition, all monitoring programs should be designed to accomplish the following:

- Demonstrate that natural attenuation is occurring according to expectations;
- Identify any potentially toxic transformation products resulting from biodegradation;
- Determine if a plume is expanding (either downgradient, laterally or vertically);
- Ensure no impact to downgradient receptors;

- Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy;

- Demonstrate the efficacy of institutional controls that were put in place to protect potential receptors;

- Detect changes in environmental conditions (*e.g.*, hydrogeologic, geochemical, microbiological, or other changes) that may reduce the efficacy of any of the natural attenuation processes[15]; and

- Verify attainment of cleanup objectives.

Performance monitoring should continue as long as contamination remains above required cleanup levels. Typically, monitoring is continued for a specified period (*e.g.*, one to three years) after cleanup levels have been achieved to ensure that concentration levels are stable and remain below target levels. The institutional and financial mechanisms for maintaining the monitoring program should be clearly established in the remedy decision or other site documents, as appropriate.

Details of the monitoring program should be provided to EPA or the State implementing agency as part of any proposed monitored natural attenuation remedy. Further information on the types of data useful for monitoring natural attenuation performance can be found in the ORD publications (*e.g.*, USEPA, 1997a, USEPA, 1994a) listed in the "References Cited" section of this Directive. Also, USEPA (1994b) published a detailed document on collection and evaluation of performance monitoring data for pump-and-treat remediation systems.

Contingency Remedies

A contingency remedy is a cleanup technology or approach specified in the site remedy decision document that functions as a "backup" remedy in the event that the "selected" remedy fails to perform as anticipated. A contingency remedy may specify a technology (or technologies) that is (are) different from the selected remedy, or it may simply call for modification and enhancement of the selected technology, if needed. Contingency remedies should generally be flexible—allowing for the incorporation of new information about site risks and technologies.

Contingency remedies are not new to OSWER programs. Contingency remedies should be employed where the selected technology is not proven for the specific site application, where

[15]Detection of changes will depend on the proper siting and construction of monitoring wells/points. Although the siting of monitoring wells is a concern for any remediation technology, it is of even greater concern with monitored natural attenuation because of the lack of engineering controls to control contaminant migration.

there is significant uncertainty regarding the nature and extent of contamination at the time the remedy is selected, or where there is uncertainty regarding whether a proven technology will perform as anticipated under the particular circumstances of the site.

It is also recommended that one or more criteria ("triggers") be established, as appropriate, in the remedy decision document that will signal unacceptable performance of the selected remedy and indicate when to implement contingency measures. Such criteria might include the following:

- Contaminant concentrations in soil or groundwater at specified locations exhibit an increasing trend;

- Near-source wells exhibit large concentration increases indicative of a new or renewed release;

- Contaminants are identified in sentry/sentinel wells located outside of the original plume boundary, indicating renewed contaminant migration;

- Contaminant concentrations are not decreasing at a sufficiently rapid rate to meet the remediation objectives; and

- Changes in land and/or groundwater use will adversely affect the protectiveness of the monitored natural attenuation remedy.

In establishing triggers or contingency remedies, however, care is needed to ensure that sampling variability or seasonal fluctuations do not set off a trigger inappropriately. For example, an anomalous spike in dissolved concentration(s) at a well(s), which may set off a trigger, might not be a true indication of a change in trend.

EPA recommends that remedies employing monitored natural attenuation be evaluated to determine the need for including one or more contingency measures that would be capable of achieving remediation objectives. EPA believes that a contingency measure may be particularly appropriate for a monitored natural attenuation remedy which has been selected based primarily on predictive analysis (second and third lines of evidence discussed previously) as compared to natural attenuation remedies based on historical trends of actual monitoring data (first line of evidence).

SUMMARY

The use of monitored natural attenuation does **not** signify a change in OSWER's remediation objectives; monitored natural attenuation should be selected only where it will be fully protective of human health and the environment. EPA does not view monitored natural attenuation to be a "no action" remedy, but rather considers it to be a means of addressing contamination under a limited set of site circumstances where its use meets the applicable statutory and regulatory requirements. Monitored natural attenuation is not a “presumptive” or “default” remediation alternative, but rather should be evaluated and compared to other viable remediation methods (including innovative technologies) during the study phases leading to the selection of a remedy. The decision to implement monitored natural attenuation should include a comprehensive site characterization, risk assessment where appropriate, and measures to control sources. Also, monitored natural attenuation should not be used where such an approach would result in significant contaminant migration or unacceptable impacts to receptors and other environmental resources. In addition, the progress of natural attenuation towards a site’s remediation objectives should be carefully monitored and compared with expectations to ensure that it will meet site remediation objectives within a time frame that is reasonable compared to time frames associated with other methods. Where monitored natural attenuation’s ability to meet these expectations is uncertain and based predominantly on predictive analyses, decision-makers should incorporate contingency measures into the remedy.

EPA is confident that monitored natural attenuation will be, at many sites, a reasonable and protective component of a broader remedial strategy. However, EPA believes that there will be many other sites where uncertainties too great or a need for a more rapid remediation will preclude the use of monitored natural attenuation as a stand-alone remedy. This Directive should help promote consistency in how monitored natural attenuation remedies are proposed, evaluated, and approved.

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OTHER SOURCES OF INFORMATION

<u>USEPA Internet Web Sites</u>

http://www.epa.gov/ORD/WebPubs/biorem/
Office of Research and Development, information on passive and active bioremediation

http://www.epa.gov/ada/kerrlab.html
Office of Research and Development, R.S. Kerr Environmental Research Laboratory

http://www.epa.gov/OUST/cat/natatt.htm
Office of Underground Storage Tanks, information on natural attenuation

http://www.epa.gov/swerffrr/chlorine.htm
Federal Facilities Restoration and Reuse Office, fact sheet on natural attenuation of chlorinated solvents

http://www.epa.gov/swerffrr/petrol.htm
Federal Facilities Restoration and Reuse Office, Fact sheet on natural attenuation of petroleum contaminated sites

http://www.epa.gov/hazwaste/ca/subparts.htm
Office of Solid Waste, information on RCRA Subpart S

http://www.epa.gov/swerosps/bf/
Office of Outreach Programs, Special Projects, and Initiatives, information on Brownfields

<u>Other Internet Web Sites</u>

http://clu-in.com
Technology Innovation Office, information on hazardous site cleanups