# THE DEPARTMENT OF ENERGY'S MONITORED NATURAL ATTENUATION INITIATIVE

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## ABSTRACT

Results from groundwater remediation efforts at sites throughout the U.S. are providing mounting evidence that in many cases, natural processes are playing significant roles in mitigating the environmental impacts of subsurface contamination. Recently, there has been an increased level of interest in monitored natural attenuation (MNA) remedies because these natural processes may offer protectiveness equal to more active remediation methods, yet at greatly reduced costs. The Department of Energy (DOE) recently issued three guides to assist project managers in using MNA remedies at their sites. This paper briefly summarizes the key tenents of these guides and highlights additional considerations for pursuing an MNA approach to waste site remediation.

## THE DEPARTMENT'S MNA GUIDANCE

In July of 1999, The U.S. Environmental Protection Agency (EPA) issued a policy directive clarifying its expectations for the use of monitored natural attenuation (MNA) as a remediation strategy for contaminated soil and groundwater (1). Due to the lack of technical guidance for implementing MNA remedies at that time, particularly for metals and radionuclides, the Department of Energy (DOE) developed its own MNA guidance to further assist its project managers in evaluating MNA as a potential remedy at their sites. DOE's MNA guidance builds off of the principles and expectations laid out in EPA's policy directive while providing an additional focus on metals and radionuclides – common contaminants at many DOE sites.

The *Decision-Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites* provides project managers with a structured analytical framework for evaluating the efficacy of MNA as a remedial alternative within the bounds established by applicable regulations and EPA's MNA policy directive.

The *MNAtoolbox* is a web-based tool developed to provide a rapid, screening-level assessment of whether MNA may be an appropriate remedial action for consideration. *MNAtoolbox* functions as a database for contaminant chemistry and degradation pathways and can be used to identify which phase transfer and degradation pathways are likely to be important in achieving remedial objectives. *MNAtoolbox* helps focus MNA evaluation by:

- Outlining the most likely attenuation pathways,
- Pointing out the factors that will mitigate against MNA, and
- Identifying potential data needs for demonstrating attenuation.

The *Technical Guidance for the Long-Term Monitoring of Natural Attenuation Remedies at Department of Energy Sites* provides project managers with technical direction on: 1) the where, when, what, and how for each of the three types of monitoring (performance, detection, and ambient); and 2) the analysis and interpretation of data for comparing data to baselines, comparing trends to predictions, and determining when a contingency trigger has been exceeded.

## Tiered Decision-Making Framework

DOE advocates the use of a "tiered" decision-making approach (Figure 1) 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 EPA's MNA directive, to guide the evaluation process. The 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).

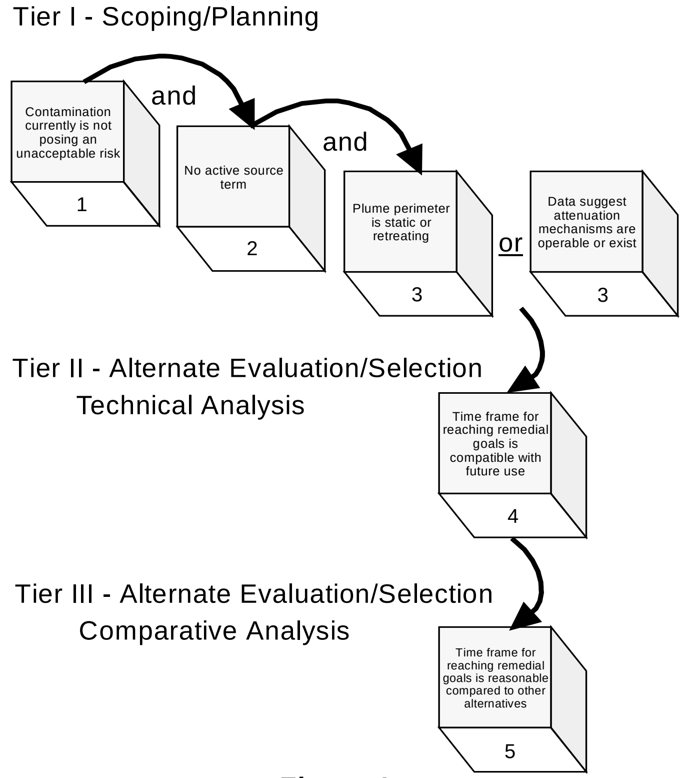



**Figure 1**
**Favorable Conditions for Evaluating MNA as a Remedial Alternative**

## Tier I

When evaluating whether MNA should be considered a viable remedial technology at a particular site, the initial focus should be on determining whether existing information sufficiently suggests that three favorable conditions are, or likely will be, met:

- Contamination is not currently posing an unacceptable risk,
- No active source term is present,[g]
- Plume perimeter is static or retreating OR data suggest attenuation mechanisms are operable or exist.[h]

Lack of a current unacceptable risk may arise from control of the resource that prevents water use or exposure, restrictions to use that are associated with lower levels of exposure, or physical constraints such as low aquifer yields that inhibit use of the resource, thereby eliminating the potential for exposure.

The absence of an active source term may be the direct result of active source control measures taken to date or planned within the near future. Alternately, the source may be depleted from natural attenuation since the time of release. In some cases, the lack of a source may reflect the simple fact that after a reasonable effort, no obvious source could be located.

Static or retreating plumes may be evidenced by empirical data indicating no or backward movement of the threshold isopleth over time. 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*, MNA may still be an appropriate option for consideration.

What is important is not that these favorable conditions have to be met at the time of scoping the problem and potential response actions, but that there be a strong expectation that they will be met at the time of remedy selection. For example, source control measures may be planned as an early response action prior to making a decision on groundwater contamination, thus supporting a presumption that the second finding will be met.

### Tier II

Once a site is identified as a good candidate for MNA, the project team needs to conduct those additional characterization and modeling activities they deem necessary to more fully assess the time frame over which MNA will attain remedial objectives. In other words, the *Tier II - Technical Analysis* serves to better demonstrate or document, as appropriate, that the three Tier I favorable conditions are satisfied and that the time frame for reaching remedial goals using an MNA remedy is compatible with anticipated future land and groundwater use.[i]

A related consideration when evaluating the MNA remediation time frame will be the degree to which any interim measures (e.g., institutional controls) are needed to prevent potential exposures until remedial objectives are reached. Another important consideration is the distance between the distal, threshold plume contour and potential receptors. Project managers need to be confident that the monitoring network will detect any unanticipated contaminant migration in time to prevent the possibility of exposure to the nearest potential receptor.

### Tier III

Once the time frame for reaching remedial objectives using MNA has been determined to be compatible with future use(s), the *Tier III - Comparative Analysis* focuses on establishing whether the anticipated time frame for reaching remedial goals is reasonable as compared to other remedial alternatives; a conclusion that involves a balancing of regulatory criteria and a corresponding risk management decision. 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. The Tier III focus is on establishing the reasonableness of that time frame as compared to other remedial alternatives, i.e., what is its relative effectiveness to other response options?

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 adequate funding to ensure their continuance.

Implementability

The implementability of an MNA remedy primarily depends on the degree to which an adequate monitoring network can be designed. In a certain sense, the monitoring network is the sole "activity" to be designed under an MNA approach; the contingency, by definition, is to move out of an MNA strategy to a more active measure(s). Therefore, the implementability of MNA is primarily dependent on whether monitoring can effectively track the performance of attenuation mechanisms and detect any unacceptable contaminant migration.

Cost

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.

The evaluation of MNA's effectiveness, implementability, and cost will require, as with any remedial alternative, a certain degree of "design" work on those activities comprising the remedial approach. Given that monitoring is the sole "activity" to be designed in an MNA alternative, a well-structured monitoring network and analytical strategy is essential to MNA's potential as a viable remedial approach worthy of serious consideration.

## MNA MONITORING STRATEGY

It is often assumed that to accomplish performance objectives under an MNA remedy, more extensive monitoring (as compared to other more active remedies) is required. This, however, is not necessarily the case. If monitoring data support initial hypotheses of attenuation rates in the conceptual site model, and the location or frequency of sampling is reduced in accordance with such confirmation, the amount of required monitoring may actually be less. On the other hand, monitoring for an MNA remedy has the potential to be prohibitively expensive unless the frequency of monitoring is scaled back over time and the suite of variables to be monitored is minimized.

The monitoring program will need to be based on the conceptual site model, which presumably provides an adequate understanding of contaminant geochemistry and transport to explain past contaminant movement and to predict future trends. Ultimately, the magnitude of required monitoring activities is directly dependant on the nature and magnitude of uncertainties. As these uncertainties are reduced through monitoring, the sampling frequency and number of monitoring locations should be reduced accordingly, as confidence in the predictive capabilities of the conceptual site model increases. This is the key to cost effectively addressing MNA performance uncertainties while ensuring no unacceptable contaminant migration occurs.

Three types of monitoring (Figure 2) are typically required for an MNA remedy:

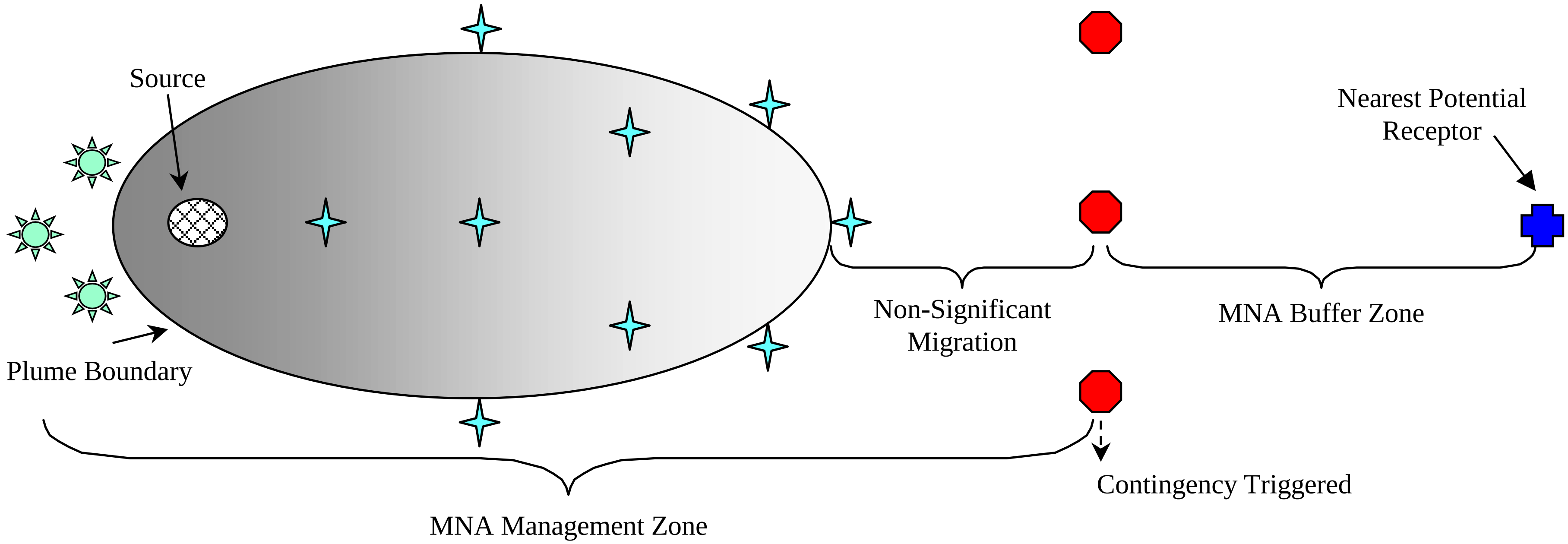
- Performance monitoring,
- Detection monitoring, and
- Ambient monitoring.

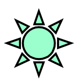
All monitoring should occur within or at the boundary of the MNA management zone (Figure 2). The MNA management zone is the maximum projected boundary of the plume based on the current understanding of flow, transport, and attenuation processes and quantitatively accounts for all remaining uncertainties. The MNA buffer zone (Figure 2) is the area extending from the MNA management zone boundary to the nearest potential receptor(s). The MNA buffer zone must be of sufficient size so that if contaminants are detected at the sentinel wells, appropriate measures can be taken before any receptors are adversely affected.

## Performance Monitoring

The purpose of *performance monitoring* is to track contaminant concentrations and key parameters or indicators of attenuation performance at a given site (e.g., degradation products, redox potential, etc.). Performance monitoring data are used to quantify the rate at which natural processes are attenuating contaminant concentrations. Performance monitoring takes place within and immediately surrounding the existing contaminant plume utilizing, to the greatest extent possible, existing monitoring locations. Monitoring locations within the plume are needed to track the evolution of plume behavior as well as to assess the efficacy of attenuation processes.

Several considerations are relevant when determining the location and number of performance monitoring stations. First and foremost, locations should provide a complete representation of the impacted area. Locations should span the vertical and lateral planes through which the plume is expected to occur. Additionally, multiple locations along the longitudinal axis of the plume may help demonstrate decreasing trends of contaminant concentrations towards the MNA management zone boundary.





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

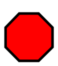

= "sentinel" (detection) wells - designed to alert site managers that contaminants have migrated to sentinel wells indicating that natural attenuation processes are not performing as expected and that contingency measures should be implemented

***Figure 2***
***Conceptual Monitoring Network***

Selecting the time interval between performance monitoring sampling events should be based on the anticipated rate of plume evolution as predicted by the conceptual site model and the degree of confidence with these predictions. The interval between monitoring events should be consistent with the rate at which varying conditions affect system behavior. If conceptual site model predictions closely match subsequent performance monitoring results, the conceptual site model is adequate and need not be modified. Moreover, it may be possible to decrease both performance and detection monitoring frequency and locations with no loss of assurance that the remedy is protective.

Over time, intervals between sampling events should be based on the current version of the conceptual site model that reflects the most recently collected performance monitoring data. If performance monitoring data continue to be consistent with the conceptual site modeling results, and natural attenuation appears to be effective, the likelihood of detection decreases. In this case, it may be appropriate to decrease the sampling frequencies for detection monitoring accordingly.

When conducting performance monitoring, data should be collected that contribute to developing one or more lines of evidence that demonstrate attenuation processes are occurring. In addition to providing evidence of attenuation, data are also needed to determine the direction and rate of any contaminant migration. Data may also be needed to indicate changes in environmental conditions over time, especially changes that may indicate diminished system performance or an inability to effectively monitor the system.

**Detection Monitoring**

The purpose of *detection monitoring* is to ensure protection of human health and the environment while the MNA remedy is being implemented. Any statistically defensible detection of a primary analyte above prescribed thresholds at the edge of the MNA management zone (i.e., sentinel wells) will trigger a contingency plan. As such, the detection monitoring network is designed to provide an additional level of assurance that in the event attenuation processes turn out to be insufficient to meet performance objectives within the MNA management zone, there will be adequate time to implement contingency measures to ensure no unacceptable exposures occur.

A fundamental issue with detection monitoring is the chance of triggering a contingency plan unnecessarily. Decision rules based on trigger level exceedences dictate when contingency measures will be implemented. Implementing contingency measures could be an expensive decision. These decisions should be evaluated carefully and must account for variability in the data and the potential for incorrect decisions to be made. Statistical methods can be used effectively to properly account for variability and to manage the decision error rates.

Detection monitoring should occur between the leading edge of the contaminant plume and the nearest potential receptor(s), on the boundary line of the MNA management zone. This line should extend far enough laterally and vertically to capture all potential/plausible plume migration paths. Detection monitoring locations should be spaced at separation distances that could be reasonably expected to intercept migration of the contaminant plume. Initially, the timing of detection monitoring will be a direct function of the potential transport velocities for site contaminants and the distance between the extant plume and the edges of the MNA management zone.

Detection monitoring should include sampling for the contaminant(s) of concern, as well as any toxic degradation byproducts that may be produced or any radioactive or hazardous daughter products of radioactive decay.

### Ambient Monitoring

The purpose of *ambient monitoring* is to provide a baseline against which to compare results of performance and detection monitoring and to provide boundary conditions for numerical modeling. Ambient monitoring is also used to monitor baseline conditions outside of the source with respect to those parameters that affect attenuation mechanisms. As such, ambient monitoring data provide a baseline for identification of contamination through comparisons with data collected during performance and detection monitoring and should be included in the conceptual site model. Additionally, ambient monitoring is used to detect trends in geochemical conditions that may impact the rate at which attenuation mechanisms will operate. Ambient monitoring data are also evaluated as a means of determining when baseline conditions have changed. Change is important in that it may impact how the trigger levels are defined, or it may indicate when attenuation mechanisms will not operate at rates on which initial predictions were based.

Ambient monitoring stations must be located outside of the contaminant plume. Where baseline levels are highly variable or geologic media are particularly heterogeneous, more locations will facilitate statistically meaningful assessments of baseline conditions. Additionally, if alternate contaminant sources are suspected, ambient monitoring stations should be located down gradient from those sources/areas to prevent misinterpretation of performance monitoring data.

Ambient monitoring is performed in the initial phase of the monitoring program to allow characterization of the baseline and calibration of the conceptual site model. Periodic ambient monitoring is performed to confirm baseline conditions are stable and can provide a check for unanticipated sources of contamination. Thus, ambient monitoring need not be performed at the same frequency as performance or detection monitoring. Ambient monitoring, however, might need to be designed to accommodate temporal or spatial patterns in environmental conditions.

Ambient monitoring should include the contaminant(s) of concern and known degradation or decay products, contaminants associated with up gradient source terms, and other parameters designated for performance and detection monitoring.

## DATA EVALUATION AND INTERPRETATION

The monitoring network is designed to collect data either to show that natural attention processes are acting as predicted in the conceptual site model or to trigger the implementation of contingency plans when they are not. The challenge for data interpretation in support of MNA is to carefully link these objectives, the resources available to collect data, the anticipated variability or uncertainty in the data, and the allowable decision errors so that cost-effective monitoring and contingency decisions can be made.

A successful monitoring network will allow the following questions to be addressed in a framework within which uncertainty can be managed effectively:

- Are monitoring data consistent with predictions? (performance monitoring)
- Do monitoring data clearly indicate that a trigger level has been exceeded? (detection monitoring)
- Have baseline conditions changed? (ambient monitoring)

To formally and rigorously address these questions, decision rules and acceptable decision errors must be developed by the core team and assessed within a statistical hypothesis testing framework. These decision errors, however, can be explicitly accounted for, at pre-specified levels of uncertainty, through the collection of a statistically specified number of samples. The acceptable level of uncertainty is identified based on the consequences of each type of decision error. Thus, decision rules, in conjunction with decision errors, help guide the design of the monitoring network and provide a statistically rigorous means of assessing the efficacy of MNA.

A primary tenet of MNA is that contingencies are identified and ready for implementation should monitoring data indicate that conditions differ significantly from those assumed when the remedy was being selected and designed. As a consequence, each monitoring activity should be accompanied by contingencies and decision criteria indicating when those contingencies should be triggered.

## ADDITIONAL CONSIDERATIONS

Although there has been a long-standing recognition that natural processes contribute to the attenuation of contaminant concentrations in the environment, it has only been in the last few years that MNA has moved to the forefront as a potentially viable remedial alternative. At DOE sites alone, nine plumes have final decisions in place to utilize MNA to address contaminated groundwater; another 16 plumes have had MNA identified as the preferred alternative.

Along with this increased attention has come criticism from some stakeholders that MNA is nothing more than a glorified "do nothing" approach, and that its promoters are simply attracted by the anticipated cost savings (which may not be the case as discussed earlier). To some extent, it appears this skepticism is manifesting itself in the requirement to generate a higher burden of proof of MNA's effectiveness as compared to that required for other innovative remedial approaches. This disparity seems to exist despite the fact that an MNA decision is to always be accompanied by a contingency remedy in the event performance objectives are not achieved as expected; a requirement not always placed on innovative technologies even when equivalent performance uncertainties exist. This apparent disparity may reflect nothing more than an understandable tendency to feel more secure in knowing that "something" is being done, regardless of whether there is truly a discernable difference in the degree of cleanup and protection being achieved

In this light, the commitment to a contingency is as essential to an MNA decision as the horse is to the cart, without one, you may fail to ever move the decision forward. Depending on a site's stakeholders, the only alternative may be to try and reduce uncertainties through time consuming and costly site characterization in excess of what may truly be needed to select MNA with a reasonable level of confidence and to design an effective monitoring network to ensure performance is adequately tracked.

Similarly, as compelling as it may seem to remove contaminant mass thorough active measures, experience has shown that for some sites, the ultimate time frame in which action levels are met is dictated not by the size of the inventory of contaminants, but by the matrix in which they reside. As such, despite active measures to remove contaminant mass, the time to reach concentration targets (e.g., maximum contaminant levels) may ultimately be more dependent on natural attenuation mechanisms. In these cases, mass removal will be most promising as a source control measure to extract contaminants until a plume has more or less stabilized, i.e., until the source is no longer "active," after which MNA will reduce environmental concentrations in relatively the same time frame as the more active measures.

Another important consideration is the potential association of MNA with technical impracticability (TI) situations. Although EPA has made it clear in their policy that MNA under no circumstances should be considered a presumptive remedy for situations involving TI issues, there is an inherent link. Natural processes will continuously work to reduce contaminant concentrations regardless of whether human intervention occurs. The question is how long will it take, and what will we do (and call it) in the interim.

Implicitly implied in any TI finding is that we cannot meet a specified environmental standard or cleanup level within a reasonable time frame. In fact, several CERCLA decisions to date have involved a TI finding in situations where the restoration time frame would require more than 100 to 200 years and, therefore, was not reasonable (2,3). Given EPA's definition of MNA, which emphasizes the attainment of remedial objectives within a reasonable time frame as compared to more active measures, one might possibly conclude that if MNA cannot attain remedial objectives within a 100 to 200 year window, a technical impracticability finding would be appropriate, assuming of course that the other more active measures were unable to clean up any faster. Under such circumstances, the remedy would best be characterized as long-term monitoring, accompanied by whatever institutional controls and engineered measures deemed necessary to ensure protection.[j] To characterize such a remedy as MNA simply because at some distant time in the future natural processes will reduce concentrations to acceptable levels, would simply serve to promote MNA as a do nothing remedy, or more accurately stated, what we do when we cannot do anything else.

Should a regulatory position be established to link TI findings to a numeric window of time, there would be direct implications for the MNA of metals and radionuclides. As a general rule, MNA would be most appropriate for those radionuclides with relatively short half lives (e.g., cesium, strontium, tritium) wherein reductions of their concentrations would typically be within an acceptable time frame simply through the decay process alone. For metals that generally do not decay and long-lived radionuclides, MNA may only be appropriate where sorption processes are serving to effectively immobilize these contaminants and remove them from the groundwater. Conversely, contaminants such as iodine-129, which does not typically bind with mineral surfaces, would not be good candidates for MNA.

## IN CONCLUSION

The basis for successfully evaluating and selecting an MNA remedy ultimately lies in a project manager's ability to effectively communicate and demonstrate three important issues to stakeholders. First, how natural processes are working to attenuate contaminants, and why he/she believes these processes will be sufficient to halt contaminant migration (conceptual-site modeling). Second, how he/she will determine overtime whether MNA is performing as expected (monitoring strategy). Finally, if MNA does not perform as expected, how protection of human health and the environment will be assured (contingency planning).

The basis for successfully implementing an MNA remedy ultimately lies in the design of the monitoring network (to accommodate residual uncertainty) and the analysis and interpretation of monitoring data (valid statistical approaches and clear decision rules). The latter includes decisions to scale back sampling locations and frequencies as the predictive capability of the conceptual-site model improves and uncertainties are reduced through confirmation using empirical data. Otherwise, the potential cost savings typically associated with MNA may not be fully realized.

Lastly, MNA should not be viewed as a fallback approach when other more active measures prove ineffective or to avoid having to invoke a technical impracticability finding. Rather, it should be selected on the basis that it represents an effective solution to address contamination while providing an equal or better balance of the regulatory remedy selection criteria under which it is being evaluated.

## FOOTNOTES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g. An active source is defined as 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.

h. The *MNAtoolbox* should be used in conjunction with the Scoping/Planning phase of the tiered evaluation strategy.

i. It may be that conditions are such that a determination of time frame compatibility with anticipated land use can be made at the time of project scooping and therefore rule out MNA during the initial analysis.

j. In general, decisions to invoke a TI finding will be associated with some type of institutional controls to prevent exposures to the affected media for as long as the waste remain hazardous, and possibly some type of engineered controls to prevent contaminant migration.

## REFERENCES

1. U.S. EPA, 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. Caldwell Trucking Company Record of Decision, September 28, 1989, EPA ID Number NJD048798953.

3. G.E. Moreau Record of Decision, November 6, 1994, EPA ID Number NYD980528335.