CHAPTER 1

Introduction

1.1. Purpose. This Engineer Manual (EM) document provides guidance and background for the appropriate screening and selection of in situ thermal remediation (ISTR) technologies, including steam enhanced extraction injection, electrical resistivity heating, and thermal conductive heating. This document is intended to help distinguish proper applications of the technology and identify important design, operational, and monitoring issues relevant to Government oversight personnel. It is intended for use by engineers, geologists, hydrogeologists, soil scientists, chemists, project managers, and others who possess a technical education but only the broadest familiarity with ISTR technologies. The appropriate Office of Counsel must be consulted with regard to the proper application of the laws and requirements under the various regulatory programs and patent law. There may be differences in application between the various Defense programs.

1.2. Applicability. This EM applies to all USACE commands having Civil Works and/or Military Programs hazardous, toxic, or radioactive waste (HTRW) project responsibillities.

1.3. Distribution Statement**.** Approved for public release and distribution.

1.4. References**.** This EM does not present a detailed, comprehensive discussion of each and every factor associated with ISTR systems. Such a presentation would require many volumes. This document does reference additional resources that do provide more detail. A listing of Government publications, books, and journal articles pertaining to ISTR technologies is presented in Appendix A. Additional, updated references are available on the internet, including this Corps of Engineers website: [http://www.environmental.usace.army.mil/sve.htm].

1.5. Background. A significant number of sites are contaminated with high levels of organic contaminants, including chlorinated solvents, oils and petroleum products, polychlorinated biphenyls, and wood-preserving compounds above and below the water table. These contaminated sites include hundreds of Federal installations and thousands of private facilities. Many of these sites are known or suspected to contain non-aqueous phase liquids (NAPL), either as mobile or residual immiscible fluids. Some of these compounds have low volatility and solubility. These contaminants, especially NAPL below the water table, have been difficult to treat with conventional technologies such as groundwater extraction, bioremediation, and soil vapor extraction. NAPL often represents a very significant long-term (decades to centuries) source of dissolved phase contaminants. More aggressive technologies have been sought that would address these conditions. These aggressive technologies include in situ chemical oxidation, surfactant/solvent flushing, and ISTR methods. The ISTR methods represent the most aggressive and effective of these techniques.

1.5.1. *ISTR Methods*. There are several mechanisms by which heat can be transferred into the subsurface, including 1) direct conduction of heat away from heaters placed in trenches or wells (thermal conductive heating or TCH), 2) electrical resistivity heating (ERH) of the subsurface by passing electrical currents through the soil, and 3) steam injection or steam enhanced extraction (SEE). These methods are addressed in this EM. These techniques are typically applied in conjunction with vapor extraction, and steam injection is typically paired with both vapor and liquid recovery. The three ISTR methods can be used independently or in combination to treat both in the vadose zone and below the water table. Further descriptions of the technologies are provided in Chapter 2. These techniques have been used in full-scale applications and are covered under a variety of patents, some held by Federal agencies, as described in Chapter 10. Vendors of the technologies typically operate under a license from the patent holders.

1.5.1.1. This EM does not address the use of electrical heating for soil melting, also referred to as in situ vitrification (ISV), the use of steam injection accompanied by the use of soil augers, or radio frequency (RF) heating. ISV involves the total melting of contaminated soil, with concomitant destruction of the organic contaminants or containment of inorganic contaminant in the vitrified mass. Heating for ISV is accomplished using electrical currents passing between electrodes through the conductive melt. A conductive "starter frit" is placed between the electrodes to initiate the melting. ISV is a patented technology that was originally developed as a means to isolate radioactive isotopes for geologically long periods.

1.5.1.2. At least one vendor injects steam into the subsurface via large rotating augers drilled into the target treatment volume. The soil disruption caused by the augers results in good contact between the steam and the contaminated soil. The augers are moved around the site to ultimately treat the entire volume.

1.5.1.3. RF heating involves propagation of radio frequency energy into the soil from source transmitters and results in the heating of the soil. The use of radio frequency heating of soil was initially tested at the bench-scale level in the mid-1980s (Dev 1986) and a well-documented field application was conducted in 1989 at Volk National Guard Base (USEPA 1997).

1.5.2. *Brief History of ISTR*. The origins of several of the ISTR technologies can be traced back to the oil industry. Steam injection to enhance recovery of high-gravity oils has been used for several decades (Ramey 1966). The use of steam injection to remediate contaminated soil and groundwater, however, was developed in the 1980s in the Netherlands (Hilberts 1986), and in the United States (Udell and Stewart 1989). ERH, as with other thermal technologies, has its origins in the petroleum industry, where it was developed to heat oil sands and oil shales to enhance oil recovery. ERH was developed in its six-phase configuration by Battelle Memorial Institute for the U.S. Department of Energy at the Pacific Northwest National Laboratory over a period from 1988 to 1992 (Hadim et al., 1993). It was field tested and demonstrated at the Hanford Nuclear Reservation and Savannah River facility in 1993 and the first removal of DNAPL was demonstrated at Dover Air Force Base in 1996. The technology was first commercially applied in Illinois in 1996. The use of radio frequency heating of soil was initially tested at the bench-scale in the mid-1980s (Dev 1986) and a well-documented field application was conducted in 1989 at Volk Air National Guard Base (USEPA 1997). The use of thermal conductive heating for remediation was pioneered by a division of Shell Oil in 1989 (Stegemeier and Vinegar 1995) based on experience gathered in enhanced oil recovery. More recently, well publicized successes with ISTR technologies such as those at the Savannah River Site, SC, and the Visalia Poleyard site in Visalia, CA, have prompted the remediation industry to look closer at ISTR. There are have been a substantial number of both pilot- and full-scale applications of ISTR technologies conducted to date and the number of ISTR sites continues to increase. Appendix C contains information about some of these projects.

1.5.3. *Appropriateness of Aggressive Source Removal*. The use of the ISTR methods may represent a significant expenditure. The benefits of this scope of investment have been debated in the remediation community over the past several years, with much of the discussion centered on the ability of the ISTR methods to achieve adequate “source” removal to reach strict remediation objectives. Some segments of the remediation community advocate source containment, while others promote the removal of the accessible mass (ITRC 2002). The benefits of the application of ISTR and other aggressive source removal technologies are still being evaluated. This philosophical issue of the appropriateness of source removal will not be debated in this EM; rather, the focus will be on the technical issues surrounding the application of the ISTR technologies.

1.5.4. *Advantages of ISTR*. Techniques that rely solely on the flow of liquids to deliver reagents or to remove dissolved contaminants are dependent on (amongst other factors) the permeability distribution in or around the contaminated volume. Permeability may vary over many orders of magnitude in natural geological material. As a result, liquid diffusion into and out of zones of low permeability often limits our ability to deliver reagents and remove contaminant mass. The effectiveness of heat in the removal of contaminant mass depends, in part, on the conduction of heat as governed by the thermal conductivity distribution and the thermal gradient. In most earth materials, thermal conductivities range over less than one order of magnitude. The relatively small range of thermal conductivities allows much more uniform heating and treatment within a contaminated zone when compared to delivery of reagents. As heat is transmitted into the contaminated materials, various processes occur to enhance the removal of contaminants. The vapor pressure of organic materials increases, viscosity of separate-phase liquids decreases, diffusion rates and solubility often increase, and rates of abiotic degradation (e.g., oxidation) may increase. Even biological degradation has been observed to increase at higher temperatures, up to a point where microbial dormancy (or, at temperatures well above 100oC, sterilization) occurs. The removal of contaminants using heat can, therefore, be more complete than is possible with other techniques. Unfortunately, the conduction of heat in earth materials is relatively slow as these materials are generally good insulators. Efficient in situ thermal treatment depends on the economical and effective delivery of heat into the subsurface.

1.5.5. *Limitations of ISTR*. The ISTR methods discussed in this EM will not remediate inorganic contaminants (with the probable exception of volatile metals such as mercury). Some of the ISTR methods may not be appropriate for remediation of very low volatility organics, such as pesticides, some PAHs, dioxins, and PCBs. Site conditions that may not be conducive to ISTR include high groundwater fluxes, buried ordnance or explosive containers, or presence of critical subsurface facilities or utilities. Chapter 2 discusses these limitations further. Where the size of the treatment volume is large, the cost of ISTR may also be considered a "limitation," depending on financial resources.

1.6. Scope.

1.6.1. *General Content*. This EM provides guidance on the appropriate use of the ISTR technologies and information necessary for Government staff to properly plan and oversee the implementation of ISTR at a site. The EM describes the guiding principles and thought processes for ISTR, as the numerous site-specific conditions that come into play in any given ISTR situation preclude a simple cookbook approach. Specifically, the EM describes the technologies and the fundamental science and engineering behind them. This EM does not provide detailed guidance on the design of ISTR systems, nor does it provide detailed information regarding treatment of associated waste streams, such as vapor-phase or wastewater treatment. The data necessary to decide whether or not ISTR is appropriate, both from site characterization and bench/pilot-testing, are described, as are the data necessary to monitor performance of ISTR. Guidance on screening the potential applicability of the technologies, based on site conditions, is provided. Considerations for review of ISTR designs are presented, as are the tools for modeling ISTR performance. Major construction and operations and maintenance (O&M) activities are discussed. The EM also identifies issues related to the implementation of the technologies, such as regulatory considerations, contracting, safety, cost and performance, and patent/licensing. Applications of the technologies are summarized where the specific information is available. A flow chart is provided as a tool for technology selection. The reader is cautioned that he or she should contact vendors of the various technologies as part of the selection process to ensure that the most up to date information forms the basis of the selection.

1.6.2. *Other Information Sources*. This EM was prepared to meet the needs of not only the USACE, but also other Federal and state agencies. The document was prepared with assistance from representatives of U.S. EPA, the Navy, the Interstate Technology Regulatory Council, and the private sector. The electronic version of this document includes links to various documents and resources from these agencies, organizations, and other sources. A linked subject index is also provided.

1.7. Organization.

1.7.1. *General Organization Philosophy.* The EM is intended to assist a project team considering or overseeing an ISTR project. Material is organized sequentially, so that the reader can conveniently begin using it at any stage of an ISTR project. Where appropriate, such as in discussing design considerations, all aspects of a specific ISTR technology are discussed together. It is recommended that regardless of the stage of a project, Chapter 4 on technology selection be reviewed first if there is any question as to whether selection of ISTR at a given site is appropriate.

1.7.2. *Sequence of Presentation*. The EM begins with this introduction. Chapter 2 describes fundamental processes and concepts of ISTR performance. Chapter 3 identifies site characterization data needs for ISTR technology screening, selection and design. Chapter 4 lays out an approach to screening the applicability of ISTR to a specific site. Chapter 5 describes current bench and pilot testing activities that may be appropriate for design of full-scale systems. Chapter 6 identifies key considerations in the design of ISTR systems so that Government staff can adequately oversee the design process and provide input as appropriate to better achieve agency objectives. Example checklists are provided in Appendix C. Alternatives for waste-stream treatment are briefly described. Information on modeling the performance of ISTR is also provided in Chapter 6. Chapter 7 summarizes the available cost and performance data for a number of ISTR applications. Appendix B provides more detailed information on the cost and performance for these sites. Chapter 8 describes the monitoring requirements and approaches, as well as operation and maintenance needs for ISTR systems. Chapter 9 presents approaches for assessing the attainment of remedial objectives for ISTR systems. Chapter 10 discusses regulatory issues that affect ISTR implementation and closure, contracting approaches for ISTR, safety issues, known patents for ISTR technologies, and community acceptance issues. A list of references is provided as Appendix A. A Glossary and list of acronyms is also provided.