ES/ER/TM--52
DE93 005173

Technology Needs for Environmental Restoration Remedial Action

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Date Issued—November 1992

Prepared for
U.S. Department of Energy
Office of Environmental Restoration and Waste Management
under budget and reporting code EW 20

MARTIN MARIETTA ENERGY SYSTEMS, INC.
managing the
Oak Ridge K-25 Site
Oak Ridge Y-12 Plant
Oak Ridge National Laboratory
under contract DE-AC05-84OR21400
Paducah Gaseous Diffusion Plant
Portsmouth Gaseous Diffusion Plant
under contract DE-AC05-76OR00001
for the
U.S. DEPARTMENT OF ENERGY

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EXECUTIVE SUMMARY

An annual summary of technology needs has been done for the Environmental Restoration (ER) Program at the U.S. Department of Energy (DOE) facilities managed by Martin Marietta Energy Systems, Inc. These facilities are the Oak Ridge National Laboratory, the Oak Ridge K-25 Site, the Oak Ridge Y-12 Plant, the Paducah Gaseous Diffusion Plant, and the Portsmouth Gaseous Diffusion Plant. The survey began with a list of suggested needs supplied by representatives from the ER programs at each site. The list of needs was assessed, and priorities were set where appropriate, but important differences in the problems addressed by different needs made some comparisons meaningless.

There is a common focus on characterization needs for most sites. This commonality can be attributed to the current focus of most ER programs on scoping the problems. The technology development needs expressed may shift toward treatment methods as the programs shift more toward treatment for permanent solutions to the environmental problems. Current characterization needs are for better field instrumentation that provides more rapid results and is less costly (permits more characterization analyses). Remote monitors are needed to follow changes in contamination and contaminant movement. Important characterization problems that at present have no current solutions (at any price) are (1) determining underground hydrogeology; (2) determining the location of dense, nonaqueous-phase liquids (DNAPLs); (3) determining the location of mercury contamination; and (4) sampling under highly contaminated regions such as burial grounds. In each of these cases, current sampling methods involve drilling (and possibly even the use of penetrometers) and include risks of altering the underground structure and/or spreading contamination. Methods that are less intrusive are needed.

New treatment methods are needed for removal of DNAPLs and mercury. The presence of tight soils at some Energy Systems sites, especially at Portsmouth, makes use of most treatment methods difficult. Even volatile organic compounds (VOCs), which can be removed relatively easily from most normal soils by gas stripping or soil venting, are difficult to treat in these tight soils. There is a strong desire for more in situ treatment methods that can reduce the risk and cost of excavation (there is also a problem in verifying that excavated soils can be returned if they contain naturally occurring contaminants in addition to potentially added contaminants). Buried wastes present special problems with ground penetration and leaching of radioactive and toxic components. Reliable methods for fixation of buried wastes and other materials injected into the ground during past operations are needed, or better methods are needed to prevent groundwater from entering or leaving the regions of these buried or injected wastes. Sediments in surface-water streams also contain contamination and need to be stabilized so they do not migrate off site. Groundwater treatment methods are needed for mercury, and a flexible treatment system is needed for temporary treatment of various radioactive contaminations.

The environmental problems at the DOE facilities managed by Energy Systems cover a wide range, and most of the technology needs are believed to also apply to other DOE facilities. Only a few needs such as those associated with the large mercury contamination are likely to be unique to the five facilities discussed in this report.

1. INTRODUCTION

This report summarizes the current view of the most important technology needs for the U.S. Department of Energy (DOE) facilities operated by Martin Marietta Energy Systems, Inc. The sources of information used in this assessment were a survey of selected representatives of the Environmental Restoration (ER) programs at each facility, results from a questionnaire distributed by Geotech CWM, Inc., for DOE, and associated discussions with individuals from each facility. This is not a final assessment, but a brief look at an ongoing assessment; the needs will change as the plans for restoration change and, it is hoped, as some technical problems are solved through successful development programs.

Because this assessment drew largely from people involved in ER rather than from those currently involved in research and development (R&D), it reflects the perception that new technology is needed, but it does not stress the likelihood that such technology can be developed. Nor does it reflect the cost, time, or effort required to develop the technology. Similar surveys that poll the people who are working to develop new technologies are better able to assess the possibility that a new technology can be developed; the scientists and engineers involved in R&D know better what new concepts are available and what new advances can soon be made. This viewpoint can also be reflected in the lists of proposals submitted to DOE, the Environmental Protection Agency, and other agencies for R&D in ER. Although lists of proposals are sometimes viewed as lists of what scientists and engineers want to do rather than what is needed, prioritization of research activities should take such lists take into account along with the perceived needs of the user. An R&D program must include studies that have a reasonable chance for success as well as those for which there is high need.

The aim of this assessment was the identification of the most important immediate needs of the Energy Systems ER sites. Complete lists of needs and possible needs have been assembled elsewhere, and such lists are not likely to change significantly from year to year, while determination of the most important immediate needs requires periodic reassessment.

This report is as brief as is practical and is organized to provide the conclusions and the most important information in the first few pages. Increasing detail is provided in the later sections of the report. Section 2 gives a brief listing and summary of the most important technology needs. These needs were assembled from suggestions provided by all five sites. Section 3 contains a summary of the needs for each site as perceived by the people at that site. The subsequent section focuses on the issues and problems that hinder the development of technology for ER in industry or government. This discussion informs the reader of issues, forces, and problems that must be overcome for efficient development of new ER technology to occur.

This assessment will be upgraded annually. The needs will change as new problems are identified, old problems are solved, new technologies become employed, and ideas for new technologies appear. Many of the needs identified currently are for better characterization methods. Future assessments may indicate more needs for better treatment methods, particularly for treatments that result in clean closures requiring little or no monitoring or retreatment followup.

2. RESEARCH AND DEVELOPMENT NEEDS FROM INDIVIDUAL SITES

This section describes the needs identified by each site. Only three of the five sites provided specific lists of needs, so the needs from the Paducah and Portsmouth gaseous diffusion plants were surmised from oral discussions with representatives from the sites and from some known similarities to the needs at the Oak Ridge K-25 Site. The information on needs supplied from each site was usually a simple list, often with a brief explanation. The lists, presented in table form, are accompanied by a brief discussion to provide additional information or explanations.

Assessment of these needs is not stressed here but is given later. However, similarities in the needs of several sites are noted. Particularly, the need for better characterization methods is mentioned by every site reporting. The exact characterization needs mentioned by all sites were not the same, but there were common aspects in the characterization needs of all sites. Better understanding of underground soil, rock formation, and waste locations are mentioned by every site. In most cases, there is a basic need to understand groundwater flow and the consequent transport of contaminants. In some cases, the attention may be on the location and nature of buried wastes or dense nonaqueous-phase liquids (DNAPLs) in the soils. Remote monitoring systems and other field-mounted characterizing equipment seem to be needed by several sites.

2.1 OAK RIDGE NATIONAL LABORATORY

Oak Ridge National Laboratory (ORNL) probably has the widest range of soil and groundwater contamination problems throughout Energy Systems. These problems include a variety of buried wastes, out-of-service underground tanks, contaminated soils around tanks and pipelines, and contaminated groundwater and surface waters. There is also a wider range of contaminants contributing to the ORNL problems. These contaminants include gamma-emitting fission products (mostly cesium and strontium), tritium, transuranic elements, and uranium and chemical pollutants. Because of the wide variety of research activities at ORNL during the last 50 years, the number of chemical pollutants in the contaminated soils and waters is also large.

The list of needs reported for ORNL is given in Table 1. The ER staff at ORNL saw principal technology needs in two areas: better characterization and location methods and better methods for stabilizing the pollutants to prevent further spread. The highest priority was placed on the need for better stabilization methods.

Most of the specific technology needs reported reflect the serious near-term need to prevent the spread of contamination, including the need to locate buried wastes and contaminated soils and to monitor waters that can transport the contamination.

Some of the radioactive components of buried ORNL wastes (strontium, cesium, and tritium) have moderately short half-lives, and sufficient retention of the radioactivity can allow time for decay and reduction of the overall hazard. Stabilization/retention may be as effective as removal and ex situ treatment, and the risks of exposure or further spreading the contamination may be much less. Tritium contamination in the buried wastes presents a special problem that probably can be solved only by stabilizing the trench and preventing tritium from leaving the waste. Removal of tritium from the waste water would require isotope separation, a very difficult and expensive operation. Pump-and-treat operations are conventional approaches for preventing transport of contaminants by groundwater and eventually remediating the site. However, slow rate of transport of contaminants from the source to the groundwater to be treated can make pump and treat ineffective as a remediation method (even if it is effective in preventing further transport of the contaminant). This is expected to be a serious problem at ORNL, so methods other than pump and treat are expected to be preferred. Concern with the effectiveness of pump-and-treat methods is expressed in need no. 3 in Table 1; matrix-diffusion resistance prevents any treatment of groundwater from dealing effectively with pollutants that are distributed principally to the soil phase, soil, or organic solids in the soil.

Present characterization methods are expensive and often intrusive. They often rely on drilling, which adds the risk of spreading contamination vertically. The are also costly, and they generate significant waste. Several needs reflect the desire for field instruments and field methods for locating and monitoring contaminants and contaminant movement with minimal or no drilling. The characterization should examine the soil and hydrogeology as well as the mere presence of contaminants.

Table 1. R&D needs reported from ORNL

1. Technologies for stabilizing, removing, handling, dewatering, disposing, etc., of large quantities of potentially contaminated sediments (medium/high priority).
2. Monitoring of surface-water flow in humid hydrologic regimes where peak storm flows can be four times base flow, resulting in problems with submergence of weirs, infilling of stillwells, and sampling (low/medium priority).
3. Understanding of the effects of matrix diffusion on pump-and-treat groundwater remediation techniques (low/medium priority).
4. A subsurface drilling method through contaminated media into zones of lesser or no contamination that does not require the use of larger diameter boreholes and telescoping casing (high priority).
5. A portable liquid-waste treatment unit capable of treating effluent flows of 1–100 gpm to be used for the collection of radioactively contaminated groundwater (high priority).
6. Laser optics technology for in situ monitoring of groundwater for water quality, hydraulic conductivity, and piezometric head (low/medium priority).
7. A probe for radioactive contamination for use with borehole logging and characterization (low/medium priority).
8. Stabilization techniques for buried wastes (trench stabilization, biological wastes, etc.) (high priority).

2.2 OAK RIDGE K-25 SITE

The K-25 Site covers a vast area, but the number of contaminants is more limited than at some of the other Oak Ridge sites. The K-25 Site has been used as an R&D facility for several isotope separation methods and has accumulated a significant number of different waste types. Of particular interest are uranium, technetium, solvents [particularly polychlorinated biphenyls (PCBs) and trichloroethylene (TCE)], and asbestos. Large volumes of pipe and equipment insulation were installed when asbestos was an almost universal insulation of choice for high temperatures. In addition, many of the buildings were constructed with external surfaces containing asbestos imbedded in other materials (Transite). PCBs and PCB-containing liquids were used as solvents, coolants, and transformer fluids. The high level of power consumption at K-25 required large cooling towers to dissipate waste heat, and these cooling towers were sources of chromate ions.

The immediate R&D needs reported from K-25 were for better characterization methods. As reflected in Table 2, there was considerable concern with hydrogeology, the source and fate of groundwater flowing through the K-25 Site. The location of the K-25 facility near the Clinch River means that groundwater can have short paths off site. (Of course, any facility like the gaseous diffusion plant, which needs vast quantities of cooling water, would have to be located adjacent to a large source of water.) Better knowledge of underground water flow is needed for control of water flow through contaminated regions (burial grounds, spill sites, etc.) and for estimating the paths of spreading contamination.

The need for better field-monitoring systems for groundwater was also cited. The numerous surface-water streams and the increasing number of groundwater wells on the site could be served better with remote and more nearly continuous monitors. Such monitoring could reduce the cost and time delays resulting from manual monitoring and provide better understanding of the effects of large variations in rainfall and water-flow rate on pollutant transport.

Although characterization information may be needed first, better methods for treatment of waste sites will be needed in the future, perhaps in the relatively near future. R&D needs to be under way soon to meet these needs. Considerable remediation work has been done and more is in progress. However, much of the past and even present work is focused on solving immediate problems, often with temporary solutions. For instance, caps required by the Resource Conservation and Recovery Act and even removal of soils for storage in drums are not permanent solutions. Permanent solutions are more likely to involve removal of uranium, PCBs, and other contaminants from soils. The uranium-mining industry has developed effective carbonate leach and acid leach methods for removing uranium from the ore materials. During the next few years, the "Uranium in Soils" Integrated Demonstration is expected to evaluate such methods for soils at Fernald; tests may also be needed for K-25 soils.

Soil-vapor extraction has been demonstrated and used for removal of volatile organic compounds (VOCs) from soils above the water table, and these can be used at K-25, but the effects of complicated, fractured geology at K-25 need to be checked. The high water table at K-25 may mean that much of the material is below the water table. Biological methods are generally available as current or near-term technologies for treating hydrocarbons, but biological methods of treating highly chlorinated compounds such as PCBs and TCE require further development. Biological treatment of petroleum in soils is planned, and tests of innovative biological treatment of TCE are in progress.

Uranium and most other soluble contaminants at K-25 can be removed with ion-exchange resins (metal ions) or by granular activated carbon (organic pollutants), but improvements are needed for higher selectivity, greater capacity, and/or cheaper adsorbents. Greater selectivities would give more concentrated recovered material (smaller waste volume) and allow longer times between adsorbent replacement or regeneration. These are critical items in the cost of cleaning up groundwater. Less costly adsorbents would also be beneficial. R&D should address the full treatment process, including the regeneration/disposal of the adsorbent and treatment and disposal of the concentrated pollutant.

Table 2. R&D needs reported from the K-25 Site

1.	Characterization of unconsolidated materials, primarily cut and fill.
2.	Methods to determine the influence of underground lines and associated backfill.
3.	Methods for determining bedrock composition and structure and the influence of these on deep flow, contaminant transport paths, and flow off site.
4.	Groundwater response to meteorological events and possible transport of contaminants.
5.	Methods to identify sources of contaminants (finger printing of organic and volatile compounds).

2.3 OAK RIDGE Y-12 PLANT

The needs reported from the Y-12 Plant are given in Table 3. The Y-12 Plant has at least two problems that are different either qualitatively or quantitatively from those at the other sites. It is the only Oak Ridge site that has known problems with DNAPLs. There are no satisfactory methods for either evaluating the extent of DNAPL contamination or remediating DNAPL-contaminated sites. The problem is made worse because conventional methods for assessing and treating underground contamination involve the use of drilling and excavation, which can spread DNAPL contamination deeper into the soil and make the problem worse. At one of the Y-12 burial ground sites, DNAPLs are believed to have already reached great depths.

Mercury contamination at the Y-12 Plant is unique because of the large scale of the problem, not because the problem exists only at Y-12. Mercury contamination exists within buildings and probably in the soils around buildings. Sump water and other drain water from these buildings flows to a creek and has carried mercury contamination off the Oak Ridge Reservation and into the creek bed within the city of Oak Ridge. This off-site contamination has raised public and regulator concerns. The source of mercury in and around two buildings needs to be treated, and the mercury levels in the creek need to be lowered to prevent unacceptable exposure of the public to mercury.

During treatment of soils immediately around the contamination, the mercury may need to be treated as a DNAPL. Mercury has a very high density and thus tends to move downward like any other DNAPL, but it also has an extremely high surface (interfacial) tension that inhibits its movement into small pores in the soil. However, normal excavation could free mercury and thus spread the contamination deeper into the soil. The Y-12 Development Division has been commissioned to investigate mercury removal methods.

Other needs identified at the Y-12 Plant are more similar to those identified for other sites. These include needs for better field instruments for screening studies. In this case, a need for down-hole instruments is indicated.

With our inadequate methods for assessing contamination of soils with DNAPLs and mercury, the Y-12 needs list probably focuses more on the characterization need than do the lists of the other sites. There are only a few ideas available for use in high-clay soils and the potential depths of contamination at the Y-12 Plant. Ground-penetrating radar and other electromagnetic methods are good only within a few meters of the surface in soils like those at Y-12. Placing transmitters and receivers in wells probably would improve the depth-of-penetration problem, but the methods may still not detect contaminants more than a meter or so from the transmitter. A down-hole transmitter is also more likely to detect vertical arrays of DNAPLs, and a surface transmitter is more likely to detect horizontal regions of DNAPLs.

The sensitivity and dependability of these methods are probably better for detecting changes in a region than they are in detecting actual presence of a contaminant. This is because the devices detect interfaces and will see interfaces between rock types as well as interfaces between DNAPLs and rock. In a highly fractured material such as the soil at Y-12, there will be a wide variety of signals from uncontaminated rock. It is likely to be easier to see the formation of new interfaces than to indicate which interfaces result from the presence of contaminants. Unfortunately, there is usually no way to obtain data from precontaminated conditions. There may be some cases where it will be desirable to survey and monitor a region to determine if a DNAPL has migrated into that region.

There are methods for detecting mercury salts dissolved in water, and it may be possible to develop a practical field instrument for monitoring mercury concentrations within well holes. There are also effective methods for removing mercury from water, and it may be possible to use these methods or develop them into practical systems at Y-12. In these two areas, there are known approaches for starting development activities.

Table 3. R&D needs reported from the Y-12 Plant

1. Method for locating and defining the presence of DNAPLs without drilling directly into the DNAPL-contaminated region or hydraulically upsetting the area.

2. Techniques to remediate DNAPL contamination in a fractured shale and karst system.

3. Methods to account for matrix diffusion in removing contaminants from groundwater.

4. A method for in situ remediation of soils contaminated with mercury.

5. An in-line, cost-effective treatment method for reducing the concentration of mercury in storm sewers and building discharges to levels below 2 ppb.

6. Field screening method for measuring mercury concentrations in soil.

7. A down-hole method for screening soils for mercury contamination.

2.4 PORTSMOUTH AND PADUCAH

The contaminants at Portsmouth and Paducah are similar to those at K-25, but there are significant differences in the three gaseous diffusion sites. An important difference at Paducah is the presence of very porous "lenses" and vertical "chimneys" in the soil that have allowed contamination to move off site. TCE has moved significant distances off site, and clean water is now being supplied to people who would normally obtain their water supply from these aquifers. Another important difference is the known or strongly suspected presence of DNAPLs at Paducah and possibly at Portsmouth. As noted in the description of Y-12 needs, this is a very difficult problem both to assess and to remediate. The soils and underground rock structure at Paducah are not as highly fractured as those in the Oak Ridge (K-25) area, and characterization of the underground structure may be slightly less difficult, but the porous lenses and chimneys may make characterization almost as difficult.

The technology needs reported from Portsmouth and Paducah are listed in Tables 4 and 5. Although Portsmouth and Paducah have similar problems, the soils at Portsmouth are very different. The upper clays at Portsmouth are extremely tight (nonporous), but this has not prevented pollutants from migrating within the site and even approaching the site boundary. The low porosity of the soil makes it more likely that transport will be along surface waters (drains) or along disturbed soils (underground pipes, utilities, construction, etc.). Again, organic solvents such as TCE and uranium are the most common problems, and better methods are needed for assessing contaminated regions and removing contaminants. A recent demonstration at Portsmouth did show that deep-soil mixing could make other methods for removing organic pollutants effective, even with the tight soils of Portsmouth. Waste storage and mixed wastes are problems for Portsmouth; treatment methods that minimize the waste problems will be preferred.

The most urgent technology need at these sites appears to be for better methods of locating pollutants and the extent of contamination. DNAPL detection and assessment is of particular importance at both sites. Although both sites have considerable uranium and TCE contamination, problems with chlorinated solvents appear to be urgent. The problems with radioactivity, however, certainly cannot be ignored. Better sampling methods, in-field analyses, and in situ treatment methods are needed at both sites.

Table 4. R&D needs for the Portsmouth Gaseous Diffusion Plant

1. Better sampling methods for soils, groundwater, and other media that require less manpower and less costly implementation.
2. Innovative soil collection and handling methods that are more representative, reduce VOC loss, and improve validity of the resulting data.
3. Improved in-field analyses that meet data quality (DQO III) standards.
4. Improved in situ methods for tight clay soils.
5. Process methods for DNAPL beneath clay formations.
6. Methods for treating near surface soils (for PCB, VOC, and radioactive contamination) without excavation.

Table 5. R&D needs for the Paducah Gaseous Diffusion Plant

1. Methods for locating DNAPLs both above and below the water table.
2. Methods for treating soils contaminated with DNAPLs both above and below the water table.
3. Methods for removing PCBs, uranium, TCE, and toxic metals (Ni, Cr, Fe, Ba, Be) in soils to low levels suitable for closure. In situ methods would be preferred.

3. PRIORITIES FOR R&D

Three considerations have to be set for recommending R&D spending. First, there has to be a need; second, there has to be an idea or an avenue to follow to meet that need; and, third, there should be no existing development program that is about to deliver the technology needed. The reports from the sites focused on the needs, but an assessment must also be made of the probability and the cost of meeting those needs and the existing programs that could meet those needs. R&D priority assessments often take only one of these viewpoints depending on who is preparing the assessment. Users of technology obviously will focus on the most important needs; developers of technology often focus on what they feel can be done, and done quickly. The following discussions attempt to view the problem in both ways. Differences in opinion on priorities are as likely to result from the emphasis placed on the two different viewpoints as from differences in the assessment of individual technologies. In this discussion, when possible, the emphasis placed on these viewpoints will be explained. A summary of priorities is presented in Table 6.

Regulatory and compliance schedules also play important roles in the selection of priorities for R&D. These are the most important drivers for those responsible for remediating sites. However, if establishment of priorities requires a consideration of the amount of time available before remediation can begin, there may not be enough time for R&D to have an effect on the most urgent regulatory needs. There could be more benefit from an R&D effort if the effort were directed toward a less urgent problem where new technology can have an impact. For this assessment, consideration was given to when regulatory pressures require a technology, but the assumption was made that all significant contamination problems will have to be handled eventually. Thus technologies to improve any important current problem are important and should be developed eventually.

The extent of potential use of the technology should also be considered. The effects of more general applications of a technology appear in the cost savings. These savings may not be reflected in the needs listed by individual sites, because these sites are not responsible for use of the technology at the other sites. Secondary priority needs at all five sites may assume a higher priority for the Energy Systems facilities as a whole. Quantitative assessment of cost savings was beyond the scope of this study. In many cases, the extent of the problems has not been fully explored, and assessment of the cost of many technologies that would meet R&D needs could only be conjectural at this time.

The amount of current effort that is already devoted to development of technologies for a need also should be considered in setting priorities for additional work. All development work need not be done at Energy Systems sites; it will be more effective to do some development elsewhere. Where possible, manufacturers should be encouraged to develop needed technologies; for example, industrial firms are likely to do most of the development of drilling techniques and commercial instrumentation. The existing work is taken into account in these discussions when the work is known, but there is obviously a possibility that a development program could be overlooked or even unknown. There are also different conditions involved when a technology is being developed at another site. The issue here is the lack of control of the fate of technology development when the principal aim is to solve problems at another site. When one site is dependent on technology that is being developed principally for another site, the development could be reduced or expanded, redirected, or terminated based on factors that are not related to the needs of a particular site.

3.1 DENSE NONAQUEOUS-PHASE LIQUIDS

Only one problem listed by the sites seems to have no alternate solution; that is location and remediation of DNAPL contamination in soils. This is a serious problem at two sites. If mercury is included as a DNAPL, this problem is even more general since it occurs twice at one of the two sites. Both of these problems are of major importance and must rank in the high-priority group.

There is considerable interest in DNAPLs at other sites. A few controlled tests have been carried out in Canada, where environmental laws do not prevent controlled releases of DNAPLs for testing purposes. The most intensive work seems to be directed at locating DNAPL contamination. The emphasis has generally been on nonintrusive methods, but success has been limited. These methods involve sound or electromagnetic waves that detect interfaces. Changes in signals can be seen when DNAPL contamination is introduced, but the signals are not clear or free from false negative or false positive identification of contamination. Because these methods principally detect interfaces between phases (such as liquid phases), they will pick up interfaces between soil phases. This means that signals from highly fractured rock such as that found in the Oak Ridge area will be complex, and changes resulting from DNAPL contamination will be difficult to detect. Because it is unlikely that we will ever have signals from a spill site before contamination, we would have to rely on the absolute signal to detect DNAPLs, not changes in the signal. The urgency for finding better methods for locating DNAPLs is based principally on the fear that taking any action within the contaminated zone will contribute to spread of the contamination. If treatment methods offered less risk for spreading contamination, it may be more acceptable to begin remediation with less assurance of the exact boundaries of DNAPL contamination.

There appears to have been less work on remediation methods, principally because the exact location and extent of contamination cannot be accurately determined. Soil venting probably could be used for volatile DNAPLs above the water table, if wells used could be located safely out of the contamination zone—no easy task if the extent of contamination cannot be reliably determined. If the maximum depth of contamination were known, horizontal drilling (as is being developed in the VOC Integrated Demonstration at the Savannah River Site) might be useful to consider as air collection channels. The use of cone penetrometers may result in less risk of spreading the contamination to greater depths, because there is a tight seal between the soil and the penetrating tube. There is hope that the DNAPLs at old spill sites have worked their way into relatively stable positions in the soil and will be less likely to move unless the disturbance is rather strong. Withdrawal of small tubes from the soil may cause little spread of contamination as the soil closes around the space occupied by the tube, but larger tubes such as those likely to be needed for remediation operations may have to be left in the soil until remediation is complete. Recent tests show that large tubes can be pushed through the relatively soft soils at Sandia; it may be possible to push moderate size tubes to shallow depths through Paducah soils and possible evenly through Oak Ridge soils. If transmitters can be placed in the soil it may be possible to improve the removal rate for volatile DNAPLs above the water table with microwave or other heating methods. If treatment using cone penetrometers is considered unlikely to spread contamination, it may be acceptable to begin treatment in the zones considered most likely to be contaminated. Removal rates from different regions may even be used as a measure of the extent of contamination. This would reduce some of the need for exact measurements of DNAPL locations.

Because the DNAPLs at Y-12 are nonvolatile PCBs, soil venting in any form is likely to be ineffective. Until a promising idea appears to solve this problem, the focus should be limited to better methods for assessing the extent of contamination. The potentially deep location of PCB DNAPLs at Y-12 may make development of a suitable method for removing them unlikely, and development should not begin until new ideas are proposed.

Some DNAPLs at both Paducah and Y-12 are probably located below the water table, making soil venting unsuitable for removing them even if they are volatile like TCE. Methods for removing DNAPLs from below the water table involve greater risk for spreading the contamination and must be developed very carefully. One method involves adding surfactants to the groundwater upstream of the DNAPL and collecting dispersions of DNAPLs in water downstream. This certainly will remove some DNAPLs, but it will also lower the interfacial tension between the DNAPLs and water. This interfacial tension is the force that prevents the DNAPLs from settling deeper into the soil, and lowering the interfacial tension will allow some DNAPLs to pass through smaller openings in the soil and thus settle deeper. Use of this approach may always carry risk, but under some conditions those risks may be acceptable. For example, if the aquifer is sealed on the bottom by impregnable bedrock and there is no apparent communication with a lower aquifer, there may be only an acceptable risk that DNAPLs will find an unknown path between aquifers. Note that the DNAPLs probably would have to settle directly into the pathway to lower levels, because the dispersion of DNAPL emulsions would not penetrate pores very easily.

The transport of DNAPLs both vertically and horizontally is complicated and difficult to predict at all Energy Systems sites. As noted earlier, the underground rock structure at Oak Ridge (Y-12) is highly fractured, with layered rock sloping in odd directions and with cracks through which DNAPLs can penetrate the rock layers. The sand and clay structure under much of the Paducah site may not be much simpler; underground flow (water and probably DNAPLs) is dominated by lenses of porous sand that can extend vertically as well as horizontally. There are active programs at both Paducah and Y-12 to locate DNAPLs, and Paducah is considering frequency-selective microwave heating to remediate some of their DNAPL problems.

Although no work on biodegradation of DNAPLs is known, it may be worth looking into such options. Most of these solvents are toxic and not easily degraded by microorganisms, but some progress has been made (for example at K-25) in degrading TCE. If bioprocesses are found that can operate at liquid-liquid interfaces, there may be a chance for destroying DNAPLs below the water table. Because many organisms also form surfactants, problems with spreading the contamination would not be eliminated. However, organisms can also form biomasses that partially or essentially completely seal porous media, a technique used in the oil industry. It may also be possible to use biotechnology to restrict spreading of contamination. This could be a way to stabilize DNAPL contamination while wells are being drilled for subsequent treatment.

3.2 FIXATION OF SOILS AND TRENCHES

If removal of buried or highly contaminated wastes from burial grounds at ORNL or elsewhere is impractical, fixation in place is the preferred alternative. Some contaminants such as tritium are not easily separated and concentrated; therefore, fixation becomes particularly desirable. The relatively short half-lives of some of the serious contaminants at ORNL actually make fixation a permanent solution for tritium, strontium, and cesium. In situ vitrification has shown considerable promise for contaminated soils at ORNL where solutions were introduced directly into trenches without tanks or other metal containers. Although two sets of early experiments showed considerable promise, further tests are needed to demonstrate that volatilized cesium can be returned to the vitrified mass, that connecting vitrification regions can be interconnected to include all of the content of trenches, and that the vitrified mass does greatly reduce the leaching of radioactivity.

Of course, vitrification will not be appropriate for containing tritium, and tests elsewhere have shown that in situ vitrification is not good for buried tanks and other buried metallic solids. A more appropriate approach proposed for those problems may be to inject cement or polymer grout into trenches to fill voids and greatly reduce the permeability of the trenches. It is desirable to completely isolate the trenches from groundwater; if that is not possible, significant reduction in the permeability will still be desirable. The lifetime of the grout should be comparable to the lifetime of the radioisotopes of interest. This technology may also be useful for reducing migration of uranium and toxic metals and organic compounds from buried wastes, but the lifetime of those contaminants would prevent this from being considered a truly permanent solution.

Development of grout injection technology would also require development of assessment methods to evaluate the results of the treatment. If grouting development involves tests in simulated but uncontaminated trenches, excavation and tracers can be used to assess the results. Because introducing grout into the trenches will affect the trenches significantly, care must be taken to ensure that the treatment is effective. Grout-filled trenches could be more difficult to remediate by excavation or other methods if retreatment is necessary.

3.3 CHARACTERIZATION OF UNDERGROUND STRUCTURE AND GROUNDWATER FLOW

Characterization of underground structure and groundwater flow ranks high for need, but somewhat lower for ideas available for explanation. This ranking is based on the need to develop methods, not to actually do the characterization. The need to do the characterization may be much higher, but that is a different problem. One reason for lowering the priority slightly is that some limitations on approaches currently under consideration appear to be inherent and are not likely to be eliminated by further development. Ground-penetrating radar or essentially any electromagnetic approach may be limited in depth of penetration. The penetration is adequate for finding buried metals and other highly visible materials that are not buried too deeply, but may not be effective for materials at greater depths or for materials with weaker signals. Sonic methods do not have this limitation, but the resolution may not be as good as desired for some applications. The priority was rated down only slightly because there seems to be room for optimization in some methods.

Down-hole methods, which offer some potential for getting to greater depths, have been studied less extensively than surface methods. If electromagnetic methods are to be considered, the hole spacing may need to be relatively close; therefore, it would be desirable to use cheaper and less intrusive methods for installing transmitters and sensors down hole. The use of smaller transmitters and sensors and smaller cone penetrometers seems promising. Because of the complexity of the problem and the limitations of known methods, using sonic, electromagnetic, and possibly other methods such as electric conductivity and comparing the results may lead to a fuller understanding of the structure.

Time and software limitations have resulted in even fewer down-hole methods used with transmitters and sensors at various depths. Use of multiple-depth readings requires greater speed in both taking the data and processing the signals. Software development (and even computer capabilities) could also play a role in allowing the use of more complex cross hole signal combination and in combining the results of measurements from several types of sensors to create an image of underground structure.

3.4 FIELD SENSORS FOR LOCATING AND MONITORING CONTAMINATION

Some form of remote sensing was listed as a priority for every site reporting its needs. No sensing problem was mentioned by the sites which could not be handled, at significant cost, with current methods; the need is to improve the performance of sensing systems and reduce the cost. The priorities include monitoring of groundwater and surface stream flow rates and radioactivity and toxic contaminants. The availability of optional current technology lowers the priority of this item somewhat, but wide applicability of remote sensing raises its priority. Furthermore, the availability of ideas and the high potential that sensors can be developed for many uses also raise the priority of this work. There has been considerable success at ORNL and elsewhere in developing sensors and even complete systems that are often sensitive, selective, and suitable for remote field operations. At least one of these technologies has been licensed to a private firm for further development and marketing. It appears likely that many of the improved field sensors needed by the sites can be developed.

Although not specifically mentioned in the needs lists, upgrading of the status of remote or manual field analyses from "screening" to "approved and validated" appears to be highly desirable. If up to 1000 samples are required to characterize a site, and the cost per validated sample is $1000 or more, the cost of site characterization can be reduced significantly by reducing the number of samples that must be sent to remote laboratories for validated analyses. Development of field instrumentation should also consider calibration and other factors that would be important in upgrading the status of the method or even fully validating the field analysis method.

3.5 REMOVAL OF MERCURY FROM GROUNDWATER AND SURFACE WATER

Mercury removal is a problem that is largely limited to Y-12, but it is a sensitive issue because the mercury that enters East Fork Poplar Creek (EFPC) leaves the Oak Ridge Reservation. Although the quantities of mercury currently entering the creek may not be large, this well-documented problem directly affects biological organisms in the creek. There are several methods for removing mercury from low concentrations such as those in the outflows from the contaminated regions around two building at Y-12. The availability of options reduces the priority of this item slightly, but the benefits from even a small development program to identify the best approach give high priority to a small testing program. A series of treatability studies that has been started at Radian Corporation is aimed principally at the EFPC soils, and a demonstration has been proposed at Y-12. The

Development Division at Y-12 is also working on the problem with a focus on the on-site issues.

Apparently, Energy Systems can give little direction to the Radian studies and may choose to await their results before considering doing further studies itself. This is a reasonable policy, providing the time will be available to do any additional development before implementation is necessary. Most effective mercury removal from water is highly likely to be accomplished with ion exchange or adsorption. The development program should screen all probable adsorbent/ion exchange materials in simple laboratory experiments using either real Y-12 water or simulated solutions. There is no need to screen these materials in columns as is usually done in treatability studies. The principles of adsorption and ion exchange are understood well enough so that most information can be obtained with inexpensive experiments. In some cases, small experiments may even be preferable. Ion-exchange materials that have been noted to be selective for mercury are those which contain "thio" groups—that is, sulfur-containing resins. They are manufactured in the United States, Europe, and Japan.

The experiments should evaluate the equilibrium loading of the resins. For initial screening, the total capacity of the resin for mercury should be determined from solutions with compositions near that of the outflows from Y-12. If all of the mercury is in the ionic form, simply determining whether a column of resin will reduce the mercury concentration to the level desired would be pointless—essentially all of the resins will do that, provided the column is long enough. Comparing the initial effluent concentrations from columns will give combined effects from both equilibrium and rate parameters, will not provide the information needed to select the best adsorption/ion exchange material, and certainly will not provide enough information to design an optimum system.

Once a few interesting adsorption/ion exchange materials have been identified, the equilibrium-loading relations should be determined. This will be either an ion exchange equilibrium or an adsorption equilibrium, and the appropriate one should be used. Dilute adsorption may be described by a single parameter, the slope of the equilibrium curve, if the equilibrium curve is linear. The concentration of other components in the solution should be changed to ensure that the slope is not affected by the presence of other components in the water. The selectivity of the adsorbent for mercury over the other components in the water should be determined, especially if the adsorbent is to be regenerated. Ion-exchange equilibrium requires evaluation of the selectivity of the resin for mercury over all of the major ions in the water, probably mostly calcium.

Design and scale-up of adsorption or ion-exchange systems may not always be simple but can be relatively reliable; therefore, little large-scale testing is likely to be needed. However, mercury-removal systems should consider the total problem, including disposal or regeneration of the adsorbent/resin and minimization of waste-handling costs.

There has been interest in installing walls of adsorbents or reactants in situ to remove or destroy a pollutant such as mercury or PCB in groundwater. The advantage of such a system is the ability to intersect groundwater flow over large areas. This method is most attractive in areas where groundwater flow patterns can be determined. This could be useful in the Oak Ridge area, but it may be more useful at Paducah or Portsmouth where there are fewer changes in underground flow direction. An attractive alternative to pump-and-treat operations, this method does not require active operations. However, it is likely to require larger volumes of reactant/adsorbent, and monitoring of adsorption breakthrough may be needed. Excavation of an adsorbent to remove the pollutant may eventually be necessary.

3.6 REMOVAL OF MERCURY FROM SOILS

Removal of mercury from sump water, it is hoped, is only a temporary measure to be taken until the source of mercury can be removed from soils. As noted earlier, the ability to remove mercury from soils will depend on the ability to both locate the mercury and remove it once it is found. There should be time to develop or test removal methods, because the final mercury removal is not likely to be complete until the buildings involved are removed. The need for this technology is given a high priority. The availability of existing technology to do the job makes some testing of the equipment a high priority. Of the two potential approaches, roasting to volatilize the mercury and leaching, most attention is devoted to roasting. The probability that this approach will work is so high that little research is recommended; moving on to the testing or demonstration seems appropriate. Commercial equipment is available for testing, which should evaluate the removal of mercury from the off gas as well as the residual mercury left in the soil. The mercury-recovery system should produce as concentrated a product as possible to reduce waste-disposal costs; it would even be desirable to recover most of the mercury for sale. There is not enough mercury in the groundwater streams to justify much effort to recover it, but there could be large quantities of mercury in some soils. Recovery of that material should not be ignored. Leaching of soils to remove mercury is not well developed and is not as likely to be practical, but at least one company has expressed an interest in developing or testing a leaching method. Their experience has been with other heavy metals, but they think they can work with mercury as well. The leach process is proprietary, and it is not possible to even estimate whether it would be more economical or less economical than roasting.

Although existing technology (roasting) seems to be available, it is not evident that removal or excavation of mercury-containing soils is fully understood. Mercury metal is a DNAPL, and there is risk that mercury contamination will be spread in the same manner that PCBs can be spread. The potential for spreading of mercury depends on where it is and on the size of metal droplets. In any case, the excavation should be designed to remove the soil with as little fragmentation and shaking of the soils as possible.

3.7 PORTABLE TREATMENT SYSTEM FOR REMOVING RADIOACTIVITY FROM SMALL WATER EFFLUENTS

Development of a portable treatment system for removal of radioactivity from small water effluents was a high priority need for ORNL. The principal radioactivity is probably from strontium and cesium. There may be problems with tritium in some effluents, but that would have to be handled in a much different way. In fact, there may be no practical way to remove small concentrations of tritium from waste water or groundwater. Although all of these problems are given high priority for need, only the strontium and cesium problem will be given moderately high priority because of the probability of success. Tritium removal will rate low in that respect.

The problems with strontium and cesium removal include the relatively low separation that can be achieved from the other cations present in groundwaters and most effluent streams. Two of the other cations most likely to be present are calcium and sodium. Unfortunately, these cations behave much like strontium and cesium (respectively). The most likely removal systems would involve adsorption or ion exchange, probably the later, because of the small concentrations involved. Separation factors between the most similar pairs of ions are not likely to be much greater that 2 or 3. This is not enough to separate calcium or sodium from the strontium and cesium in a single column; therefore, considerable amounts of calcium and sodium (as well as magnesium, potassium, etc.) will also be removed from the water, increasing the waste volume when the resin is sent to disposal or when the resin is regenerated. The probability for developing an effective system is high, but the probability for finding highly selective ion-exchange materials is low. The priority for building and testing a small unit (which probably could later become at least part of the actual remediation device) is high, but the priority for searching for better selectivity is no more than moderate because of the limited probability for more than modest success. Tests should include regeneration or disposal of the resin and placement of the contaminant in a suitable waste form.

3.8 BETTER DRILLING METHODS FOR CONTAMINATED SOILS

The need for better ways to drill through contaminated soils was mentioned only by ORNL, but the need probably exists to a significant extent at other sites also. Manufacturing and other industrial firms should be encouraged to work on developing new drilling techniques. There are efforts under way to develop new drilling methods, particularly faster methods. There probably are fewer efforts to develop less disruptive drilling methods. Cone penetrometers have been mentioned before in this report. Because they do not remove material and because the surface of the penetrometer appears to be sealed by the tight fit of soil around the tube, this method is less likely to spread contamination vertically. Cone penetrometers can be useful in getting sensors into deep positions in the soil, but they do not remove a core for evaluation. One drilling approach that, like cone penetration, does not use a drilling fluid and minimizes disruption of nearby soil is sonic drilling. This technique, much like conventional drilling, pushes an open tube into the ground, but the tube is not rotated to cut into the soil. Instead, the tube is vibrated and punched into the soil. The tub is then filled with a core much as in conventional drilling. There is no cutting fluid, and there may be little spreading of contamination. The ability of such a technique to penetrate deep into hard rock and the complex soils at Oak Ridge may be questioned. To the author's knowledge, such a system has been tested only on relatively soft and sandy soils. However, if the technique could be used in the same environments as cone penetration, it may be useful at Oak Ridge.

Table 6. Summary of priorities

Need	Priority need	Priority likelihood	Priority work in progress
DNAPL detection	H[a]	M[b]	H
DNAPL remediation	H	M	H
Mercury detection in soils	H	M/H	H
Mercury remediation in soils	H	M	H
Mercury remediation in groundwater	M/H	H	H
Fixation of trenches	H	H	M
Characterization of subsurface structure and groundwater flow	H	M	M
Field sensors	M	H	M
Portable treatment of water for RAD	M	H	M
Improved drilling through contaminated soils	H	H	M

[a]H = high
[b]M = medium

4. ISSUES

Section 4 describes a few issues that are important in any development program on environmental problems. These issues are usually situations where optimization is needed. The aim of this discussion is to point out that there are often conflicting needs, and the optimum technology program must search for the way to best meet all of these needs. The purpose of this section is not to imply that the present program is not optimum, although it should be obvious that no program will be absolutely optimum, but to remind the readers of the factors that must be incorporated into technical decisions. If there is one theme to these issues, it is the need for informed and reliable technical judgment. A good understanding of the technologies is needed even to hire outside contractors. The more advanced the technology, the more advanced is the technical judgment needed to evaluate and select technologies and contractors.

4.1 SHORT-TERM VISION

Perhaps the greatest issue affecting the optimum use of RD&D funds for improving the performance and minimizing the cost of remediation is the short-term vision. Priorities are often forced by regulatory pressures. This means that the highest priorities must be determined by the necessity of meeting the next compliance requirement. Even the emphasis of needs studies on characterization may partially reflect the short-term vision. The time available may be too short to allow suitable R&D effort; there may not even be time available for an optimal demonstration.

The constant search for suitable technologies that have been developed elsewhere and can be applied immediately is desirable and appropriate, but it is inappropriate to rely totally on this approach. The needed technology simply may not be available, or it may not be fully evaluated. This may not mean that the compliance requirements cannot be met, but that excessive costs will be required to use conventional technology or to perform interim treatments that do not reduce the cost of ultimate treatment. Interim treatment may even increase the ultimate treatment cost. Placing large quantities of soil and sludges in temporary drums is one example of temporary solutions that may be costly in the long term. Problems can arise when available technologies are not fully evaluated. Failure of a technology because of failure to properly develop or test the technology can result in even greater long-term costs. The short-term vision may be most harmful when schedules are set that will not or cannot be met. In those cases, attempts to adhere to an unrealistic schedule can delay the necessary development of technology.

4.2 LONG-TERM PLANS

In some cases, technology development can be as hindered by long-term vision as it can by short-term vision. Developing plans for long terms can inhibit the development and testing of new technologies if the plans are taken too rigidly. Obviously, plans for remediation that is to take place in 10 or 20 years can be based only on current technologies. If the plans are over specified, they can make introduction of new ideas and new technologies difficult; then new development of improved methods can be discouraged, except possibly in the few cases where the costs are obviously unreasonable and needs for new methods are obvious. The existence of a plan to use a particular technology can obscure our lack of understanding of the technology.

4.3 EFFECTS OF LIABILITY ON TECHNOLOGY DEVELOPMENT

Within industry and the Environmental Protection Agency, there is a growing recognition that liability concerns can hinder innovation and encourage the use of older, more costly, and even less effective technologies. There may be less legal exposure for a company using standard technologies than for one trying new ideas. The legal risk that the innovative technology may fail or have negative consequence is obvious. There is risk even if the innovative technology is better than standard methods. For example, when neither standard technology nor innovative technologies perform as well as some people would like, the innovative approach could be more easily challenged than an established technology, even if it is better. Although personal legal liability may be of less concern to Energy Systems and DOE employees, there can be related concerns for professional careers.

4.4 SEPARATION OF TECHNOLOGY DEVELOPMENT FROM TECHNOLOGY USERS

Separation of management for long-term development from the users of the technologies presents important opportunities for eliminating duplication and concentrating the work at highly qualified institutions. It can also protect R&D efforts from overly frequent redirection caused by changing views of R&D needs. But it also makes it difficult for the development program to respond to even moderate-term changes in program needs. Consolidation of R&D into a single organization means that the development must focus on even longer-term problems because it is less likely that special studies can be initiated quickly to start looking at nearer term needs. Breaking up the development into Integrated Programs and Integrated Demonstrations may allow the program to focus relatively quickly on problems at one site, the host site for the program or demonstration, but is often of little help in speeding development toward solution of problems at other sites. Such integration may hinder initiation of R&D directed at nonhost sites because it is difficult to obtain R&D funds from outside the Integrated Demonstrations and Integrated Programs. When the principal problems to be addressed are at the host site, the net benefit of integration may be significant. When the problems are spread more evenly over the numerous DOE sites, there may be no benefits. The danger of provincial management of Integrated Programs and Integrated Demonstrations must be fought vigorously.

4.5 DEPENDENCE ON OUTSIDE CONTRACTORS FOR EXPERTISE AND TECHNOLOGY

Effective use of outside contractors requires either good understanding of the technology in use or much confidence in the contractor. It is not always safe to assume that a contractor will or can do what is expected. Even the potential for liability against the contractor will not ensure success if the contractor does not fully understand the problem. Contractors do not always adequately understand the complexity of ER problems, and the use of an outside contractor does not fully eliminate Energy Systems' and DOE's liability for unacceptable performance. Environmental laws hold the generator of wastes or the owner of properties as well as hired contractors responsible for correcting problems; thus it is necessary for Energy Systems and DOE to be fully aware of the potential for success of all treatment actions. Availability of technologies from outside contractors needs to be assessed with sufficient care that there is reasonable confidence that the desired goals will be achieved. In many cases, this means that testing of contractor technologies will be desirable; in other cases, it means that expert technical oversight will be needed. The issue of contractor performance is particularly important for those situations where correcting a poorly completed job would be more costly and difficult than doing the job right in the first place. In other cases, inaccurate characterization work can result in excessive costs because problems were either over- or underestimated.

4.6 EXCESSIVE STRESS ON DEMONSTRATION OVER R&D

The desire to obtain quick answers results in a desire for a quick demonstration that will solve problems. This feeling can be encouraged by contractors who are eager to promote their particular capabilities. The greatest danger in excessive reliance on short demonstrations results when the demonstration does not fully evaluate all aspects of the problem. When there is much to learn about the technology, demonstrations are usually expensive ways to obtain the information because of the size of equipment and the number of people usually involved. Developing technologies should be carried out in the most cost-effective way. Time, costs, and effectiveness can represent conflicting goals. Failure to allow sufficient time for developing and evaluating technologies can result in increased environmental risk as well as additional cost if the underdeveloped technology fails to meet the required goals. It is in the best interests of both DOE and the regulatory agencies that milestones be set properly so that the optimum development work can be done. There are notable examples on the Oak Ridge Reservation where the rush to meet schedules has resulted in problems that had to be corrected later at a greater cost. In the future, there could be similar problems that result in greater environmental risk. It will always be difficult for DOE and regulatory agencies to set optimal schedules that allow for proper development and testing but do not permit unnecessary procrastination or delays. Establishment of optimal schedules requires excellent judgment by all involved.

Demonstrations are an expensive way to evaluate a range of treatment variables. It is more efficient to explore the importance of variables such as variations in groundwater composition or in soil properties using small-scale equipment. Demonstrations should follow good and complete development programs and simply verify that important parameters have not been overlooked. Demonstrations should be as short as practical while demonstrating all uncertain aspects of a treatment. When time constraints require a rush directly to a demonstration, either higher costs will be necessary to explore the important variables, or all of these variables will not be explored.

4.7 SEGMENTATION OF RESPONSIBILITIES

Separation of restoration responsibilities into segments that are too small can leave units with insufficient benefits of technology to justify the cost of development, even when there is obvious justification within the entire DOE system or even within the Oak Ridge system. Even when there is sufficient justification, too much fragmentation can result in duplication. DOE is making great efforts to transfer technologies between sites, which involves frequent meetings and technology exchanges between sites. That this necessary exchange requires continuing effort and time must be recognized. Because two different groups of people are involved in the Environmental Restoration (EM-40) and Technology Development (EM-50) programs, it is of particular importance that adequate transfer of information and technologies between these two programs be made. The danger that technologies will be lost in this transition may place an additional burden on the EM-50 research people who develop the technology to ensure that the knowledge is adequately disseminated.

5. CONCLUSIONS

There are several known needs at all of the Energy Systems sites for new technologies to carry on the mission of the ER Program Division to correct the environmental problems at these sites. In some cases, there are no known or tested technologies available to meet these needs. Characterization and cleanup of DNAPL-contaminated sites is one example; isolating buried waste trenches from groundwater is another. In other cases, the cost and time required to use current technologies do not appear to be acceptable. Better characterization methods were cited that can locate pollutants and buried wastes to minimize the amount of soil and other materials treated. It is especially important that technologies be sufficiently well developed that the danger of failure and more costly repeated treatment is reduced to acceptable limits.

Better technologies are also needed to reduce the risk of using current technologies. This is evidenced by the frequent citation of the need for better characterization methods. Failure to detect a pollutant represents a risk to the environment and possibly to the public. Failure to understand groundwater flow can result in transport of pollutants to sensitive parts of the environment. Use of inadequately developed technology results in greater risks that the results will be inadequate and thus create a more serious problem.

The technology requirements reported by the various Energy Systems sites reflects the necessity of addressing immediate needs. Many environmental activities have to be focused on characterization, and this is reflected in the needs mentioned by the sites. A large portion of the funds spent on ER at Energy Systems and most Superfund sites has been for characterization and temporary solutions to the problems. These efforts have been necessary both to prevent further spread of contamination and to meet regulatory requirements. However, dirty closures and other temporary measures require continuous monitoring and sometimes even continuous treatment. Eventually we will need to seek better and permanent solutions to the environmental problems. There should be an increasing desire to seek permanent solutions where possible, and this is more likely to require more extensive treatment and new technologies. Otherwise, the long-term cost for maintaining the Energy Systems sites (as well as other DOE and industrial sites) will certainly become excessive. Some R&D for long-term solutions is being considered, and the interest in those needs is expected to grow in the coming years.

ACKNOWLEDGMENTS

Information was supplied from the ER Site Programs by Robert Poling, Marc Norris, Jerry Kuhaida, Doug Davenport, and Walter Richards. That information was the core of this report, and their help is greatly appreciated. The report was reviewed by Ken Cook, Bruce Kimmel, Willie Brown, Richard Snyder, Dennis Cope, and their staff, who had several helpful suggestions. Julia Spradling prepared the manuscript, Pam Wood formatted the report, and Pam Shamblin and Kathy Swain edited the report and included numerous helpful comments.

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