Decision-Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites

Office of Environmental Restoration

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INTRODUCTION

The purpose of this guide is to provide Department of Energy (DOE) Remedial Project Managers with a decision-making framework for evaluating the efficacy of monitored natural attenuation (MNA) as a remedial alternative within the bounds established by applicable regulations and the Environmental Protection Agency's (EPA's) recent MNA policy directive.[1,2] The Department supports the principles set forth in EPA's directive and has used these principles as a foundation to develop this guide.

Although this decision-making framework is not intended to be a technical protocol for evaluating the efficacy of natural attenuation, it does utilize examples that are technical in nature to illustrate many complex concepts. Any decision to select MNA as a remedial alternative, however, should be based on site-specific information and previous experience, not on the examples provided herein. Furthermore, the guide addresses only "passive" remediation by natural attenuation. Use of enhanced in-situ approaches (*e.g.*, introduction of nutrients or microorganisms to speed contaminant degradation) may be appropriate for consideration, but these approaches are outside the intended scope of this guide. Nevertheless, many of the concepts presented are also applicable to the assessment of these more active remedial measures. Similarly, even though many of the examples in the guide focus on the attenuation of metals and radionuclides, the framework is applicable to the evaluation of <u>all</u> types of contaminants at <u>all</u> types of sites.[3]

This guide should be used in conjunction with other Departmental guidance, specifically the *MNAtoolbox* and the *Technical Guidance for the Long-Term Monitoring of Natural Attenuation Remedies at Department of Energy Sites*. The <u>*MNAtoolbox*</u> is a recently developed DOE software tool *(http://www.sandia.gov/ee sector/gs/gc/na/mnahome.html)* that assists site managers in determining whether their sites are good candidates for the implementation of MNA. The <u>*Technical Monitoring Guide*</u> (in draft) outlines the role of monitoring in effectively implementing an MNA remedy, key considerations in designing monitoring networks, and statistical approaches for analyzing monitoring data.

This guide is organized into the following sections:

- <u>Background</u>: Provides a brief description of natural attenuation processes and the definitional context under which these processes can be used as a remedial approach.

- <u>Decision-Making Framework</u>: Outlines key considerations and recommended tiered evaluation strategy during the remedial scoping/planning and alternative evaluation/

[1] USEPA, Office of Solid Waste and Emergency Response (OSWER), Directive 9200.4-17P, "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites," April 21, 1999.

[2] Section 120 (a) (1) and (2) of CERCLA requires, in part, that all guidelines, rules, regulations and criteria applicable to remedial evaluations and remedial actions are applicable to Federal Facility NPL sites in the same manner and to the same extent as at private NPL sites.

[3] Although the majority of natural attenuation information and analysis has centered on the attenuation of organics, available laboratory and field data indicate that natural attenuation can often contribute significantly to limit potential exposures to many inorganics as well.

selection phases of environmental restoration projects.

BACKGROUND

Natural Attenuation Processes

Natural attenuation processes occur at all sites, but to varying degrees depending on the types and concentrations of the contaminants and the hydrologic and geologic characteristics of the site. Natural attenuation may reduce the potential risks posed by site contaminants in one of three ways, depending upon the type of contaminant:

1. Contaminants may be transformed to a less toxic form through destructive processes (*e.g.*, biodegradation, radioactive decay);

2. Potential exposure levels may be reduced by lowering concentration levels (*e.g.*, dilution, dispersion); and

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

Natural attenuation processes for reducing **organic contaminant** levels are currently best documented at petroleum fuel sites. Organisms in the soil and groundwater break down chemicals through biological degradation processes into byproducts that are often non-toxic and harmless. For example, under appropriate field conditions, the compounds benzene, toluene, ethyl benzene, and xylene (known collectively as BTEX) may naturally degrade through microbial activity and ultimately produce non-toxic end products (*e.g.*, CO_2 and H_2O).

Chlorinated solvents, such as trichloroethylene, represent another class of common organic contaminants that may also biodegrade (generally via reductive dechlorination) under certain environmental conditions. However, hydrologic and geologic conditions favoring biodegradation of chlorinated solvents may not occur at a given site.

Some **inorganics**, more specifically **radionuclides**, also "break down" over time. Unlike organic contaminants, radionuclides have a predictable rate of decay. The specific half-lives of radionuclides allow for accurate prediction of the time required to reduce their radioactivity to levels that are no longer hazardous.

The concentrations of mobile and toxic forms of non-degradable **inorganic contaminants** may also be effectively reduced by other natural processes. The movement of metals and radionuclides is attenuated in the subsurface via sorption to mineral surfaces or soil organic matter and occasionally through volatilization. In addition, oxidation/reduction (redox) reactions can transform the valence states of some inorganic contaminants to less soluble, and thus less mobile, forms, or to forms that are less toxic (*e.g.*, hexavalent to trivalent chromium).

Contaminant immobilization through natural processes is contaminant and matrix dependent. Some metals/radionuclides often have very little interaction with the matrix and can, consequently, move unretarded through the subsurface. Furthermore, sorption can be reversible depending upon the contaminant and method of attenuation, *i.e.*, it either becomes a permanent fixture within that particular matrix or maintains the potential for re-release.

Even though some **organic** and many **inorganic contaminants** cannot be destroyed or transformed through natural attenuation processes, they are diluted and/or dispersed as they move through the subsurface. Unlike contaminant destruction or transformation, dilution and dispersion do not lead to a reduction in contaminant mass, but rather a reduction in contaminant concentration.

Monitored Natural Attenuation Definition

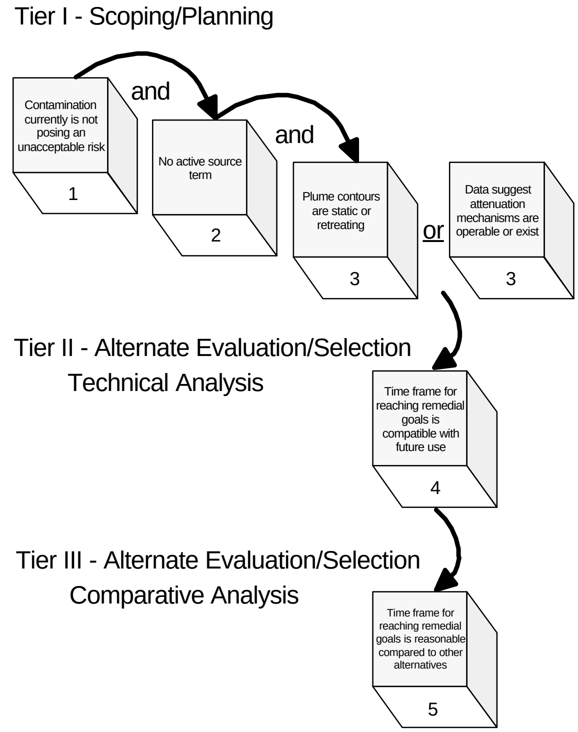
Monitored natural attenuation may be defined as the *reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup, to achieve site-specific remedial objectives within a time frame that is reasonable compared to that offered by more active methods*. Monitoring, therefore, is the critical component of any remediation by natural attenuation. Monitoring is imperative to: (1) ensure performance objectives are being achieved as expected and (2) detect unacceptable migration of contamination so that contingency measures can be implemented to prevent any unacceptable risks to human health and the environment.

DECISION-MAKING FRAMEWORK

The evaluation process used to determine if MNA is a viable remedial alternative should be fundamentally no different than the process used to evaluate more active remedial measures (*e.g.*, pump and treat). In other words, once the "problem" being addressed is defined by the **core team**, MNA (should it be considered a viable remedial option) will need to be evaluated against the same statutory and regulatory criteria used to evaluate any other viable remedial alternative.[4]

DOE advocates the use of a "tiered" decision-making approach to assess whether MNA is a viable remedial alternative. This tiered framework utilizes a set of favorable conditions based on the expectations and guidelines contained in the OSWER Directive to guide the evaluation process. These tiers are structured to streamline the MNA evaluation process while ensuring site resources are expended wisely, *i.e.*, data collection and modeling to support MNA are initiated only in those situations where MNA appears sufficiently promising as an effective remedial strategy. This tiered evaluation strategy is presented in Highlight 1.

Highlight 1
Favorable Conditions for Evaluating MNA as a Remedial Alternative



Scoping/Planning Phase (Tier I)

The key to successfully scoping environmental restoration projects is to gather all existing information, develop a conceptual-site model based on that information, and determine: 1) What is (are) the problem(s), *i.e.*, conditions at the site that require some type of response action; and 2) What is (are) the likely response action(s)?

When problem statements cannot be sufficiently defined and/or likely responses identified, the information required to do so constitutes data needs around which investigations should be focused. Once a problem statement is adequately defined and likely responses are identified, information required to objectively evaluate the potential actions being considered, and ultimately to select and design a remedy, constitutes the remaining data needs.

The extent of site characterization required to evaluate remediation by natural attenuation may encompass additional parameters and mechanisms than those typically targeted for

[4] As used in this guide, core team includes the DOE, EPA, and State project managers. Therefore, "consensus by the core team" is analogous to the "acceptable to the overseeing regulatory agencies" language in EPA's MNA policy directive.

more active remedial measures.[5] However, the degree of additional site characterization ultimately will reflect the individual views of the core team representatives, which in turn will reflect the degree of uncertainty that will remain once existing information has been compiled and the corresponding conceptual-site model developed.

The time and resources needed to adequately evaluate an MNA alternative may be substantial, and therefore, careful consideration needs to be given to any decision to pursue such an option. To determine whether MNA should constitute one option within a hierarchy of preferred remedial technologies, the initial focus should be on determining whether existing information sufficiently suggests that the Tier I favorable conditions are, or likely will be, met.

1. Contamination Currently Not Posing Risk

The underlying assumption in this framework is that under no circumstances would it be appropriate to proceed with MNA for contamination currently posing an unacceptable risk to human health and the environment.

2. No Active Source Term

The term "source" often has special meaning from a regulatory perspective, typically referring to primary sources (*e.g.*, a tank and associated piping) as opposed to secondary sources (*e.g.*, residual contaminants, either as free product or bound to the soil matrix, that contribute mass to a plume). However, such distinctions are of little use with respect to determining total contaminant mass. Therefore, the term "active source," as used in this guide, means *any inventory of contaminant in the environment that is being released to the plume at a rate greater than that at which it can be attenuated*, *i.e.*, the inventory of mobile contaminants is increasing over time at a rate such that concentrations will exceed health-based levels.

Site evaluations to determine if there is an active source term can result in one of four conclusions:

- The source term is active, *i.e.*, producing more mobile phase contaminant (both non-aqueous and dissolved phase) in any time period than will or could be attenuated in that time period (a condition typically resulting in a growing, non-stable plume).

- The source term is in equilibrium with the dissolved phase groundwater plume (a condition typically resulting in a stable plume).

- The inventory of contaminant is sufficiently depleted such that fluxes to the mobile phase are less than removal due to attenuation (a condition typically required to have a diminishing or collapsing plume).

- The location and/or presence of a source term cannot be ascertained -- the latter being a possibility even if efforts are initiated to do so (*e.g.*, sampling points have periodic hits, but no clear source of the contamination can be found).

Should an active source term be identified, the assumption here is that it will be **actively remediated** as part of a phased response. Under a phased response, the Department would take whatever measures were agreed to by the core team to address the source and

[5] Historically, a bias towards conservatism has resulted in minimal attention being given to attenuation phenomena, *i.e.*, attenuation is ignored in order to generate "worst" case scenarios.

concurrently begin the necessary monitoring to evaluate system response and to determine whether MNA would be adequately protective. Therefore, in the end, there is no substantive difference between the four outcomes with respect to the appropriate lines of evidence and subsequent analyses to assess and document MNA's potential as an effective remedial option for the remaining contaminant plume. However, there may be differences in the degree of uncertainty regarding plume stability and, therefore, corresponding differences in monitoring strategies and the level of contingency planning. [NOTE: Even in situations where the source term is in equilibrium with the dissolved phase, the benefits of additional source control measures should be evaluated because such measures may significantly reduce the time frame required for MNA to attain remedial objectives.]

3. Plume Perimeter is Static or Retreating

Plume stasis occurs when the perimeter of the plume attains sufficient size or location such that attenuative mechanisms equal or exceed the mass flux at that boundary. Ultimately, all plumes would become static by virtue of dilution/dispersion alone, if not for other natural processes working to limit contaminant migration. Since the timing for reaching stasis is both contaminant and site dependent, it is unique to each plume.[6]

If a plume has not yet become static, that does not necessarily eliminate MNA as a viable remedy. Should the plume be expected to reach stasis in the near future, and the expansion of the plume during that time will be *limited in extent and limited to areas where there is no potential exposure*, the core team may still consider MNA to be appropriate for achieving remedial objectives.

Any assessment to determine if the plume perimeter is, or soon will be, static or retreating must fully consider the temporal variability of those parameters affecting attenuation, *i.e.*, it will be necessary to consider both present and future conditions. With respect to present conditions, the best tests to see if the plume is static are quantitative measures/methodologies such as statistical trend analyses on temporal data from monitoring locations at the contour of interest or sustained observation of concentrations below levels of concern down gradient of the perimeter. These empirical data, however, are only sufficient if there is general agreement by the core team that the monitoring network from which the data are derived adequately represents the system.

Even when empirical data are sufficient to demonstrate plume stasis, these data alone may not be adequate to predict if attenuation will suffice in the future because changing site conditions could alter the relationship between the relevant concentrations or rates. Therefore, the long-term effectiveness of MNA requires the site and surrounding natural and anthropogenic conditions not change to the extent that natural attenuation processes are no longer effective.

<u>**OR**</u> *Attenuation Mechanisms Are Operable or Exist*

If sufficient monitoring data are not available over a long enough period of time to fully evaluate plume stability, the core team can agree to utilize secondary lines of evidence to evaluate the likely effectiveness of MNA. To

[6] Historical analyses of similar plumes can often provide a good indication of what the important hydrogeologic parameters are for determining the probability/rate of attenuation.

determine whether the degradation rate and/or geochemical data suggest a strong likelihood that attenuation at the site is probable, the core team will need to consider the expected rates of dilution and dispersion, as well as the two mechanisms by which contaminants are removed: 1) **degradation or decay** mechanisms, which can destroy the contaminant; and 2) **phase transfer** mechanisms (*e.g.*, sorption, precipitation, volatilization), which can reduce the mobile fraction of the contaminant mass in the transport medium.[7] [NOTE: The *MNAtoolbox* provides a simple and expedient means for assessing (on a general level) whether attenuation processes will reduce concentrations at a rate faster than they will be transported beyond the present contour.]

At the completion of project scoping/planning, there are three general conclusions the core team may reach with respect to MNA: 1) MNA is <u>not</u> appropriate for further consideration because one or more of the favorable conditions is clearly not satisfied; 2) MNA is considered to be a viable response option because based on existing data, the favorable conditions appear to be met and further evaluation is warranted;[8] and 3) based on assumptions of system response to an ongoing or planned measure to eliminate an active source, MNA has been identified as a potential response option within the context of a phased response strategy.

<u>Alternative Evaluation/Selection Phase (Tiers II & III)</u>

The following discussion is based on the premise that the core team has initially concluded the three favorable conditions are satisfied, and therefore, further evaluation of MNA is warranted.

The evaluation of MNA, like the evaluation of more active remedial measures, is as much an assessment of what is not known, *i.e.*, uncertainties, as what is known. Once the key uncertainties are identified, specific decisions must be made to either: 1) reduce the uncertainties through additional data collection to better define the problem or assess an alternative's effectiveness, implementability, and cost; or 2) manage the uncertainties through contingency planning.[9]

Because MNA relies entirely on natural processes over which the core team has no control, performance uncertainties associated with MNA may be greater than other engineered remedial strategies.[10] With active remedies, it is possible to over design as a contingency against some unknowns. With MNA, there is no activity to be designed beyond the monitoring network; the contingency, by definition, is to move out of an MNA approach and into a more active strategy.

In short, the alternative evaluation/selection phase for MNA will involve the implementation of those activities and analyses determined

[7] The evaluation of phase transfer mechanisms may or may not incorporate dilution effects depending on how the evaluation is conducted.

[8] In most situations, the expectation is that MNA would be evaluated along with other more active responses (*e.g.*, pump and treat).

[9] DOE/EPA, *Uncertainty Management: Expediting Cleanup Through Contingency Planning,* Fact Sheet, February 1997.

[10] In some circumstances, natural attenuation processes can be enhanced; however, as indicated earlier, such approaches are outside the intended scope of this guidance.

during scoping to satisfy data needs and to support a remedial decision. In other words, this phase incorporates both technical and risk management considerations.

The Tier II (technical) analyses serve to: 1) better demonstrate or document, as appropriate, the three Tier I favorable conditions are satisfied; and 2) more fully assess **whether the anticipated time frame for reaching remedial goals is compatible with the anticipated future land and groundwater use**.[11] The Tier III comparative (risk management) analyses serve to determine whether **the anticipated time frame for reaching remedial goals is reasonable as compared to other remedial alternatives**.

Tier II - Technical Considerations

Once a site is identified as a good candidate for MNA, the core team will need to outline what additional, site-specific characterization and modeling activities are necessary to determine the probable time frame needed for MNA to attain site-specific remediation objectives. Ideally, the core team will have sufficient time to collect the empirical data to determine whether plume stability has been achieved. However, as previously discussed, secondary lines of evidence may be needed to provide sufficient confidence that stasis, if not yet achieved, will be achieved within an acceptable time frame, and that any plume migration will be limited in extent and to areas where there is no potential exposure.

Estimating attenuation time frames involves explicit consideration of the contaminants of concern and the hydrologic and geochemical parameters initially identified during project scoping as indicators that natural attenuation is likely. Presumably, the core team will have utilized the scoping/planning phase to identify not only the critical geochemical parameters likely to play a key role in the natural attenuation process, but also what, if any, additional data are necessary to support an MNA determination. For example, if sorption mechanisms are the principal attenuation processes to address inorganics or radionuclides, the core team will need to: 1) identify soil-specific mineral sinks for metals and radionuclides of concern; 2) quantify sequestering mechanisms; and 3) assess long-term stability of sequestering mechanism(s).

In addition to understanding the general mechanism(s) operating to attenuate contaminants, the core team must also agree that the particular hydrogeologic setting provides sufficient "capacity" to attenuate the contaminant load. For example, if adsorption is anticipated on specific mineral surfaces, the prevalence of those surfaces should be evaluated in order to estimate the capacity the site would have for that contaminant.

Furthermore, because the elemental chemical composition of soils and groundwaters determines the transport characteristics of contaminants (often present at trace levels), the core team will need to consider the likely range of groundwater compositions and their potential effects on contaminant transport.[12] Large-scale changes in elemental chemistry at a

[11] In some situations, the time frame for planned future uses will clearly be incompatible with the time frame needed for remediation by natural attenuation, and thus, the MNA option may be eliminated from further consideration during project scoping for this reason alone.

[12] Groundwater compositions are, to a large extent, determined by: 1) chemical equilibrium with soil CO_2; 2) weathering of/equilibrium with soil minerals; 3) atmospheric inputs; 4) organic activity; and 5) adsorption and ion exchange reactions.

site can conceivably cause very drastic changes in the transport of trace contaminants, and therefore, the efficacy of MNA.

In situations where sorption or redox reactions are the primary mechanisms in the attenuation process, close attention will also need to be given to the "reversibility" of the attenuation mechanisms. Events such as changes in contaminant concentration, pH, redox potential, and chemical speciation may reduce a contaminant's stability at a site and cause re-release into the environment. Hydraulic conditions at a site could change as a result of varying pumping regimes (for new or existing wells) or future remedial actions (*e.g.*, installation of a cap), thereby altering attenuation rates. Similarly, biological attenuation processes may change as food sources are depleted as a result of contaminant degradation or from other causes.

Another key consideration will be the potential toxicity of transformation products resulting from the breakdown of organics or chain daughter products from the decay of radionuclides. However, sometimes the concern over transformation or daughter products may center on mobility rather than toxicity. If the daughter or transformation product is less toxic than the parent but becomes more mobile, the potential harm to human health and the environment may also increase. Conversely, if the toxicity of the transformation or daughter product is greater than that of the parent but mobility is reduced, there may be a substantial decrease in risk. For example, relatively mobile ^{234}U in the hexavalent state will decay to ^{226}Ra, which is much more toxic but typically much less mobile.

The technical considerations above will need to be evaluated within the context of the site-specific factors outlined below to determine **whether the anticipated time frame for reaching remedial goals is compatible with the anticipated future land and groundwater use**.

<u>Land (resource) use</u>. The potential risks associated with future uses of impacted land and water resources will be a critical consideration for evaluating whether remediation through MNA would adequately protect human health and the environment. Therefore, an explicit consideration of the future use(s) of a site, including an assessment of the time frame in which resources might be needed, is required.

For organic contaminants that undergo biodegradation in addition to other natural attenuation processes, the expected timing of future use activities is important to the extent it is the target against which the predicted efficacy of MNA must be assessed, *i.e.*, degradation processes must sufficiently reduce concentrations below levels of concern prior to the future land and groundwater use change. For contaminants which do not degrade, assessments will also need to consider the potential effects of future use activities on any immobilized contaminants in the subsurface and the risks posed by these immobilized contaminants.

In the case of some radionuclides, the expected timing of future land and groundwater use changes may be sufficiently distant to ensure protection (*e.g.*, if remobilization of ^{90}Sr or ^{137}Cs occurs over a 100 year time span, a significant fraction [~ 90%] of the radioactivity will have decayed away). For metals and longer-lived radionuclides, however, dilution may be the only attenuation process working to lower concentrations should these contaminants be remobilized due to human activities.

Although most DOE facilities have established stakeholder workgroups to assist in developing future use assumptions/expectations for their sites, uncertainties with such assumptions for extended time periods remain. While future land and groundwater use plans and associated assumptions may support decisions where the need for response is obvious, decisions in situations where future use uncertainties are significant will be more difficult.[13]

Protection during implementation. Because the time frame for achieving remedial objectives under an MNA approach may be quite long, measures to prevent potential exposures in the interim must be maintained. Historically, most cleanups have relied on institutional controls (*e.g.*, deed restrictions, well-drilling prohibitions) to prevent exposures until such time as remedial objectives are achieved. However, the ability of agencies to control use and exposures in the future is often assumed to diminish with the length of time over which such control is needed. Therefore, the ability to ensure the effectiveness of institutional controls over extended time periods will be an important consideration.

Distance to potential receptors. An important aspect of any MNA decision will be whether monitoring can detect unanticipated contaminant migration and provide an adequate warning in time to prevent the possibility of exposure to the nearest potential receptors. The large size of many DOE facilities, much of which was intended for the sole purpose of providing a "buffer zone" to the public and is restricted by institutional controls, may provide a greater degree of certainty that unacceptable exposures will not occur. However, *these large tracts of land should not be viewed simply as opportunities to let contaminants migrate up to the "fence line" in hopes they will attenuate before moving offsite and reaching potential receptors*. Furthermore, these large tracts of land do not diminish the importance of demonstrating plume stasis with adequate certainty or that any contaminant migration deemed acceptable by the core team, be limited in extent, and to areas where no potential exposures can occur.

Tier III - Risk Management Considerations

Response selection under any regulatory/policy framework involves the consideration and balancing of those factors and criteria identified by the specific authority/program under which cleanup is being performed. In general, the factors used to compare alternatives and to support risk management decisions can be distilled down to three basic criteria: 1) effectiveness; 2) implementability; and 3) cost.

Effectiveness. The Tier II evaluation serves to establish whether MNA is "adequate" to achieve remedial objectives within a time frame that is compatible with future uses. Once the core team concludes MNA is compatible with anticipated future uses, the focus shifts to establishing whether **the anticipated time frame for reaching remedial goals is reasonable as compared to other remedial alternatives**.

As clarified in the OSWER Directive, a "reasonable time frame" conclusion is a "complex and site-specific decision," which must include an evaluation of: 1) the affected aquifer and its value, including when its use as a drinking or irrigation water source may be needed; 2) the degree of uncertainty with estimates for contaminant mass and travel time; and 3) the reliability of monitoring and institutional controls and provisions for

[13] Potential future uses of groundwater generally are determined by State classifications or similar distinction.

adequate funding to ensure their continuance.[14]

With respect to the first factor, the appropriate focus, as stated earlier, is to determine whether the anticipated time frame for reaching remedial goals is compatible with the anticipated future land and groundwater use. With respect to factors 2 and 3, the core team will need to determine what is the appropriate balance of site characterization (to reduce contaminant mass and travel time uncertainties) and reliance on monitoring/ contingency planning with institutional controls to manage uncertainties. The balance that is ultimately reached will be a reflection of site characteristics, remaining uncertainties, core team consensus, and stakeholder input.

A critical aspect of evaluating reasonable time frames for the remediation of radionuclides will be to what extent active measures can expedite natural attenuation processes. For example, the time required to attain remediation objectives may be reduced by implementing additional source control measures or by actively treating a portion of the plume.

In some cases, however, the very processes that may be operating to attenuate contaminant levels in the groundwater (*e.g.*, sorption) will also serve to negate the effectiveness of extraction processes such as pump and treat. Furthermore, some active measures can actively inhibit or negate natural attenuation processes (*e.g.*, air sparging kills anaerobic bacteria responsible for biodegradation of chlorinated solvents). Ultimately, the decision to select MNA as the remedy at a site comes down to determining whether MNA or another more active remedy will best protect resources and prevent potential exposures.

<u>Implementability</u>

The evaluation of MNA, as with any remedial alternative, will require a certain degree of "design" work on those activities comprising the remedial approach as a means to assess its implementability and ultimately, its effectiveness and cost. As indicated previously, the monitoring network is the sole "activity" to be designed in an MNA alternative; the contingency, by definition, is to move out of an MNA approach to a more active strategy.[15]

Necessary long-term monitoring for an MNA remedy may be classified as: 1) <u>ambient monitoring</u>, designed to provide hydrogeologic information from monitoring locations upgradient of the original source and contaminant plume as a baseline of pre-contamination conditions;[16] 2) <u>performance monitoring</u>, designed to trace contaminant concentrations within and in proximity of the plume and to measure other indirect parameters (*e.g.*, redox potential, degradation products) to determine if attenuation mechanisms are, or likely will be, functioning as predicted in the conceptual-site model; and 3) <u>detection monitoring</u>, designed to alert site managers that contaminants have migrated to "sentinel" wells, indicating that natural attenuation processes are not performing adequately and that previously

[14] The issue of long-term funding for DOE's surveillance and maintenance requirements for residual contaminants at its sites is being captured with the ongoing stakeholders' dialogue on long-term stewardship and is not addressed within this guide.

[15] The degree to which the contingency is designed prior to the selection of a remedy will be a site-specific, core team decision. At a minimum, there should be consensus on the general approach (*e.g.*, pump and treat, slurry wall) that would be taken, and whenever possible, outlined in the decision document.

[16] This type of monitoring can also be used to detect possible contaminant migration into the area from other sources.

agreed to contingency measures should be implemented. A conceptual illustration of these three types of monitoring is presented in Figure 1. [NOTE: A more detailed technical discussion of the role of monitoring and the key considerations in designing monitoring networks can be found in DOE's *Technical Guidance for the Long-Term Monitoring of Natural Attenuation Remedies at Department of Energy Sites*.]

Although the monitoring approach for natural attenuation is primarily based on EPA's 1994 pump and treat remediation monitoring strategy, there are unique aspects and considerations within an MNA context.[17] For example, MNA performance monitoring, in addition to tracking contaminant concentrations, may also include tracking those parameters which serve as indicators of how well attenuation is working (*e.g.*, biodegradation products).

The main purpose of MNA detection monitoring is to establish whether attenuation mechanisms have failed to achieve the desired reduction in contaminant concentrations, and therefore, the implementation of previously agreed upon contingency measures should proceed. The detection monitoring system (sentinel wells) should be constructed somewhere between the downgradient edge of the plume and the nearest potential receptor(s). More specifically, sentinel wells should be sufficiently far from potential receptors so that contingency remedial actions, if required, can be effectively implemented. They should also be sufficiently far from the leading edge of the plume to account for the range of possible plume expansion based on the uncertainties evaluated within the conceptual-site model.

Ultimately, the location of sentinel wells will be a site-specific, core team decision which will reflect a variety of factors, including: 1) size of plume and contaminant load; 2) expected performance of attenuating mechanisms and degree of uncertainties; 3) distance to receptors; 4) reliability of institutional controls within the "MNA remedial action management zone" (see Figure 2); and 5) public acceptance. In practice, however, the proposed location of sentinel wells represents a site-specific determination by the core team as to what degree of plume expansion, if any, is considered acceptable, *i.e.*, the distance between the leading edge of the current plume and the sentinel wells reflects a level of migration that can reasonably be expected based on the conceptual-site model. Should a decision to select MNA include some degree of expected contaminant migration, such migration would, by definition, be "non-significant" as it reflects consensus of the agencies (and presumably the public) as the preferred remedial strategy.

Once the core team has elected to proceed with an MNA approach, they will need to reach consensus on the specific monitoring that will be required, including monitoring locations, parameters to be measured, frequency of sampling, and most importantly, what actions/ activities will be initiated if results do not meet performance objectives or reflect expectations (see Table 1). The latter finding would likely result from performance monitoring data within the MNA remedial action management zone and would typically require the core team to reassess the conceptual-site model and possibly reconfigure sampling locations and/or frequencies. As discussed previously, detections of unacceptable levels of contaminants in sentinel wells would

[17] USEPA, 1994. *Methods for Monitoring Pump-and-Treat Performance*, EPA/600/R-94/123, June 1994.

automatically require initiation of contingency measures to halt any further migration.

Cost

In those situations where the core team concludes that an MNA approach will achieve remedial objectives within **a time frame that is reasonable compared to other remedial alternatives**, careful consideration will need to be given to the long-term (life-cycle) costs of such an approach. Typically, the expectation is that the use of MNA will cost less than taking more active measures to address contaminants, and therefore, from strictly a cost perspective, would be more attractive (assuming it was also considered adequately protective). However, it must be recognized that monitoring is a cost and that MNA may require a greater degree of site characterization and long-term monitoring over time than more active remedies. It is for this reason that consideration needs to be given to optimizing available opportunities to shorten the time to reach remedial objectives by comparing: 1) remedial alternatives that use only MNA to alternatives that combine active measures and MNA, and 2) remedial alternatives that use only MNA to alternatives that use only active measures.

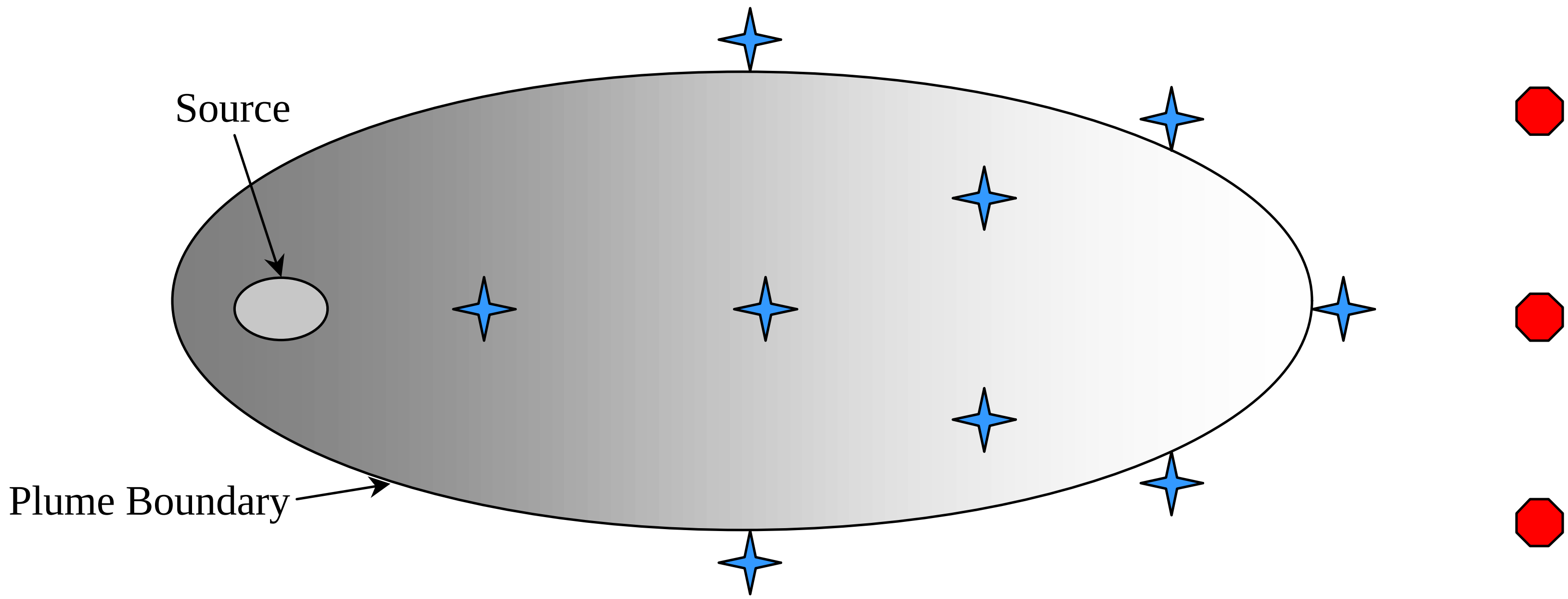
In those instances where MNA is selected, the Department recommends a tiered approach to monitoring wherein the frequency and locations of sampling are reduced in response to confirmation of conceptual-site model hypotheses and corresponding reductions in uncertainties. For example, monitoring may be initiated quarterly for years one through five, reduced to annual or semiannual for 10 years, and then every three to five years depending on the groundwater flow velocity, the contaminants of concern, and associated attenuation mechanisms. The *Technical Monitoring Guide* (in draft) outlines the key technological considerations for evaluating monitoring data, refining conceptual-site models, and revising monitoring strategies accordingly.

In closing, MNA may be considered as a remedial option under a variety of state and federal regulations, each with their own specific requirements for evaluating and selecting response measures. Therefore, the successful implementation of an MNA alternative ultimately will depend on rigorous, technically defensible analyses and management strategies. The tiered decision-making framework outlined in this guide is designed to ensure such defensible analyses are generated, and only in those situations where MNA truly represents a viable remedial strategy.

Often, the assumption is that MNA would not be a viable alternative in states with non-degradation policies. However, all remedies take time to implement and time to meet final objectives. In fact, it is often the case that active measures alone are not sufficient to reach target concentrations without natural processes attenuating residual contamination. Therefore, time to reach remedial objectives may not differ substantially between MNA and more active remedies; determinations regarding the latter are, in fact, the central focus of alternative comparisons and reasonable time frame assessments.

In some circumstances, site-specific conditions will be such that achieving remedial objectives is technically impracticable. In such situations, MNA should never be considered a default or presumptive remedy. MNA should only be selected when it is determined that it will achieve remedial objectives in a time frame compatible with future use(s) and is reasonable when compared to other more active remedies.

Figure 1
Conceptual Monitoring Network



= "ambient" wells - designed to provide hydrogeologic information from wells upgradient of the original source and contamination plume as a baseline of precontamination conditions

= "performance" wells - designed to trace contaminant concentrations within the plume and to measure other indirect parameters to determine if attenuation mechanisms are functioning as predicted in the site-conceptual model

= "sentinel" (detection) wells - designed to alert site managers that contaminants have migrated to sentinel wells indicating that natural attenuation processes are not performing as expected and that contingency measures should be implemented

Figure 2
Conceptual Monitoring Strategy

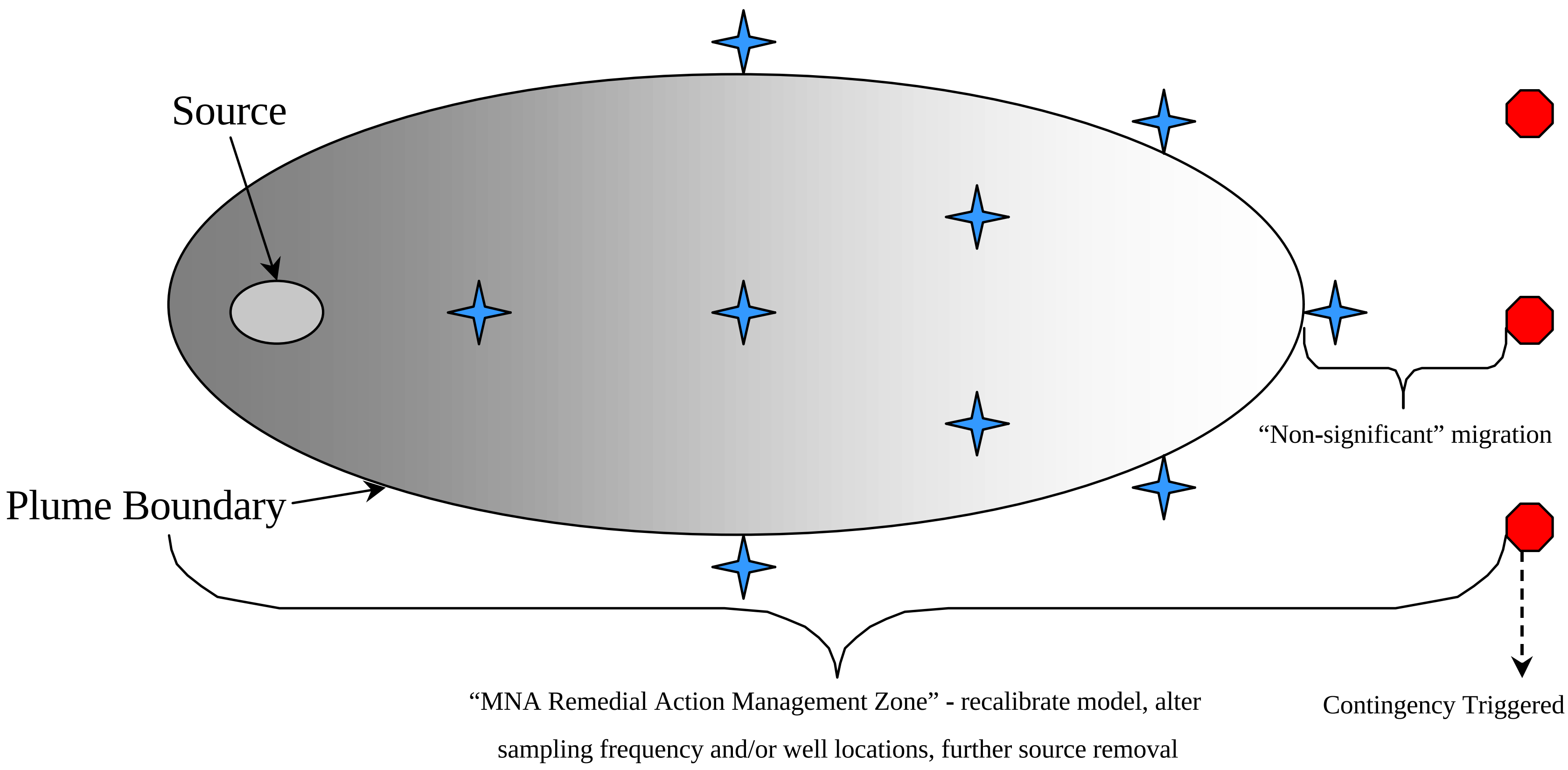


Table 1
Monitoring Requirements for Natural Attenuation

MONITORING TYPE	LOCATION	PARAMETER	FREQUENCY[18]	RESULTS OF EXCEEDANCE
Detection	Between plume perimeter and receptor	COC	Annual or less	Initiate contingency
Performance (direct)	Extant of plume	COC	Quarterly - declining to annual	Increase monitoring frequency/locations, recalibrate model[19]
Performance (indirect)	Extant of plume	Attenuation factors	Quarterly - declining annual or less	Increase monitoring frequency/locations, recalibrate model[19]
Ambient trend	Background - upgradient	COC and select attenuation factors	Same as model calibration	Identify offsite sources

COC = contaminant of concern

[18] The frequencies given here are for purely illustrative purposes. The necessary frequency of monitoring is a site-specific decision made by the core team.

[19] In certain circumstances, the core team may conclude that an unexpected increase in contaminant concentration indicates their assumption that all necessary source measures were taken was incorrect, and that additional source measures are appropriate.

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