In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones (BIODNAPL-3)

EXECUTIVE SUMMARY

The Interstate Technology & Regulatory Council's (ITRC) Bioremediation of DNAPLs (BioDNAPL) Team was formed in 2004 with the aim of developing the technical and regulatory guidance needed to support the use of in situ bioremediation (ISB) as a treatment option for subsurface dense, nonaqueous-phase liquids (DNAPLs), particularly those associated with chlorinated ethenes. Chlorinated solvents were once widely used throughout a number of industries, leading to numerous environmental contamination problems. Both the U.S. Department of Defense and the U.S. Department of Energy face DNAPL contamination problems at many of their facilities. DNAPLs, primarily those containing chlorinated ethenes, pose one of the most widespread and prominent types of contamination associated with Superfund sites. Historical and many current DNAPL remediation technologies require the use of energy, fluids, or oxidants to recover or degrade DNAPL. A potential advantage of bioremediation technology is that microorganisms—which can attack the contaminant at or near the DNAPL/water interface, minimizing the need for mobilization—may provide an effective, efficient, and less costly approach to DNAPL source zone remediation.

The objective of this guidance is to provide a systematic understanding of the technical and related regulatory considerations for ISB of chlorinated ethene DNAPL source zones. It is based on scientifically sound and credible evidence supporting the safe and cost-effective application of ISB of DNAPL source areas. The guidance provides the reader with information related to site characterization requirements, application and design criteria, process monitoring, and process optimization.

This guidance focuses on chlorinated ethene DNAPL source zones in the saturated subsurface, where the DNAPL acts as a reservoir that sustains a contaminant plume in groundwater. ISB of such DNAPL source zones relies on microorganisms to convert contaminants to less harmful compounds. ISB involves stimulating the activity of microorganisms already present in the subsurface (biostimulation) or, in some cases, the addition of selected organisms (bioaugmentation). ISB of DNAPL source zones occurs under anaerobic conditions via enhanced reductive dechlorination.

ISB of DNAPL technology has two main components:

- enhanced dissolution and/or desorption of nonaqueous- and/or sorbed-phase contaminant mass
- biological degradation to nonchlorinated, nontoxic end products

The ability of ISB technology to enhance the dissolution and desorption of nonaqueous-phase contaminants to the aqueous phase, where they can be degraded by the microbial population, is what makes the ISB technology applicable to DNAPL source zones. This typically results in faster remediation compared to traditional technologies that are limited by the NAPL dissolution rate (i.e., groundwater extraction). Because it has such a significant impact on the remediation

time frame, enhancement of the NAPL dissolution rate and increasing mass flux are fundamental to the implementation of ISB in a DNAPL source zone.

In a previously published case study document (ITRC 2007a), the BioDNAPL Team established that ISB is a viable, credible, and effective technology for remediation of DNAPL source zones and provides several advantages over traditional source zone remediation technologies. However, as is the case with other remediation technologies, ISB has limitations. Similar to those of other technologies, many of these limitations can be addressed through careful attention to engineering and design and an iterative process of evaluating the system performance followed by optimization.

Some of the most apparent advantages of enhanced ISB include its ability to treat other contaminants present with the chlorinated ethenes, specifically other chlorinated organic compounds, and its ability to be used in combination with a number of other treatment technologies as part of a larger overall site remediation strategy. Also, contaminants are degraded (destroyed) in situ, thereby eliminating secondary waste streams and minimizing potential health and safety concerns. By destroying mass, ISB can shorten the overall remediation time frame at a DNAPL-contaminated site. Finally, capital costs are usually lower than those of other DNAPL source zone treatment technologies.

On the other hand, ISB can be challenged by low aquifer permeability and/or the presence of aquifer heterogeneities and preferential pathways. These natural aquifer characteristics may limit the distribution of amendments throughout the DNAPL source zone, which is a key to the successful implementation of the technology. It should be noted, however, that challenges resulting from the natural aquifer characteristics apply universally to any in situ technology where reagent delivery is required. ISB can also be limited by specific biogeochemical conditions, e.g., where high concentrations of competing electron acceptors or unacceptable aquifer conditions (e.g., low or high pH) exist. This guidance assists the user to understand how to overcome these limiting conditions, if possible.

The length of time required for a microbial system to become fully established and work effectively on a scale relevant to source zone remediation may be months. This allows development of appropriate environmental conditions or the growth of adequate populations of appropriate microbes (i.e., dechlorinating bacteria) to obtain desired rates of treatment able to degrade DNAPL chlorinated ethene compounds. For large source zones, a combination of remedial methods that includes a bioremediation component can be an effective site remedial approach. In 2008 ITRC will begin developing an integrated DNAPL source zone strategy to assist users in the proper selection and application of compatible DNAPL-contaminated site remediation technologies.

The trends that a particular site may follow largely depends on site-specific conditions such as DNAPL architecture, groundwater velocity, lithology, and attenuation parameters. There are models that evaluate the relationship between source depletion and the remedial time frame; however, many researchers, including authors of this guidance, continue to debate the assumptions, variables, and equations in these models. To understand the fundamental approach, we have included in Appendix C of this guidance a preliminary description of the process as it is understood. We still see this as one of the greatest challenges within the science of ISB of DNAPL source zones and will continue to openly document the results of continued study during ITRC's integrated DNAPL source zone strategy project beginning in 2008.

Additional detailed discussion of the advantages and limitations of enhanced ISB technology is found within the guidance. It is the expectation of the ITRC BioDNAPL Team that this guidance will accelerate technology transfer to and among the states, as well as those charged with site remediation.