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DEMONSTRATING AND IMPLEMENTING INNOVATIVE TECHNOLOGIES: CASE STUDIES FROM THE U.S. DEPARTMENT OF ENERGY OFFICE OF TECHNOLOGY DEVELOPMENT

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ABSTRACT

This paper describes elements of success for the demonstration, evaluation, and transfer for deployment of innovative technologies for environmental restoration. The elements of success have been compiled from lessons learned through the U.S. Department of Energy (DOE) Office of Technology Development's Volatile Organic Compounds in Arid Soil Integrated Demonstration (VOC-Arid ID). The success of the VOC-Arid ID program was determined by the rapid development, demonstration, and transfer for deployment of technologies to operational sites that improve on safety, cost, and/or schedule of performance over baseline technologies. The VOC-Arid ID successfully fielded more than 25 innovative technology field demonstrations; several of the technologies demonstrated have been successfully transferred for deployment.

Field demonstration is a critical element in the successful transfer of innovative technologies into environmental restoration operations. The measures of success for technology demonstrations include conducting the demonstration in a safe and controlled environment and generating the appropriate information by which to evaluate the technology. However, field demonstrations alone do not guarantee successful transfer for deployment. There are many key elements throughout the development and demonstration process that have a significant impact on the success of a technology. This paper presents key elements for a successful technology demonstration and transfer for deployment identified through the experiences of the VOC-Arid ID. Also, several case studies are provided as examples.

INTRODUCTION

The Volatile Organic Compounds in Arid Soils Integrated Demonstration (VOC-Arid ID) was sponsored by the U.S. Department of Energy (DOE) Office of Technology Development. The VOC-Arid ID was one of several integrated demonstrations designed to support the demonstration of emerging environmental restoration technologies. The principal objective of the VOC-Arid ID was to identify, develop, demonstrate, and transfer for deployment new and innovative technologies for environmental restoration at arid or semiarid sites containing VOCs with or without associated contamination (e.g., radionuclides and metals). Technology demonstrations have been hosted primarily by the DOE's Hanford Site in southeastern Washington State. The DOE's Office of Environmental Management has recently reorganized its technology development efforts within the Office of Environmental Management around five "focus areas." The scope of the VOC-Arid ID, along with several other efforts, have been incorporated into the Contaminant Plume Containment and Remediation Focus Area (Plumes). The goal of this reorganization is to build upon the successes and failures of the integrated demonstrations and improve the technology development and implementation process.

TECHNOLOGY PROCESS FLOW

The movement of a technology through the VOC-Arid ID consisted of technology identification, demonstration and evaluation, and transfer for deployment. The process of identifying a technology was initiated through the preparation of a needs statement that was distributed in a call for proposals made available by the DOE. The needs statement was developed based on input from environmental restoration operations staff and technical experts in the area of VOC monitoring, characterization, and remediation. Proposals received were processed through DOE program management and were then reviewed and evaluated by the VOC-Arid ID technical support groups. Using the technical support groups' recommendations and working to funding limitations, VOC-Arid ID management recommended technologies to be included in the program. Final decisions on technologies accepted into the program, and their funding levels, rested with DOE program management.

The demonstration process began immediately upon a technology being accepted into the VOC-Arid ID. A Demonstration Operations project engineer was assigned to guide the principal investigator for each technology through the rigors of the field demonstration and was responsible for all aspects of the demonstration. For the principal investigator's use, Demonstration Operations developed a guide for preparing demonstration documents (Koegler et al. 1994). This guide defines the required documentation and delineates at what point in the process each document is due. Following each field demonstration, a series of reports were produced in evaluation of the technology.

ELEMENTS OF SUCCESS

The VOC-Arid ID has been successful in demonstrating innovative technologies and transferring those technologies for deployment. This has been due in large part to established organization, process, and interfaces. Several elements that have been identified as contributing to the program's success are described below. Woven throughout the elements for success is the consistent application of a structured process. Specific lessons learned of these elements can be seen later in the case studies.

Technology Selection

A key to the successful demonstration, evaluation, and transfer for deployment of a technology is the selection of appropriate technologies.

The VOC-Arid ID used technical support groups to provide technical review and screen technologies. The technical support groups consisted of recognized experts in the areas of environmental restoration, e.g., characterization and monitoring, drilling or access, and remediation. The technical support groups represented a cross-section of staff from DOE's operations contractors and national laboratories, universities, industry, and other Federal agencies from across the nation.

The technical support groups ensured that there was a real need for a proposed technology, and that the technical basis for the technology was sound. The technical support groups also monitored the development and demonstration of each technology to ensure that the expectations of the technology were being achieved.

Criteria, Objectives, and Parameters

Establishment of criteria by which technologies will be evaluated is a key to the successful demonstration and evaluation, and transfer for deployment of a technology.

Criteria that were established for use by the VOC-Arid ID incorporated guidance from the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). These criteria were modified to incorporate input received through stakeholder involvement activities (stakeholder involvement as an element of success is discussed later). Criteria developed through this process include the following:

- Technology performance: remaining contamination
- Technology performance: process waste
- Implementability and practicality of technology
- Does the technology function as intended?
- Cost
- Time
- Worker health and safety
- Public health and safety
- Environmental impacts
- Technology reputation/familiarity to public
- Future land uses/tribal rights
- Socioeconomic impacts
- Regulatory infrastructure requirements
- Compliance with regulatory requirements
- Overall protection of human health and the environment.

Identification of appropriate demonstration objectives and the parameters to measure those objectives is a key to the successful demonstration, evaluation, and transfer for deployment of a technology.

The structured demonstration process implemented by the VOC-Arid ID ensured that appropriate information was gathered during field demonstration, e.g., information needed to evaluate the technology against the criteria. This process included identification of appropriate demonstration objectives, and appropriate parameters to be measured. Focus on the development of objectives and parameters in planning for the demonstrations prevented the gathering of inadequate information by which to evaluated the technology.

Documentation

Complete documentation is a key to the successful demonstration, evaluation, and transfer for deployment of a technology.

Documentation required from each VOC-Arid ID principal investigator before fielding a technology included a conceptual test plan with a technology profile, demonstration objectives worksheet, and environmental regulatory checklist attached. The purpose of the conceptual test plan was for the principal investigator to formulate demonstration objectives, provide information to initiate regulatory and demonstration host site compliance activities, and provide for review of plans for field activities. The technology profile was used for stakeholder involvement activities. The demonstration objectives worksheet was a tool to aid the principal investigator in formulating objectives for the field demonstration. Regulatory experts used the environmental regulatory checklist to ensure compliance with applicable regulations.

The conceptual test plan was incorporated into an integrated test plan that was the document that guided the field demonstration. The integrated test plan ensured that the demonstration was conducted in a safe and controlled manner. The integrated test plan incorporated all aspects of conduct of operations including all operating procedures necessary for the demonstration.

Following each field demonstration, a series of reports were planned. The principal investigator was responsible for producing an evaluation report of the technology demonstration. The project engineer was responsible for producing an independent evaluation of the usefulness and potential of the technology. Independent cost effectiveness and stakeholder acceptability reports were also part of the reporting process. Drawing on all of the reports listed previously, the VOC-Arid ID would produce an overall technology evaluation summary report.

Environmental Restoration Interface

Demonstration conducted through the infrastructure of an environmental restoration project, or operational platform, is another key to the successful demonstration, evaluation, and transfer for deployment of a technology.

When possible, VOC-Arid ID technology demonstrations were conducted as systems in conjunction with an operational environmental restoration project. This provided the opportunity for the comparison of innovative technologies against one another, and against baseline technologies, under real-world field conditions. Bechtel Hanford, Inc. (BHI), is the Environmental Restoration Contractor at the Hanford Site. Having the operations of the VOC-Arid ID conducted through BHI provided for the technology demonstrations to be wrapped into environmental restoration project activities.

Success was found in putting the innovative technologies in the hands of the people doing the environmental restoration work. This allowed those individuals in the field to become familiar with the technology and how it could improve on the safety, cost, and/or schedule performance of baseline technologies. It also provided for input to the principal investigator on improvements that might be accomplished during the development of the innovative technology.

Emphasis on Commercialization

Emphasizing the earliest possible establishment of a tie between the technology and a commercial partner is another key to the successful demonstration, evaluation, and transfer for deployment of a technology.

At the time a technology was brought into the VOC-Arid ID, work began on commercialization. The commercialization process was managed by the principal investigator who was required to involve industry to ensure the technology would be manufactured and made commercially available. It is generally expected that technologies will be made available by commercial suppliers of goods and/or services rather than by Federal contractors, national laboratories, or universities. The goal was to ensure industry involvement in the development and demonstration process to enhance the technology's likelihood of ultimate deployment. Identification of a commercial partner is a strong indicator of the potential of an innovative technology.

Commercialization plans and partnership plans are used by the Office of Technology Development to ensure that projects consider commercialization early in the development cycle. A commercialization plan lays out specific actions, and a general business strategy, for commercializing the technology. This plan usually sets a path toward ultimate commercialization of a technology where an industrial partner has already been identified. A partnership plan establishes a path for projects or technologies where an industrial partner is needed but not identified. This plan includes schedules and strategies for soliciting or identifying partners to support a commercialization effort.

<u>Stakeholder Involvement</u>

Initiating stakeholder involvement as early as possible is still another key to the successful demonstration, evaluation, and transfer for deployment of a technology.

Part of the initial documentation package required by the VOC-Arid ID from the principal investigator included a technology profile. The technology profile was the basis for many of the stakeholder involvement activities conducted in support of the VOC-Arid ID. This included providing information for ProTech, a computer-based communication system designed to facilitate public understanding of innovative technologies. The ProTech audience targeted individuals and groups with a stake in a technology's deployment including, but not limited to, regulators, special interest groups, citizens in a community where an environmental technology may be used, and potential industrial codevelopers and users of a technology. The technology profile was also updated upon completion of the demonstration and used in the reporting process.

Analysis of stakeholder acceptance was conducted by a technology acceptance task team. This team used the technology profile to provide preliminary information to stakeholders on upcoming technologies, systems, and field demonstrations. Focus groups and workshops with stakeholders (e.g., regulators, interest groups, and technologists) were conducted to identify issues and concerns they may have about a technology. In addition, the technology acceptance task team conducted interviews and presentations with a variety of stakeholders with the same objective. Establishment of the VOC-Arid ID evaluation criteria were developed in part from this process.

The Plumes Focus Area has established a management approach and strong emphasis on stakeholder involvement based on the VOC-Arid ID's stakeholder process. In addition, the DOE sites, such as the Hanford Site, are developing similar stakeholder involvement processes as part of their role within the Focus Area.

TECHNOLOGIES DEMONSTRATED

Following is a list of technologies that have been demonstrated over the past several years as part of the VOC-Arid ID. These are in addition to the technologies discussed later in the case studies.

Characterization and Monitoring Technologies:

- BoreSampler
- Cross-Hole Seismic Tomography
- Portable Acoustic Wave Sensor
- Arrayed Sampler
- Colloidal Borescope
- Unsaturated Flow Apparatus
- Odyssey Sensor
- Passive Soil Gas Monitors
- Fiber Optic Sensor

FTIR Instrument
Prompt Fission Neutron Logging Tool

Drilling or Access Technologies:
Cone Penetrometer
Directional Drilling
ResonantSonic Drilling

Remediation or Treatment Technologies:
In-Well Vapor Stripping
In-Situ Bioremediation
Tunable Hybrid Plasma
Passive Soil Vapor Extraction

CASE STUDIES

After completing more than 25 field demonstrations of innovative technologies for characterization, monitoring, drilling or access, and remediation, the VOC-Arid ID conducted a rigorous review of many of these demonstration projects to identify barriers to, and attributes of, successfully deployed technologies. These case studies represented both privately developed and federally developed technologies and included systems for both VOC remediation and characterization or monitoring. The following sections summarize five of these case studies and the lessons learned. Each case briefly describes the technology and a limited history of development and demonstration, along with the findings of the review.

Membrane Separation System for Treatment of VOC Off-Gases

A membrane separation system developed and supplied by Membrane Technology Research, Inc. (Menlo Park, CA), was demonstrated for concentration and removal of vapor-phase chlorinated solvents from a soil vapor extraction (SVE) system. This technology was demonstrated to assess its viability as a cost-effective alternative to granular activated carbon for treatment of SVE off-gases. Off-gas membrane systems have been used commercially in industrial solvent recycling operations, but not for soil or groundwater cleanup operations. The anticipated benefit of the technology was a lower cost separations process that produced a liquid VOC waste stream that could be more easily and inexpensively treated relative to the offsite shipment and regeneration requirements of activated carbon. A field demonstration of a pilot membrane system was conducted in the spring and summer of 1993 at the Hanford Site, in conjunction with an ongoing CERCLA cleanup operation. Planning for the demonstration began nearly a year before the field activities through the development of a detailed test plan (Field 1993). Operations staff interested in off-gas alternatives were selected to lead the field demonstration working directly with a lead technical engineer to lease, install, and test the pilot unit. The ongoing cleanup operation allowed the membrane system to be tested without significant regulatory compliance permitting by leveraging off a previously approved system. A split stream from the SVE system was drawn into the membrane unit. Effluent from the test system was returned to the SVE system for treatment through the baseline activated carbon system, thereby reducing any potential regulatory concerns.

The membrane system demonstration successfully accomplished its objectives and provided both technical performance and cost data to support an analysis of the technology's cost benefit (King 1993). Results indicated that the system operated well, performed at high separation efficiency, but only produced significant cost savings over the baseline at VOC concentrations above approximately 600 ppm carbon tetrachloride by volume under the conditions tested. These conditions included an assumption that the VOC from this waste site could not be recycled, therefore the cost benefit associated with this technology's usual application in solvent recovery was not possible. Although the technology was not successfully implemented following the field demonstration, the effort was considered successful because it provided valuable data to the Environmental Restoration Program. This data essentially prevented an unnecessary expenditure of capital and operating funds that may have occurred if a system was procured or leased for full-scale operations or testing based on performance of systems used in the solvent recovery area.

The following are several key attributes of this demonstration and lessons learned.

- Staff responsible for operations of an actual cleanup were intimately involved from the beginning in selecting, planning, and operating this technology demonstration.

- Test objectives and performance criteria were clearly established before the demonstration to ensure that all operations costs and technical performance issues were addressed during testing.

- The operation staff's interest in demonstrating the system was enhanced by (1) the desire to consider off-gas treatment alternatives to reduce the cost of the baseline system, (2) the fact that it was a commercial technology with existing data on previous applications (i.e, track record) even though they were under different conditions, (3) the technology's attributes of being a skid-mounted, fully-engineered system with simple operational controls (i.e, could be easily integrated into existing systems), and (4) the fact that it was a commercially available system that could be purchased or leased quickly to meet immediate needs.

Halosnif™ Fiber Optic Spectrochemical Sensor

The Halosnif™ sensor was developed by researchers at Battelle Pacific Northwest Laboratory (Richland, WA) for detecting chlorine or fluorine-containing compounds in air, such as trichloroethylene or carbon tetrachloride. The sensor's attributes include a wide dynamic range of detection (e.g, 10 ppmv to 10,000 ppmv), and continuous, real-time detection. Over several years, development efforts improved the sensor's detection limit, portability, and stability. The resulting sensor system used an improved commercial power supply and could be easily set up and operated as a continuous monitor.

The sensor was demonstrated at several DOE sites, functioned well, and compared favorably against other baseline techniques for chlorinated VOC detection (Blumenkranz 1993). The demonstration efforts accomplished their objectives and demonstrated the technology's performance; however, this system has yet to be successfully commercialized or implemented. Although the system has several favorable attributes, it has not satisfied the requirements of end users. Primary user needs for VOC sensing are centered around lower detection limits (e.g., 1 ppm) for health and safety monitoring, and hand-held instrumentation for field monitoring. The Halosnif™ system is too large and bulky for hand-held applications. The system is well suited to process monitoring; however, this is a different market and there are other commercial systems that can adequately, and more effectively meet the process monitoring and control needs.

A number of lessons were learned as this technology advanced through development and demonstration.

- Commercialization, market assessment, and technology transfer are critical components of successful deployment, and must be considered very early in the development cycle. A more thorough market assessment and user survey may have identified the functional requirements of a new sensor system, and competing commercial systems that any VOC sensor would have to outperform to ensure commercial success. Commercialization plans that set a path forward and identify key decision points for a technology's development effort are critical to the process of either redirecting, redesigning, or ceasing development efforts.

- Several field demonstrations were conducted over 2 years in an effort to assess the technical performance of the sensor. These tests were very successful in identifying the technical areas needing improvement. However, these test did little to define the right market, target problems, or technical attributes (i.e., size, portability, detection limit, etc.) that would ensure user needs were being met. If development objectives and criteria are adequately defined, they can be key elements in the decision process for continuing development. Commercial research and development typically assesses the business or market factors early in the development cycle. In this case, those assessments were incomplete and did not adequately identify the market for this type of sensor system.
- User needs are often vague, and ill defined. This sensor system was developed based on a defined, but general need identified by environmental restoration staff. Without functional requirements, or clear

performance goals associated with each need, technologies can be developed that appear to meet the requirements. Only after years of development and demonstration does the developer realize the need has either changed, or was never adequately defined.

In Situ Permeable Flow Sensor for Groundwater Flow Measurement

A groundwater flow sensor developed by researchers at DOE's Sandia National Laboratories (Albuquerque, NM) was developed and demonstrated under DOE's VOC in Non Arid Soils Integrated Demonstration (VOC Non-Arid ID) in 1993 (Ballard 1994). In 1994, this technology was used at DOE's Hanford Site by environmental restoration staff as part of remedial investigation efforts within the Site's 100 Area. This deployment of the in situ permeable flow sensor represented a successful technology transfer from a research and development program to a cleanup effort.

This sensor uses heating elements and temperature sensors to indirectly measure water flow, and is deployed by placement in an uncased borehole below the water table. The formation is allowed to collapse around the sensor, resulting in a system that measures flow within the natural sediments rather than within a significantly disturbed borehole or well. The goal is to achieve accurate measurement of flow that is not likely possible with conventional methods. The system can be used for aquifer characterization or monitoring before, during, or after remediation of the aquifer.

Development, demonstration, and technology transfer of the in situ permeable flow sensor was successful for the following reasons.

- The technology was demonstrated multiple times as part of the VOC-Non Arid ID and its performance thoroughly documented.

- Environmental restoration staff responsible for remedial investigation/feasibility study and cleanup actions at the Hanford Site learned about this innovative sensor system through direct involvement as technical reviewers within DOE's Technology Development Program. Although information on many new technologies is disseminated through publications, conferences, and technology databases, direct, one-on-one contact between the developers or suppliers and the operations staff is critical. In addition, operations staff involvement in review and evaluation of technology demonstrations resulted in immediate, complete, and unbiased information on performance of the sensor technology.

- Characterization and monitoring technologies are more easily transferred because they are generally less expensive to deploy and/or test than remediation systems. In addition, they are typically not held to the rigorous performance standards of remediation technologies (especially for screening applications), and do not usually require lengthy regulatory review or approval prior to deployment.

- At the time of deployment at the Hanford Site, this sensor system was not commercially available. Therefore, deployment of the sensors was accomplished through a direct contract between the operations program and the original investigator from a DOE national laboratory. Although it is generally felt that technologies are more readily accepted if commercially available, in this case the presence of an industrial supplier was not important to the environmental restoration staff. If hardware could be procured easily and technical support obtained from the developer, a viable industrial supplier was not important. However, broad application of the technology to multiple customers would clearly require an effective commercial partner.

Six-Phase Soil Heating for Enhanced Removal of VOCs from Soils

A variety of soil heating methods are being developed and demonstrated by industry, DOE, and other Federal agencies as a means of enhancing volatilization and subsequent removal of VOCs from soils. Six-phase soil heating is an electrical resistance or "ohmic" heating method developed by researchers at Battelle Pacific Northwest Laboratory. Field testing was accomplished by the VOC-Arid and VOC-Non Arid IDs at DOE's Hanford and Savannah River Sites, respectively. The technology was tested at pilot-scale in an uncontaminated area at the Hanford Site as part of shakedown testing, and then tested at the Savannah River Site's M-Area for enhanced removal of trichloroethylene and perchloroethylene from a clay lens (Gauglitz et al. 1994). The technique uses six electrodes in an array, with six-phase alternating current power to resistively heat soils in situ, thereby drying the soil and volatilizing contaminants. A soil vapor extraction system is used in conjunction with the heating system to recover and treat released vapors.

The demonstration was successful in heating soils to approximately 10 °C (50 °F) within a 6-m (20-ft.) dia. zone. In addition, post-test analysis of soils within the heated zone indicate that greater than 95 percent removal of contaminants was accomplished in the 2-month duration test. The demonstration resulted in increased interest from both industry and environmental restoration staff at other DOE sites. Specifically, the Environmental Restoration Program at DOE's Rocky Flats plant in Colorado requested support in remediating several operable units with VOCs and dense nonaqueous-phase liquids (DNAPLs) present in low conductivity soils. Efforts are being planned for use of soil heating at Rocky Flats. Development activities for six-phase soil heating are being finalized this year with the completion of a design tool to support deployment of the technology and commercialization.

Although deployment within the Federal and private sectors has not yet been accomplished, the outlook is very positive. Several lessons learned have resulted from this development and demonstration effort.

- A well-designed, phased approach was used to develop this heating technology over approximately 4 years. Several sources of funding, primarily from DOE's Office of Environmental Management, were obtained during this time, and at times leveraged with other funding, to accomplish all of the lab-, bench-, pilot-, and field-scale tests necessary to scale-up the technology.

- Commercial interest in the technology was observed early in its development cycle; however, serious interest from industry was not realized until after the Savannah River field demonstration. This is likely a result of two things. First, industrial enthusiasm was dependent on solid evidence of the effectiveness of the technology in a field test. Until an initial contaminated site test was completed, there was little proof that the technology could be effectively used. Secondly, commercialization of the technology was not a primary focus of the funded activities. The developers focused on technical development in conjunction with the establishment of appropriate intellectual property. Identification of one or more commercial partners was somewhat delayed until intellectual property was protected, and proof of performance was obtained. Commercial interest and partnering may have been possible and beneficial earlier in the development cycle if it had been a priority. The DOE and the developers may have sacrificed some intellectual property, but the timeline for deployment may have been reduced.

SEAMIST™ Membrane Instrumentation and Sampling System

Science and Engineering Associates (Santa Fe, NM) developed an inflatable membrane system that is used as a continuous packer system in uncased (i.e., open) boreholes and as a platform for deploying a variety of instruments and sampling tools. The purpose of this technology is to provide for more representative sampling of soil gas, VOCs, and other soil contaminants, as well as for in situ air permeability measurements. The SEAMIST™ system is commercially available and is being used for site investigations and monitoring. The technology is now owned by Eastman-Cherrington Co., Albuquerque, NM.

SEAMIST™ was demonstrated at a variety of sites, including DOE sites such as Savannah River and Sandia National Laboratories. Environmental restoration staff at the Hanford Site became aware of the technology several years ago and purchased a system to be used in characterizing sites contaminated with VOCs (Rohay 1992). However, SEAMIST™ use at the Hanford Site was significantly different than the originally intended purpose. For example, operations staff requested a system to be used in large diameter wells, to depths of 76 m (250 ft), without predetermined sampling ports. Because of the geology at the Hanford Site, temporary casing is needed to maintain borehole stability during drilling. Open boreholes are not possible for any significant depth. Hanford Site contractors desired a system that could be deployed during drilling to collect samples at the current depth of the borehole. Therefore, a modified SEAMIST™ system was used where the soil vapor sampling was accomplished through a sampling line dropped down the well to depth, and the SEAMIST™ system was used to create a continuous packer and ensure vapor sampling occurred only from the formation adjacent to the end of the sample line.

SEAMIST™ is currently being used at the Hanford Site in routine characterization efforts and is gaining additional applications through continued use by environmental restoration staff. In addition, the developers are expanding applications of the technology to other contaminants and analyses.

This technology was successfully deployed at several sites and is still being used for additional applications. Several key features resulted in the successful deployment of the SEAMIST™ system.

- Environmental restoration staff had a well-defined, immediate need (e.g., collection of representative soil gas samples during drilling) and were prepared to use their resources to find and test new approaches to sampling. Existing techniques for sampling had shown wide variability and provided inadequate results. In addition, end users gained knowledge of the details of the technology's operation, recognized applicable features, and identified features that would tailor the technology to the specific needs of the site.

- End users took ownership of the modification, industrial interface, and demonstration of the technology. Direct and significant involvement from the site user resulted in a product that met the needs of the site.

- The SEAMIST™ system was commercially available, and was supported by a company eager to modify, adapt, and redesign the system to best support the needs of the customer.

CONCLUSIONS

The ultimate goal of DOE's Technology Development Program is deployment of new technologies and technology systems that improve on safety, cost, and/or schedule of performance over baseline technologies. Field demonstrations are a critical component of successful development and deployment of environmental technologies. However, field demonstrations alone do not guarantee successful transfer for deployment. There are other key elements throughout the development and demonstration cycle for any technology or technology system that have significant impact on the likelihood of deployment. The VOC-Arid ID established a development and demonstration process designed to enhance the likelihood of successful deployment following field demonstration. This process includes clearly defined methods for technology selection, performance evaluation involving stakeholders in the development and demonstration cycle, and commercialization. Many keys to successful technology deployment were identified in lessons learned from more than 25 field demonstrations. Also, several key attributes for successful deployment were identified through case studies. The case studies further highlight the applicability of the development and demonstration process established by the VOC-Arid ID, and identify areas where additional emphasis must be placed.

In summary, key attributes include the following:

- Well-defined needs that clearly describe performance objectives and requirements for technical solutions. These needs are then used in the selection of appropriate technologies.

- Well-designed development efforts with phases and tasks that identify key decision points. Clearly defined performance objectives and evaluation criteria are needed for each stage of development. A broad set of criteria is needed to ensure that as many issues can be addressed as early as possible in the development cycle. Projects unable to meet these key performance goals are redirected or terminated early, allowing more promising methods to continue toward demonstration and deployment..

- Clear and complete documentation of all phases of the development, demonstration, and performance evaluation process. Thorough reporting of results with wide distribution. Effective communication of demonstration results, especially to a variety of potential end users, is critical to deployment.

- When possible, conduct field demonstrations in conjunction with environmental restoration projects. This allows the opportunity for end users to become familiar with the technology and affect its development. This also provides the opportunity to view the innovative technology under field conditions along side baseline technologies.

- Early efforts are needed to assess commercial markets and identify commercial partners. Industrial involvement early in the development cycle can enhance marketability, funding for development, and availability of the technology immediately after demonstration.

- End user and other stakeholder involvement in the development, demonstration, and/or adaptation process for technologies and systems. This involvement includes management, oversight, and technical involvement in the development and demonstration efforts, as well as significant involvement in the development review and evaluation process.

The DOE's Office of Environmental Management has recognized the strengths and weaknesses of its past technology development and demonstration program, and has recently initiated a "New Approach" involving focus areas. This new process incorporates the key attributes identified above and in the case studies. Specifically, the focus areas are emphasizing direct user and stakeholder involvement in every facet of the development cycle, along with technology selection that is targeted more directly to complex-wide, but site-specific problems or needs. The demonstration efforts and lessons learned from the VOC-Arid ID, along with other development and demonstration efforts, have been incorporated into the Contaminant Plume Containment and Remediation Focus Area (Plumes) and are providing a building block for the New Approach.

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