



Department of Energy
Office of Environmental Management (DOE-EM)

2009 DOE-EM Long-Term Monitoring Technical Forum



"Improving the Long-Term Monitoring Paradigm"



Office of
Environmental Management

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Summary Report

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**2009 DOE-EM
Long-Term Monitoring
Technical Forum**

February 11-12, 2009

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Summary Report

September 2009

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EXECUTIVE SUMMARY

The U. S. Department of Energy's (DOE) Office of Environmental Management (EM) has the responsibility for cleaning up 60 sites in 22 states that were associated with the legacy of the nation's nuclear weapons program and other research and development activities. These sites are unique and many of the technologies needed to successfully disposition the associated wastes have yet to be developed or would require significant re-engineering to be adapted for future EM cleanup efforts.

In 2008, the DOE-EM Engineering and Technology Program (EM-22) released the *Engineering and Technology Roadmap* in response to Congressional direction and the need to focus on longer term activities required for the completion of the aforementioned cleanup program. One of the strategic initiatives included in the *Roadmap* was to enhance long term performance monitoring as defined by "Develop and deploy cost effective long-term strategies and technologies to monitor closure sites (including soil, groundwater, and surface water) with multiple contaminants (organics, metals and radionuclides) to verify integrated long-term cleanup performance." To support this long-term monitoring (LTM) strategic initiative, EM 22 and the Savannah River National Laboratory (SRNL) organized and held an interactive symposia, known as the 2009 DOE-EM Long-Term Monitoring Technical Forum, to define and prioritize LTM improvement strategies and products that could be realized within a 3 to 5 year investment time frame. This near-term focus on fundamental research would then be used as a foundation for development of applied programs to improve the closure and long-term performance of EM's legacy waste sites.

The Technical Forum was held in Atlanta, GA on February 11-12, 2009, and attended by 57 professionals with a focus on identifying those areas of opportunity that would most effectively advance the transition of the current practices to a more effective strategy for the LTM paradigm. The meeting format encompassed three break-out sessions, which focused on needs and opportunities associated with the following LTM technical areas: (1) Performance Monitoring Tools, (2) Systems, and (3) Information Management.

The specific objectives of the Technical Forum were to identify: (1) technical targets for reducing EM costs for lifecycle monitoring; (2) cost-effective approaches and tools to support the transition from active to passive remedies at EM waste sites; and (3) specific goals and objectives associated with the lifecycle monitoring initiatives outlined within the *Roadmap*.

The first Breakout Session on LTM performance measurement tools focused on the integration and improvement of LTM performance measurement and monitoring tools that deal with parameters such as ecosystems, boundary conditions, geophysics, remote sensing, biomarkers, ecological indicators and other types of data used in LTM configurations. Although specific tools were discussed, it was recognized that the Breakout Session could not comprehensively discuss all monitoring technologies in the time provided. Attendees provided key references where other organizations have assessed monitoring tools. Three investment sectors were developed in this Breakout Session.

The second Breakout Session was on LTM systems. The focus of this session was to identify new and inventive LTM systems addressing the framework for interactive parameters such as infrastructure, sensors, diagnostic features, field screening tools, state of the art characterization monitoring systems/concepts, and ecosystem approaches to site conditions and evolution. LTM systems consist of the combination of data acquisition and management efforts, data processing and analysis efforts and reporting tools. The objective of the LTM systems workgroup was to provide a vision and path towards novel and innovative LTM systems, which should be able to provide relevant, actionable information on system performance in a cost-effective manner. Two investment sectors were developed in this Breakout Session.

The last Breakout Session of the Technical Forum was on LTM information management. The session focus was on the development and implementation of novel information management systems for LTM including techniques to address data issues such as: efficient management of large and diverse datasets; consistency and comparability in data management and incorporation of accurate historical information; data interpretation and information synthesis including statistical methods, modeling, and visualization; and lineage of data to site management objectives and leveraging information to forge consensus among stakeholders. One investment sector was developed in this Breakout Session.

Based on the investment sectors identified by the Breakout Sessions, the Technical Forum participants were asked to identify and prioritize those near-term areas to improve the current LTM paradigm. A total of six LTM investment sectors were identified by the three Breakout Sessions. The top four investment sectors chosen by the investment totals allocated by the exercise's participants included, in order of most to least, (1) "DOEgle Environment," (2) *Subsurface Remote Sensing and Non-Invasive Techniques*, (3) *Compliance to Performance Monitoring*, and (4) *Bioindicators as Leading LTM Indicators*.

The fundamental objective in cleaning up and closing a legacy waste site is to achieve performance that will protect the surrounding environment with a long-term focus on health and human safety. LTM is key to verifying the long-term performance with these engineered closure systems. Toward addressing the reduction of the technical risks and uncertainties identified in the 2008 *Roadmap*, the participants at the 2009 LTM Technical Forum recommended five initiatives. For each initiative, the anticipated outcomes and benefits have been described, and a Federal Initiative Manager will be named who will develop additional details on the scope and schedule of each initiative. These five initiatives are intended to contribute to the near-term improvement of the LTM paradigm, and thus to ensure DOE's success in cleaning up the legacy waste sites.

INTRODUCTION



The U. S. Department of Energy's (DOE) Office of Environmental Management (EM) has the responsibility for cleaning up 60 sites located in 22 states, which collectively encompass over 200 subsurface contaminated plumes. These sites were variously associated with the legacy of the nation's nuclear weapons program as well as other DOE research and development activities. "Protecting the environment by providing a responsible resolution to the environmental legacy of nuclear weapons production" is one of DOE's five strategic themes (DOE 2006). The primary challenge related to the cleanup of these sites and achieving the resolution of that associated strategic theme is driven by important fundamental questions that remain largely unanswered. These would include questions such as:

- What and how does one monitor to ensure that a closure system is performing correctly?
- What are the risks to the human and natural environments if that system fails?
- Can one realistically expect these systems to continue working and be sustainable for possibly up to tens of thousands of years?

Within DOE the terms "environmental stewardship" and "long-term stewardship" refer to the mechanisms necessary to ensure both short- and long-term protection of the public and the environment after initial cleanups at facilities in the DOE Complex have reached closure.

These mechanisms include physical and institutional controls, information management, environmental monitoring, and risk assessment. The U. S. Department of Defense (DoD) faces similar issues in the post-closure period of its cleanups. The emergence of "stewardship" reflects a shift in the federal view from the short-term cleanup perspective of the past decade to a focus on the long-term performance of remedies and the effects of residual contamination at cleanup sites decades from now. Stewardship encompasses many daunting technical issues, including:

- Understanding and monitoring material deterioration in barriers and closure systems,
- Managing and maintaining critical information systems with access for future generations, and
- Sensing and accessing changes in site risks over decades.

The need to reduce the costs of stewardship, while providing acceptable risks to the public, drives DOE to create new approaches.

The DOE's contaminated sites are unique in three ways as follows: (1) huge physical footprint size, (2) types of waste (mixed radiation/chemical), and (3) quantities of waste (Gochfeld et al. 2007). Many of the programs to treat, dispose and monitor these waste types and volumes unique to DOE have been "first-of-a-kind" and,

as such, are unprecedented in their scope and complexity. The successful closure of these waste sites so that human and ecological exposure is limited for extremely long periods of time represents an unprecedented engineering challenge. This has meant that many of the technologies needed to successfully disposition these wastes have yet to be developed or require significant re-engineering to be adapted for EM's cleanup efforts. As such, DOE faces a long-term and costly challenge to assure sustainable protectiveness at these sites. This will include not only traditional risk methodologies, but also the assessment and surveillance necessary for stewards for long-term monitoring (LTM) of risk from historic and future exposure to maintain that sustainable protectiveness (Gochfeld et al. 2007).

Although great steps forward has been made toward safely disposing of this legacy waste, much remains to be done. The unique nature of many of the remaining challenges will require a strong and responsive applied research and engineering program. To address these needs, DOE-EM has placed this responsibility within the Engineering and Technology Program (EM-22). Part of EM 22's mission is to provide DOE with the best-in-class engineering foundation, technical assistance, and new technologies to reduce costs and schedules for completion of the DOE mission to successfully disposition legacy waste and close the associated sites.

In a recent report (NRC 2005), the National Research Council recommended that "an improved capability for environmental monitoring would strengthen EM's plans to leave waste and contaminated media at DOE sites." In addition, the report stated that "Monitoring systems at EM closure sites have been estimated to be some 25 years behind the state-of-art." Reliable and scientifically-sound LTM of these closure sites is necessary to verify the successful performance of the implemented cleanup. LTM activities consist primarily of ensuring that use restrictions remain in force and maintaining site integrity to protect public health and the environment. Environmental LTM is a critical component of legacy waste site cleanup/closure for three reasons: (1) data provide ongoing evidence of environmental compliance and protection of the public and the environment; (2) the monitoring program, in part, determines the life cycle cost and extent of stewardship; and (3) the monitoring program provides a framework to develop trust and agreement between the site steward, stakeholders, and public (Moore et al. 2001). Many of these cleanup efforts will require the need for extensive monitoring and long-term stewardship actions, including surveillance

and maintenance of installed structures and systems. In most cases, these sites will have to continue to maintain surveillance/maintenance and environmental monitoring activities to ensure regulatory compliance for an unspecified number of years in the future. Such efforts are not insignificant, with typical LTM costs estimated to be over one-third of the total life-cycle cost of cleanup at most DOE sites. To be successful in these cleanup efforts, the strategies and technologies supporting the LTM paradigm to be used by EM must be improved.

In 2008, prepared in response to Congressional direction and the need to focus on longer term activities required for the completion of the cleanup program, EM-22 released the *Engineering and Technology Roadmap* (DOE-EM 2008), which detailed thirteen strategic initiatives aimed at reducing the technical risks and uncertainties associated with cleaning up legacy waste over the next ten years. The *Roadmap* also proposes how these strategies would be implemented. Within the Integration and Cross Cutting Initiatives Program Area, one of the Technical Risk and Uncertainties in Assessing Long-Term Performance was that "Inadequate long-term monitoring and maintenance strategies and technologies to verify cleanup performance could potentially invalidate the selected remedy and escalate cleanup costs." The associated strategic initiative to enhance long term performance monitoring was to "Develop and deploy cost-effective long-term strategies and technologies to monitor closure sites (including soil, groundwater, and surface water) with multiple contaminants (organics, metals and radionuclides) to verify integrated long-term cleanup performance." To support this cross-cutting initiative from the *Roadmap*, EM-22, in collaboration with the DOE Offices of Science and Legacy Management (LM), decided to host an interactive forum to identify technical solutions that would advance the LTM paradigm for EM waste sites. The overarching goal of this technical forum was to define and prioritize EM strategies and products that could be realized within a 3 to 5 year investment time frame. This near-term focus on fundamental research would be used as a foundation for directed research and development efforts in the longer-term, which would be directly and immediately transferred to the applied programs.

The "2009 DOE-EM Long-Term Monitoring Technical Forum," sponsored by DOE-EM and the Savannah River National Laboratory (SRNL), was held in Atlanta, GA on February 11-12, 2009. The meeting was attended by 57 professionals (see Fig. 1; Appendix A) with a focus on identifying those areas of opportunity

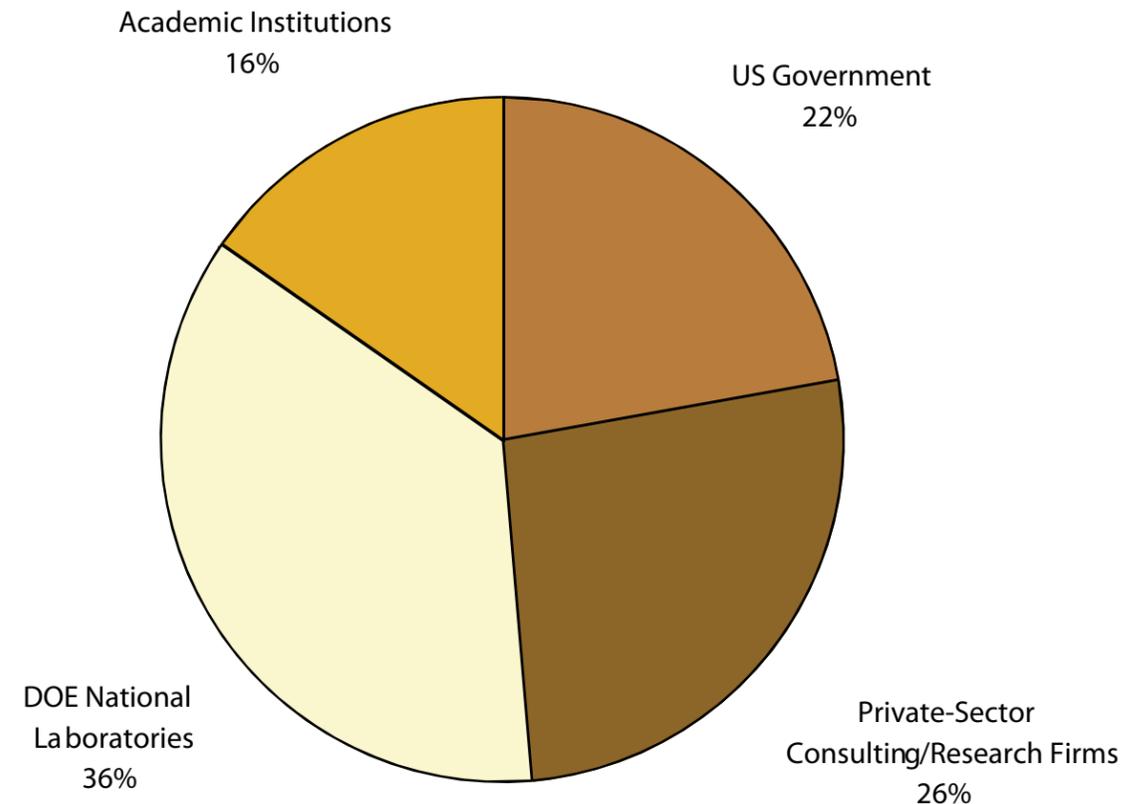


Figure 1. Attendee affiliations at the 2009 DOE-EM LTM Technical Forum.

that would most effectively advance the transition from current practices to a more effective LTM strategy. The meeting was accomplished through three break-out sessions, which focused on needs and opportunities associated with the following LTM technical areas: (1) Performance Monitoring Tools, (2) Systems, and (3) Information Management. The results of the Breakout Sessions were consolidated into initiatives and presented to the overall group for review and recommendation.

The specific objectives of the Technical Forum were to identify:

- Technical targets for reducing EM costs for life-cycle monitoring, which typically represent as much as one-third of the overall life-cycle estimate for EM waste sites;

- Cost-effective approaches and tools to support the transition from active to passive remedies, such as monitored natural attenuation (MNA), at EM waste sites; and
- Specific goals and objectives associated with the lifecycle monitoring initiatives outlined within the *Roadmap*.

This report represents the summary document of the results of the Technical Forum as well as the recommended initiatives that were developed during the Breakout Sessions. The Technical Forum was also evaluated by the participants as to the structure, scope and success. The results of that evaluation are provided in Appendix B.

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BACKGROUND



Throughout EM's history, over one-third of the "needs statements" collected from the EM operating divisions have been related to technologies to support verification and validation of remedial performance (Looney 2002). About half of those needs were for improvements of sensor and detection methods for specific contaminants. The remainder of the needs were for general detection capabilities, system infrastructure, and sensors/systems for hydrogeologic parameters, microbiology/geochemistry processes, fluxes, and surrogate parameters. This latter grouping may be of particular interest for LTM applications. All of the contaminated ground water plumes identified in the DOE complex will require verification of cleanup and acceptable risk performance over tens of years beyond final cleanup at a total projected cost in excess of \$2 billion. Much of this cost is associated with frequent analyses of contamination in a large number of monitoring wells. Such measurements are expensive and the resulting datasets have been determined to be inefficient and often inadequate for meeting LTM objectives. The tabulated cost above does not include closure monitoring of Uranium Mill Tailings facilities, or vadose zone soil at remediated sites, landfills or other engineered containment units. All remediated facilities or sites require comprehensive, but cost effective, LTM activities. Additionally, stakeholders will expect updated assurances of continued closure status and that they are "safe."

In response to these challenges, EM operating contractors have worked with regulators to implement several types of improvements in LTM systems. These improvements include: (1) developing and negotiating "Area Closure" strategies; and (2) application of statisti-

cal and scientific tools to optimize monitoring networks, sampling frequency, and data interpretation. Area Closure strategies support improving future efficiency monitoring by combining efforts for co-located and closely spaced facilities. System optimization methods have yielded significant benefit by reducing sampling and analytical costs. Importantly, the potential for continued improvement using these two strategies is constrained by their tight linkage to traditional monitoring well based systems. Thus, technical challenges and opportunities remain in EM LTM activities, primarily in expanding monitoring approaches to allow alternative but improved paradigms. The need for such development is highlighted in several recent independent reviews of DOE-EM programs by the National Research Council of the National Academies (e.g., NRC 2000, 2005a, 2005b).

A central tenant of the EM applied science program related to LTM is developing systems to provide straightforward and compelling information at a reasonable cost. An expanded set of technologies that go beyond traditional well networks and periodic sampling are envisioned as described below. The primary consideration in selecting and assembling technologies for monitoring is the conceptual model for the site and the conceptual model for the contaminant and associated risk. In each case, the monitoring system should focus on the factors that demonstrate that the system is "in control" and the factors are causing the contaminant to behave as expected. In the case of metals and radionuclides, for example, many plumes are relatively stable and further migration of the contaminants is governed by the geochemical gradients. In this scenario, an effective moni-

toring strategy would focus on documenting the status and evolution of the geochemical gradient over time.

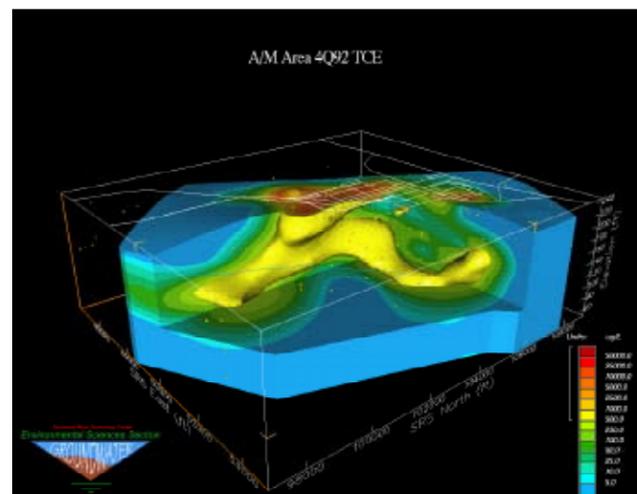
The challenges faced by DOE in verifying the performance of EM actions are shared with the commercial nuclear industry, DoD installations, and chemical manufacturers and users. Thus, the proposed applied science developments in the EM program will be coordinated with the Nuclear Regulatory Commission, federal agencies (e.g., Environmental Protection Agency, U. S. Geological Survey, and DoD), state regulators and representatives such as the Interstate Technology and Regulatory Council, and stakeholder groups. This is particularly important for challenging scenarios such as sites where predicted transport timeframes are centuries or millennia.

The following are specific examples of the general direction and topics currently identified in the DOE-EM applied science needs portfolio:

- Develop and apply approaches to validate performance of active remediation, isolation, or natural attenuation strategies over long timeframes.
- Increase use of integrating measurements (e.g., remote sensing, geophysics, and flux) – this will be one tool in addressing heterogeneity.
- Optimize LTM strategies [i.e., what, where, how often, how accurate, and how expensive to measure and with what sensor(s)]. Encourage appropriate use of screening techniques and field methods to reduce overall costs.
- Expand LTM beyond traditional monitoring wells. This includes ecosystem monitoring, biomarkers, biological monitoring, and boundary condition monitoring (i.e., weather, streamflow, evapotranspiration, etc.).
- Build tracers, markers and/or engineered features into remediation systems to provide direct measures of performance or early warning of failure. Encourage the development and application of surrogates and indicator parameters.
- Develop approaches and durable sensors for measuring contaminant concentrations, key processes/transformations, or relevant proxies over field relevant scales.

- Improve cybersystem to provide a current or support a future living database for data storage and visualization that is integrated with analysis tools.
- Formalize protocols to revise conceptual/numerical models and to refine remedial approaches based on information provided by LTM datasets.

The key to closing and transitioning a waste site into an LTM program will rely on the confidence that the regulators and stakeholders have in the remedy or containment system. This confidence will be built on having a predictive capability of the long-term effects, identification of failure indicators and a reliable monitoring system that can detect these indicators. In order to develop a cost-effective system, the monitoring of failure indicators must be gathered by passive or simple field screening methods. These systems must be highly automated or rapid and low cost. They must screen for changed conditions in a manner that is easy to understand and present. The information must be made available at a central location for further analysis and archive. A high degree of automation can be achieved through the synergistic combination of sensors for measurements and periodic multidimensional measurements to provide information between the measurement points. The design of an LTM system should enhance confidence in the system being monitored. Stakeholders and regulators need authenticated and scientifically-defensible information that remedial actions ensure the safety of future generations. Gathering, archiving, analyzing and most importantly, openly distributing information, builds trust.



BREAKOUT SESSION SUMMARIES



The results of the three LTM Breakout Sessions, (1) Performance Measurement Tools, (2) Systems, and (3) Information Management, are summarized in the following sections. The participants in the Breakout Sessions were provided with the following guidelines:

- Consider successful monitoring efforts employed in related fields (e.g., agriculture, oceans/ fisheries, fires, hurricanes, etc.) and in other agencies and organizations (e.g., NASA, USDA, NOAA, EPA, USGS, etc.);
- Try to expand discussion beyond current paradigms;
- Consider new and alternative concepts to serve as the basis for monitoring system design (e.g., mobile versus “immobile,” contaminants that are controlled by an evolving geochemical gradient, ...);
- Summarize and document both strengths and weaknesses of ideas that are put forward; and
- Overall, remember the unique challenges faced by LTM systems (e.g., as noted by Paul Johnson when describing subsurface monitoring: “It’s dark down there”).

The participants in the Breakout Sessions were also asked to:

- Identify traditional approaches, alternatives and emerging ideas within topic;
- Tabulate strengths and weaknesses and synergies;
- Identify 2 to 3 investment sectors (i.e., initiatives) within each topic; and
- Identify issues for other teams (share and discuss as needed).

LTM Performance Measurement Tools



Session		
Participants:	Brooke Traynham, Co-Chair David Esh, Co-Chair Vince Adams Joanna Burger Ann Clarke Jim Clarke Jay Cornish Dan Kaplan Jay McArthur Carl Miller Tom Nicholson	Mike Paller Charles Poweres Roger Seitz Becky Sharitz Ray Siegener Karen Skubal Terri Stewart Yi Su Dave Watson Latrincy Whitehurst



The focus of the first Breakout Session, LTM performance measurement tools, was on the integration and improvement of LTM performance measurement and monitoring tools that deal with parameters such as ecosystems, boundary conditions, geophysics, remote sensing, biomarkers, ecological indicators and other types of data used in LTM configurations. The Breakout Session had 21 participants covering a variety of organizations and a broad variety of technical disciplines. The goal of the session was to identify alternatives or options for improving the existing LTM paradigm with respect to the performance measurement tools employed or envisioned. Initially, the session included presentations and discussion on system level concepts in order to provide context for presentations and discussion on individual tools and technologies. The attendees agreed that selection of monitoring tools should be based on mitigating technical and decision risk. In order to effectively do this, initially some form of analysis must be performed to identify key monitoring areas and associated indicators. Attendees also agreed that the process should be iterative, such that monitoring observations can be used to improve analyses and could, in theory, result in changes of focus or direction to the overall monitoring program. Without changes to regulatory requirements, changing the process and implementation of LTM will be impeded.

Indicators should focus on those items that can mitigate decision risk and are of most concern to key stakeholders. In order to be most effective at achieving these goals, the LTM process should optimize the selection of indicators and associated tools because the optimum set should be defined globally for the monitoring system and decision and not locally for a particular component or process. The indicators should be leading, provide early warning of unanticipated changes to system conditions, and at appropriate temporal and spatial scales. LTM tools should have as many of the following characteristics as possible:

- Be remote, robust, durable, non-intrusive, and cost-effective;
- Cover appropriate spatial scales;
- Aggregate properties; and
- Align with stakeholder concerns.

The Breakout Session included a variety of presentations on particular tools and technologies (see attached CD). The presenters and attendees were asked to consider the following questions with respect to the tools:

- Can the tool be applied remotely?
- What scale does the tool address (temporally and spatially)?
- What properties does it measure? (indicators)
- If it uses embedded sensors, how long will they last? How durable is the tool?
- How labor intensive is the collection of information?
- What resolution does the technique have?

- Does it provide a measure of performance or an inference of performance?

Although specific tools were discussed, it was recognized that the Breakout Session could not comprehensively discuss all monitoring technologies in the time provided. Attendees provided key references where other organizations have assessed monitoring tools (e.g., Burger 2006, Burger and Gochfeld 2001, Ho et al. 2004, Malusis and Benson 2006, Versteeg and Johnson 2008).

For organizational purposes, tools are grouped into two general categories: traditional and remote sensing. Traditional monitoring tools have a longer track record of use than remote sensing tools and provide direct high resolution on-the-ground measurements. However, traditional tools are: (1) limited in their long-term durability, subjective to impacts that may compromise equipment integrity, and (2) labor intensive. Traditional monitoring tools have historically been used for both surface and subsurface processes including ecological, hydrological, and structural components. Remote sensing technologies (e.g., satellite imagery, Lidar) have potential to serve as a vital component in an LTM toolbox by collecting regular data over large areas, for long periods of time. An area of key interest is in coupling remote sensing technology with high-resolution ground sensors.

Sensors may be useful to measure hydrological components, gases, structural components, and biogeochemistry. Sensors can be used in networks to cover large areas and can be integrated with “smart” chips to assist in data management/filtering. The relevancy of subsurface sensors is determined by the extent to which the subsurface processes of interest affect the properties sensed by the sensor. Incorporating sensor technologies into LTM plans is inhibited by the nature of sensors to break easily, have high costs, and lack environmental sensitivity.

Ecological monitoring tools include sensors; however, this type of tool also should include bioindicators. Bioindicators are temporally robust, measure cumulative impacts, and have relevance to stakeholders. They are limited in their ability to serve as leading indicators and represent an indirect measurement of the system.

LTM Performance Measurement Tools Investment Sectors

The investment sectors developed in the LTM Performance Measurement Tools Breakout Session included the following:

- *Surface Techniques* - Improvement of surface remote sensing and non-invasive techniques (e.g., translating biotic changes at the surface into identifying subsurface changes).
- *Subsurface Techniques* - Development of techniques to remotely and non-invasively provide subsurface hydrology, chemistry, and structural conditions.
- *Bioindicators* - Improvement/study of bioindicators as leading and long-term indicators.

LTM Systems



Session		
Participants:	Dave Roelant, Co-Chair Roelof Versteeg, Co-Chair Bob Aylward Craig Benson Tyler Gilmore	John Gladden Jack Mayer Mark Peterson David Shafer Jody Waugh

The second Breakout Session was on LTM systems. The objective of the LTM systems workgroup was to provide a vision and path towards novel and innovative LTM systems, which should be able to provide relevant, actionable information on system performance in a cost-effective manner. More specifically, this group both discussed the current state-of-the-art of LTM systems, as

well as approaches, paradigms and frameworks associated with novel systems. This session was attended by 10 participants representing a variety of organization and backgrounds.

LTM System Definition and Scope - An LTM system (LTMS) is defined as the combination of elements which provide regulatory compliance and system performance information on contaminated sites or locations to regulators and stakeholders. Elements of a LTMS typically include:

- Sensors and supporting infrastructure used for data collection;
- Enabling cyberinfrastructure (data management, analysis and visualization tools, reporting tools);
- Data reduction and analysis efforts (including the use of conceptual and numerical models); and
- Reporting.

Within DOE, LTMSs typically will be used for four different types of contaminated systems:

- Caps and covers (i.e., engineered systems),
- Highly concentrated source zones (e.g., ponds, bldg structure left, cribs, USTs, etc.),
- Engineered remediation systems (e.g., enhanced attenuation, PRBs), and
- Large “diffuse” contaminated sites.



Each of these systems (and each specific instance of these systems) has unique attributes and risks associated with it. Thus, to some extent each LTMS will be customized to a specific site. However, it is the feeling of the working group that the underlying paradigms and

approaches to LTMS are for a large part identical for all systems.

State of the Art - The state of the art described here represents a consensus high-level view of the Technical Forum attendees of what is currently occurring at ongoing DOE LTM sites.

Current LTMS efforts typically consist of point measurements that are compliance driven, followed by reporting of the results of these point measurements in a graph or table format to regulators and stake holders. The compliance thresholds are typically set only once, with this being accomplished through a negotiation between regulators and DOE.

Current LTMS efforts typically do not include:

- Use of decision support tools, risk and site conceptual models to inform design and operation of LTMSs;
- Prediction of system behavior in the short and long term through either analog sites, conceptual or numerical models and/or use of data to provide improvement to models of the system;
- Data collection or analysis focused on quantifying or understanding overall system performance (including that caused by sporadic high impact events); and
- Incorporation of the effect of the natural ecosystem (watershed, area of influence around sources, etc.) on the contaminated system.

Ideal LTMS Attributes - The consensus by the Technical Forum attendees was that by focusing on regulatory compliance monitoring (and not including any of the items listed above), LTMSs are substantially less efficient than they should and could be. In addition, the cost/benefit ratio of LTMS is less than what is possible.

The discussion about what was missing from current systems led to the development (at the Technical Forum) of a bulleted list of “ideal” LTMS attributes. This list is given in Appendix C of this report for the reader to consult. Note that there is significant overlap between some of these attributes. While minimal editing of this list was done for clarity and to remove duplications after the Technical Forum, the objective of presenting this list here “as is” is to communicate the range of different ideas.

Based on this list of ideal LTMS attributes and a discussion among the attendees, the Breakout Session came to the conclusion that an LTMS paradigm shift is needed. Consequently, the group laid out a path toward new LTMS.

LTMS Novel Paradigms - The attendees concluded that novel paradigms are needed in the design and operation of LTMSs. Specifically, future LTMSs should:

- Shift from compliance monitoring to whole system (i.e., watershed, disposal facility + ecosystem) performance monitoring;
- Move to a risk-based decision process for entire LTM system; and
- Actively use decision support tools, risk and site conceptual models to inform the design and operation of LTMS.

Path Forward for Developing Next Generation LTMS and Associated Investment Areas

- It is clear that translating the novel paradigms listed above into a fieldable LTMS that has part of all of the attributes listed in Appendix C will be challenging for several reasons, including but not limited to regulatory acceptance, potential initially higher cost, lack of tools, and buy in from the applicable DOE-EM operations or field office. In addition, achieving a system which has all of the attributes identified by the Technical Forum participants in the first iteration will be impossible.

Thus, a path forward is envisioned in which DOE-EM would focus on two investment areas. One should note that both of these areas will require close collaboration with regulators and stakeholders.

LTM Systems Investment Sectors

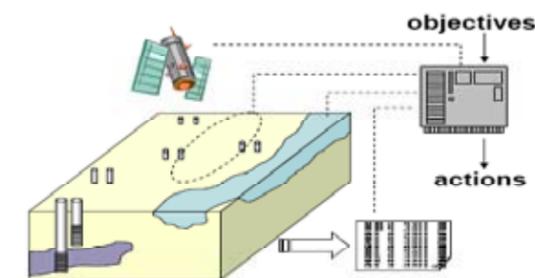
The two investment sectors developed in the LTM Systems Breakout Session included the following:

- *Compliance to Performance* - The objective of this investment area would be to field demonstrate the benefit and feasibility of a shift from compliance driven monitoring to performance monitoring. This likely would occur on an active or new LTMS. Within this area several objectives could be pursued simultaneously, for instance, demonstrate the ability to refine long-term remedy system performance monitoring iteratively, evaluate the accuracy and validity of different monitoring and predictive tools, and develop integration between risk and

performance models.

- *Point to Landscape Measurement* – The objective of this investment area would be to field demonstrate the benefit and feasibility of a shift from point measurements to landscape scale measurements. This likely would occur on an active LTMS. For example, research in this area could include how macroscopically observable ecological parameters can be used as leading indicators of system performance, how such parameters are related to smaller scale observations, and how natural analogs can be used to predict long-term system performance.

LTM Information Management



Session Participants:	Ann Miracle, Co-Chair Mindy Vanderford, Co-Chair Dave Becker Rich Bush Kirk Cameron Tony Carter Skip Chamberlain Jenny Chapman David Dougherty	Mark Freshley Andrea Hart Tim Jannik Brian Looney John Morse Bobbie-Jo Webb-Robertson Kathy Yeager
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The third Breakout Session of the Technical Forum was on LTM information management. The session focus was on the development and implementation of novel information management systems for LTM including techniques to address data issues such as: efficient management of large and diverse datasets; consistency and comparability in data management and incorporation of accurate historical information; data interpretation and information synthesis including statistical methods, modeling, and visualization; and linkage of data to site

management objectives and leveraging information to forge consensus among stakeholders. The information management Breakout Session had 16 participants.

The goal of information management is to collect, organize, analyze, archive, and communicate information to serve diverse populations over the long term. Effective information management is central to the task of long-term environmental care of DOE sites. Long-term environmental monitoring data are required to confirm the protectiveness of environmental remedies, evaluate ecosystem restoration and provide assurance of safe conditions for human and ecological communities.



The Information Management Forum (IM) Breakout Session was convened to provide suggestions for the development and implementation of efficient information management systems for LTM across the DOE complex. The IM Breakout Session topics include approaches and techniques to address issues such as:

- Efficient management of large and diverse datasets;
- Consistency and comparability in data handling and incorporation of accurate historical information;
- Accessibility of relevant data to stakeholders in a timely fashion;
- Data interpretation and information synthesis including statistical methods, modeling, and visualization; and
- Linkage of data to site management objectives and leveraging information to forge consensus among stakeholders.

Environmental information management challenges at DOE center around communication between and within agencies in transition, and effective technology transfer for sites entering LTM. The program faces challenges establishing database systems that can accommodate large quantities of diverse data in evolving formats. Additional challenges include providing useful user interfaces and analysis options to distill monitoring output to a level that can be interpreted by and communicated to stakeholders easily. Tools to analyze and distill data must be flexible enough to adapt to change in data input and evolving environmental support objectives. A five-year vision for addressing these challenges seeks to leverage existing cyber-infrastructure, provide guidance for addressing management and communication deficiencies, and establish data management tools for integrating environmental operations.

The IM Breakout Session has identified six major categories of challenges presented by current environmental information management practices at DOE. These are discussed in the following paragraphs:

Relevancy of data: *Effective environmental management decisions are supported by the right type and quantity of data delivered in a timely fashion.* Currently, environmental data collection is driven by regulatory compliance, management inertia or a “one-size-fits-all” approach and often, is not tied to specific management objectives. Several types of inefficiencies result from failure to ‘right-size’ data collection. Too much unstructured data can overwhelm decision-makers and divert focus from important issues. Too little of the right type of data can cause decisions to be made without adequate support or confidence. Data are not collected in a vacuum, and ancillary, supporting information relevant to a method or to the site is often not preserved. Missing details of how the data were collected can make interpretation and comparison of data over time extremely difficult. Historically, data have been condensed into formats that made sense at the time, but critical support information has been lost reducing its long-term usefulness.

Curation/Archiving: *Data must be maintained in a way that preserves the integrity of the data while still allowing for significant additions as well as efficient search and retrieval.* Data storage formats regularly evolve over time and become obsolete. Simultaneously, routine data collection generates larger and larger quantities of data to be stored, and new types of data from advanced monitoring tools enter the data management

system. Problems of digital curation as well as historic archiving are common across environmental management programs, but the scale of the dilemma at DOE is particularly daunting. With different contractors present at different labs and sites across the DOE complex, there are different data storage systems, different databases and formats, and different levels of data maintenance. Some data stored with consultants can be lost to the complex if measures are not taken to secure and maintain that data. Currently, there is a lack of consistency in how environmental data are stored and maintained. Data from historic monitoring programs may lack reference information that is critical to integrating it with new data to provide a long view of environmental processes. Additionally, the type of data files that may be used for LTM in the future may have storage issues that current sites do not have the funding to address. Archived data are often not readily available and are not in a usable format for long-term preservation. Poorly archived data may be vulnerable, as there is no redundancy in the system. In some cases, the environmental history of many sites may be lost forever in single disaster event.

Accessibility: *Critical data from environmental management programs should be available to project managers, contractors and stakeholders to the extent that the information does not pose a security risk.* An efficient long-term environmental management program is dependent on timely access to data and tools to interpret that data. Many factors currently restrict broad access to data that may support site management decisions. Some of factors related to curation and archiving of data are discussed above. In addition, security issues often prevent easy access for site contractors to deposit or retrieve information related to monitoring. While some DOE sites may not have security restrictions preventing easy access to monitoring information, there are sites where this challenge that will need to be addressed if a paradigm shift for LTM is to be realized. In order to gain the maximum leverage from complex-wide data, project managers should be able to efficiently access information on their own projects, but should also be able to access information from similar sites across the complex. By sharing how certain environmental conditions are described or regulated at other locations, project managers may have better tools to manage their own sites. Currently, access to information is designed for human eyes, but systems should be put in place so that content can be evaluated automatically by software in order to streamline access to relevant data.

Quality Assurance: *Environmental management decisions are only as good as the quality of data supporting them.* Data quality is integral to reducing uncertainty around performance of remedies as well as containment technologies at closed sites. High quality data are those data that are fit to support site management decisions on current operations and are useful in future planning for the site. Quality data have sufficient supporting information to assess the completeness, validity, consistency, precision, comparability and accuracy of the dataset. For example, supporting documentation for tools and technologies used to gather the data should accompany the primary data. Supporting information would show instrumentation calibration, data validation, or certified post-processing of raw data. These supporting files should be included as curated / archived information with accessible links provided from the data source files.

Integration: *Evaluation of long-term environmental restoration requires a complex and diverse dataset in order to develop a ‘lines-of-evidence’ formulation to support management decisions.* The complexity of data required under performance-based monitoring will necessitate integration of data in a cost-friendly and timely manner. Integration of complex datasets will be necessary to move from single, point source monitoring technologies to multiple point and non-point source tools. The DOE requires integrated tools for assessing and predicting change in the environment at spatial and temporal scales across a variety of measurable processes and endpoints. As the paradigm shift moves LTM from compliance-based to process and performance-based, an understanding of how different types of data are interrelated becomes necessary. Integrated datasets are required to predict effectiveness of technologies designed to minimize impacts to human and environmental health. Multiple sources of information, collectively assembled and used in a cross-validating manner to provide a near real-time status of the site goes a long way in reducing uncertainties associated with managing risk. Integration extends to methods and tools to analyze and visualize data, including software products and models.

Communication: *In order for data to become information, it must be processed and structured within a given context. In order for information to become communication, it must be heard.* Communication is the essential final step in long-term environmental information management. Effective risk communication ensures that all parties involved in long-term environmental restoration have equal information for making decisions. Effective

communication is necessary to be able to demonstrate to stakeholders, special interest groups, and the public, that LTM data provide assurances that human and environmental health are protected. The products of integrated data and information management should be readily interpretable for decision makers, and should match the objectives of LTM of the site. Communication at the finer levels of data and information resolution is also important for maintaining an active dialog within the research community to ensure transfer of ideas, approaches, and successes within the DOE complex.

LTM Information Management Investment Sectors

In order to address the challenges of data management for LTM decision-support and to lay the foundation for future care of legacy sites, the following three investment sectors have been identified:

- Identify and build on existing information infrastructures;
- Review and revise governing DOE orders related to information management;
- Develop a distributed data search engine with comprehensive coverage of DOE complex environmental information and relevant sources outside of DOE (e.g., EPA, NOAA, NASA, etc.). Data and content from the network should be processed for use by 'middleware' interfaces that facilitate data review and the analysis of resources.

Build on Existing Information Infrastructures

The DOE is one of the largest data generating entities in the world. In addition to the substantial amount of environmental management data generated by the complex, the DOE has historically had scientific and technological missions that would support future environmental and global sustainability research. DOE-EM requires an integrated environmental data management system where data resources composed of diverse formats from complex-wide locations and programs can be archived and made accessible to stakeholders and decision-makers.

DOE currently has many data-management and web-based information storage and dissemination tools. However, the tools are widely distributed between locations and missions, and there is not one central clearing-house for complex-wide environmental data. As part of the long-term IM survey, IM resources within DOE should be identified. Strengths and weaknesses of dif-

ferent systems for complex-wide information management should be identified. For example, DOE-LM uses an existing database structure, Geospatial Environmental Mapping System (GEMS), for real-time mapping of legacy sites with environmental monitoring data. Tools like GEMS should be identified and evaluated for their functionality and broad applicability.

Many of the information management challenges faced by DOE have been encountered and addressed by other governmental agencies as well as the private sector. Entities such as the National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), National Oceanographic and Atmospheric Administration (NOAA), U. S. Geological Survey (USGS), Environmental Protection Agency (EPA) and Department of Defense (DoD) have significant data generation, archiving and retrieval issues. Many of these agencies have had to adopt cost-effective and efficient systems for managing large and diverse environmental datasets with modest budgets. Information management at DoD has the added requirement of maintaining appropriate security of data. Outside of the public sector, private sector businesses have significant expertise in managing and linking data in secure environments. The DOE may consider interrogating other Agencies on the strengths and weaknesses of wide-scale data management systems.

The IM Breakout Session recommends that DOE formally investigate solutions to large-scale, complex-wide environmental data management challenges by identifying high performing data management solutions that have been adopted by other agencies. A formal process would identify data management systems that contain:

- Large quantities of scientific data of diverse formats;
- Flexibility that can be modified to accept new data formats;
- Capabilities where data can be uploaded by a large number of distributed users;
- Appropriate levels of security; and
- Capabilities where data can be retrieved by a large number of distributed users.

Review and revise governing DOE orders related to information management;

Contractor Standards: In order to address challenges related to archiving of environmental data collected or generated for the DOE by outside contractors, govern-

ing DOE orders should mandate delivery of all data in a format compatible with DOE information systems at appropriate points in the contracting cycle. In the past, contractor incentives have not included the requirement to turn over all raw environmental data as well as all accompanying quality assurance/quality control and other supporting metadata in a consistent and timely fashion.

Requirements to relinquish datasets should be outlined explicitly in all contracts. Acceptable formats for final datasets should be negotiated by the site managers, but should retain minimum features outlined in a Data Standards Guidance document.

Data Standards: The DOE should develop a complex-wide guidance for minimum data collection and archiving standards for all environmental or sustainability related datasets. The guidance should not be over-prescriptive, but should lay the groundwork for developing a consistent data format, inclusive of significant metadata, in order to make the data useful for both current and future decision-making. For example, specific supporting data requirements for certain types of molecular data must accompany submission of data generated for NIH studies, or for submission or publication in peer-reviewed journals, and these requirements have been adopted world-wide as minimum information necessary to interpret data results (i.e., Minimum Information About a Microarray Experiment (MIAME) guideline:

http://www.mged.org/Workgroups/MIAME/miame_2.0.html).

Another example of this type of document may be the DoD Spatial Data Standards for Facilities Infrastructure and Environment:

<http://www.sdsfie.org/WebTools/GlassBoxViewer/tabid/111/ctl/Privacy/Default.aspx>.

Efforts such as the National Spatial Data Infrastructure (<http://www.fgdc.gov/>) are intended to coordinate and standardize data for spatial analyses.

Finally, while instituting a complex-wide security standard for environmental data may not be possible, declassified data should be identified and made available for project managers as efficiently as possible. Complex-wide guidance on security issues for environmental data may improve the efficiency of declassifying critical data for inclusion in long-term data preservation systems.

Software standards: Software to be used for archiving, analysis or visualization of DOE EM data should be able to accept data in a consistent format. New software tools and purchase of tools should stipulate the format of input data, and that format should be consistent with the data standards described above. Emphasis should be placed on appropriate software currently available and on open-source software that can be modified to integrate various types of environmental data.

Develop a distributed data search engine with comprehensive coverage of DOE complex environmental information resources.

In order to address the challenges of access to information, integration of resources, risk communication, data curation and institutional memory, the IM Breakout Session recommends the development of a data search engine with comprehensive coverage of DOE complex environmental information as well as links to relevant exterior information sources. The development of a search engine would accompany a complex-wide effort to make both historic and current environmental data available in standard electronic format.

The DOEgle environment, a transparent, web-based system to provide access to relevant environmental data from complex-wide resources: The proposed system (with the working name of *DOEgle*) would employ traditional as well as the latest semantic web structure to provide a google-like search of DOE environmental resources and relevant external resources. The search engine would be available to DOE environmental managers and select consultants in order to streamline environmental decision making within the complex and provide an appropriate level of institutional memory to support long-term site care. Access to raw data maintained in a distributed network at DOE sites and server farms would be searchable through graded security levels as dictated by DOE management. The *DOEgle* project would be built through collaboration with US innovators and DOE and government expertise (identified in the aforementioned recommendation).

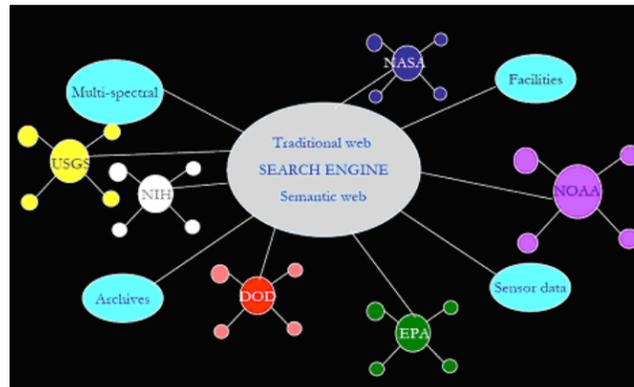


Figure 2. Illustration of the *DOEgle* system.

Development of the *DOEgle* environment would be done by investing in structured layers. *DOEgle* would provide the user an access portal to search for site-specific-databases, analysis and visualization tools, training and tech transfer, supporting data, metadata, and ancillary information sources. Environmental information is stored in a number of locations, from multiple programs, and in a number of formats across the complex. Rather than transferring data to a central repository from the disparate sites and programs, the *DOEgle* portal would link to and query the distributed repositories.

DOEgle is conceived as an interface between localized data sources and final information products. *DOEgle* will access analysis widgets and models that can be used for data integration, analysis and visualization. Part of the project will be the development of middleware – software that will automatically search and interrogate information sources, converting the raw data into a format that would feed into specialized widgets or applications. The middleware would provide the means to efficiently format data for common statistical analysis, visualization and communication applications. Communication of results can be further enhanced by development of ‘results widgets’ that produce easily interpretable graphs and reports. Site managers would have rapid access to the status of implementation technologies and a resource for communication of effective stewardship to the public and stakeholders. *DOEgle* would query the network, middleware would retrieve and transform the data and specialized widgets would compile the data into information that can be conveyed to stakeholders.

By streamlining access to environmental data, the quality and efficiency of environmental decision making will improve and cost savings will be realized. Currently, lack of transparency and lapses in risk communication can undermine trust between citizens, regulators and environmental managers. Improving transparency in the decision making process will elevate the level of trust between stakeholders and speed progress toward environmental management goals.

The DOE mission is to discover solutions to power and secure America’s future. Environmental issues are central to the current energy, security, health and welfare concerns of Americans. These issues are best addressed through appropriate data collection, analysis, technology development and risk communication. By developing an environmental information cyber-infrastructure, scientific and technological missions that support environmental sustainability research would be achieved. By making information on environmental technologies available to scientific and technical communities, technologies can be enhanced and commercialized for the benefit of American industries.

The *DOEgle* environment represents a modest investment that would improve efficiency and credibility of federal programs and serve as a model for distributing other types of technology information from DOE in the future.



LMT INVESTMENT SECTOR ALLOCATION EXERCISE



A major component toward improving the LTM paradigm is to identify areas in need of continued and future research. Those areas would ultimately be developed into the initiatives that would define and prioritize EM’s LTM activities within the near-term 3-5 year time frame. Following the example developed for a previous workshop (Silbernagel and Hafera 2000), one of the challenges of the present Technical Forum was for the participants to identify and prioritize those near-term areas (i.e., investment sectors) to improve the current LTM paradigm. Those LTM investment sectors would then be used to develop the LTM initiatives.

This component of the Technical Forum was called the *LTM Investment Sector Allocation Exercise*. At registration, each of the Technical Forum’s participants was given a total of \$100 “LTM Bucks” (i.e., two \$5s, two \$10, one \$20 and one \$50). The participants also completed a demographic form (see Appendix D) about their background including the following: *Affiliation* – Government, Academia, Industry or Other; *Focus* – Basic Research, Applied Research, EM/Administrative, Regulatory, or Other; and *Discipline* – Geology/Hydrology, Geophysics, Biology, Chemistry, Engineering, or Other. As part of their charge, each of the three Breakout Sessions was asked to identify between one and three priority near-term investment sectors within the focus area of that group (i.e., Performance Measurement Tools, Systems and Information Management). During the final Plenary session, the co-chairs from each Breakout Session was asked to present and explain the group’s investment sector(s). Following the investment sector presentations by the co-chairs, all of the partici-

pants were then invited to invest their LTM Bucks into one or more of the choices provided.

LTM Investment Sectors

A total of six LTM investment sectors were identified by the three Breakout Sessions. By session, these included the following:

LTM Performance Measurement Tools –

Surface Techniques - Development/Improvement of remote sensing and non-invasive techniques for surface monitoring
Subsurface Techniques - Development/Improvement of remote sensing and non-invasive techniques for subsurface monitoring
Bioindicators - Development/Improvement of bioindicators as leading indicators for LTM
 LTM Systems –

- *Compliance to Performance*
- *Point to Landscape Measurement*

LTM Information Management –

- *DOEgle Environment*

Results

A total of 46 of the Technical Forum’s attendees participated in the *LTM Investment Sector Allocation Exer-*

cise. The demographic profile of those participants is presented in Figure 3. Most participants were affiliated with the government (67%), had a work focus on applied research (70%), and were geologists/hydrologists by discipline (33%). The majority of this latter category was followed by engineers (31%).

A total of \$4,600 “LTM Bucks” were allocated into the six investment sectors. Individual allocations per a single investment sector ranged from zero to \$100 (i.e., one person allocating their complete allotment into a single sector). The overall allocation totals for the six investment sectors is presented in Figure 4. The collective total allocation percentages by Breakout Session focus topic were as follows: Performance Measurement Tools – 44% (3 sectors); Systems – 29% (2 sectors); and Information Management – 26% (1 sector).

The top four investment sectors include (in order of most to least): (1) the *DOE*gle Environment, (2) Subsurface techniques, (3) Compliance to Performance and (4) Bioindicators. Eighty percent of all resources were allocated among those four investment sectors.

Prioritization of the top four investment sectors varied by affiliation (Fig. 5). The government participants, again the largest group by affiliation, mirrored the overall investment totals from most to least. However, the academic affiliation group invested in the exact reverse of the government group, with Bioindicators as the top investment sector and the *DOE*gle Environment as the least sector to be invested in. The industry group generally followed the government investment allocations, with the exception of the Compliance to Performance sector being the lowest sector.

The work focus of the participants also resulted in a different percent resource allocation among the top four investment sectors compared to the collective totals (Fig. 6). The applied research focus also selected the *DOE*gle Environment as the highest investment sector, but, in contrast to the general totals, that was followed by the Compliance to Performance sector, and then closely by the Subsurface Techniques. Consistent with the academic affiliation, the basic research selected Bioindicators as the top investment sector; however, in this comparison, this was followed very closely by the *DOE*gle Environment. Both EM/Administrative and regulators favored the Subsurface Techniques investment sector, followed by the *DOE*gle Environment.

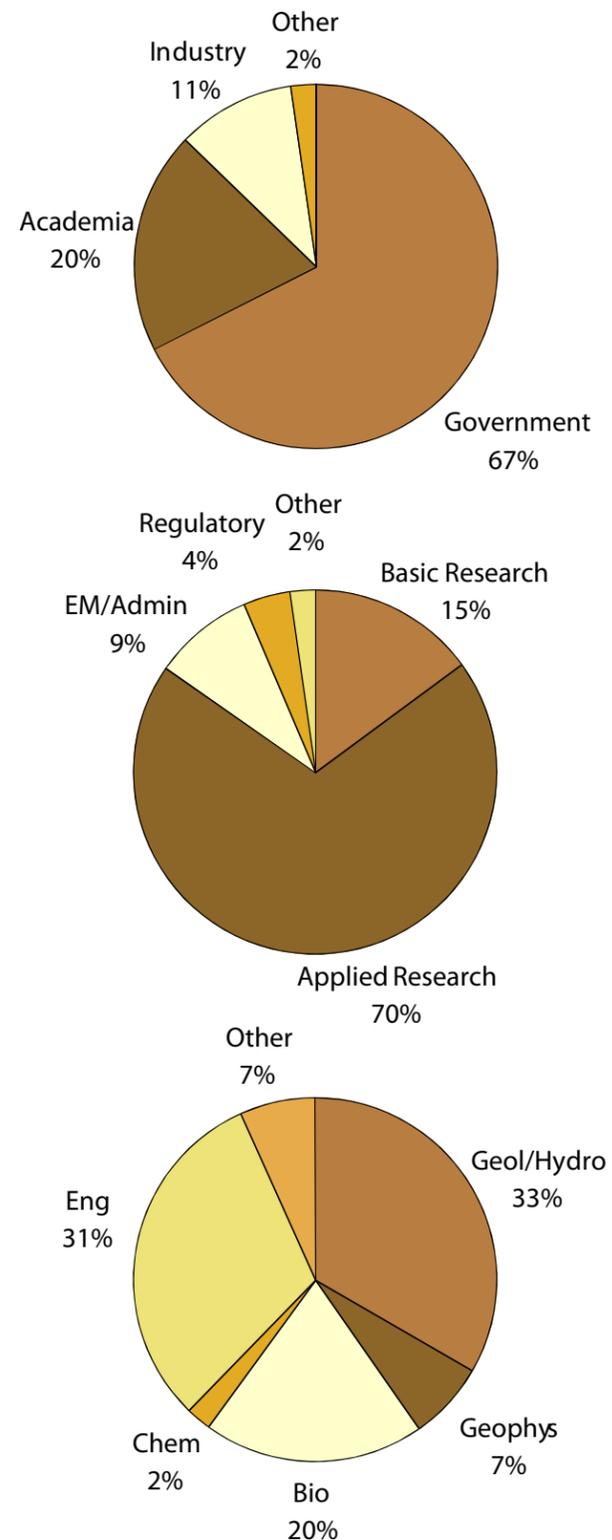


Figure 3. Demographic profile of the participants from the LTM Investment Sector Allocation Exercise.

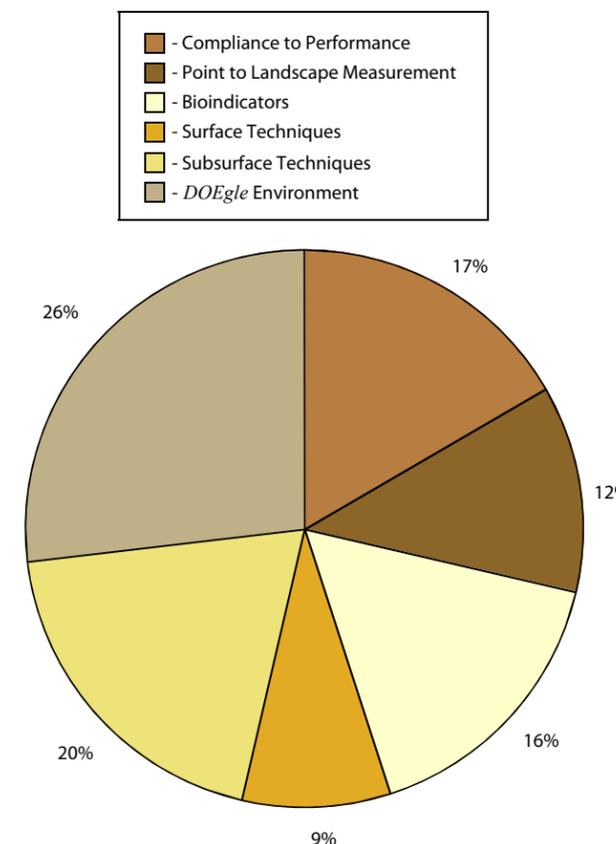


Figure 4. Overall allocation totals for the six investment sectors.

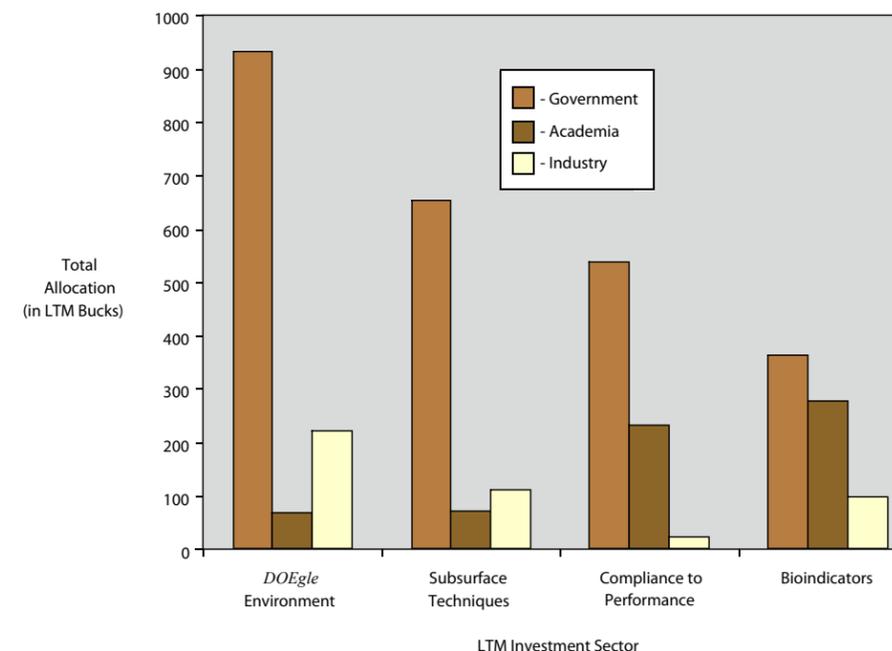


Figure 5. Investment allocation into top four sectors by affiliation.

With respect to the investment sector allocations based on the participant’s professional discipline, again most of these varied from the overall allocation totals. The biologists strongly favored the investment into bioindicators. Chemists and geophysicists selected subsurface techniques followed by the *DOEgle* environment as their top allocation choices. The engineers mirrored the overall totals in their investment selections. Finally, the geologists/hydrologists allocated their resources into three closely ranked sectors, from Compliance to Performance, then Subsurface Techniques, and finally the *DOEgle* Environment.

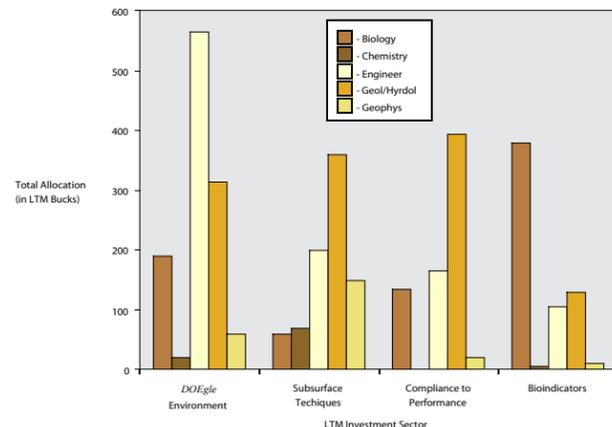


Figure 7. Investment allocation into top four sectors by discipline.

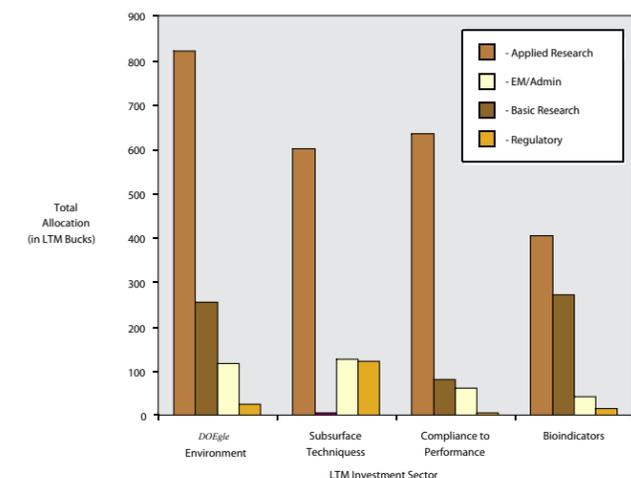


Figure 6. Investment allocation into top four sectors by work focus.

Although differences among the investment sectors did exist, this exercise did highlight a total of six priority areas that would serve as near-term initiatives toward improving the LTM paradigm within the next 3-5 years.



CONCLUSIONS AND SUMMARY OF RECOMMENDED INITIATIVES

The fundamental objective in cleaning up and closing legacy waste sites is to achieve performance that will protect the surrounding environment with a long-term focus on health and human safety. LTM is key to verifying long-term performance with these engineered closure systems. In a recent report, the National Research Council of the National Academies found that “Engineered barriers have limited design lives compared with the time periods over which wastes will remain hazardous and hence will require ongoing surveillance and maintenance, and, in some cases periodic replacement, to insure their continued ability to isolate wastes.”

With respect to achieving successful clean up and closure of these DOE sites, the LTM paradigm needs to be improved. The participants in this Technical Forum concluded that to improve this paradigm, we must consider and, in some form, include the following:

- Employ the existing technology for affordable remote monitoring systems that employs sensors and remote sensing tools;
- Monitor containment system elements as well as the surrounding environment;
- Use monitoring systems for compliance monitoring, to validate designs, and to plan/create future strategy;

- Regulatory requirements must be changed in accordance with changes implemented within the LTM paradigm;
- Use design processes and systems that provide continuous assessment by coupling monitoring, design, and maintenance; and
- Learn from monitoring data to facilitate evolution of containment systems.

Toward addressing the reduction of the technical risks and uncertainties identified in the 2008 *Roadmap*, the participants at the 2009 LTM Technical Forum recommended five initiatives (Table 1). For each initiative, the anticipated outcomes and benefits have been described. For each initiative, a Federal Initiative Manager will be named who will develop additional details on the scope and schedule of the initiative.

As stated in the 2008 *Roadmap*, focused, applied engineering and technology development has played a crucial role in many of DOE-EM’s past successes. The initiatives listed below are intended to contribute in that same function for near-term improvement of the LTM paradigm, and thus to ensure DOE’s “success in paying off the mortgage of the Cold War – achieving the safe and compliant disposition of legacy wastes from defense nuclear applications.”

Table 1. Listing of the LTM Paradigm Improvement Background Description, Initiative Details, and Outcome and Benefits.

Background Description	Initiative Details	Outcome and Benefits
Technical Focus Area: LTM Performance Measurement Tools		
LTM tools should have as many of the following characteristics as possible: be remote, robust, durable, non-intrusive, cover appropriate spatial scales, aggregate properties, align with stakeholder concerns, and are cost-effective	Improve surface remote sensing and non-invasive techniques	Implement more cost-effective non-intrusive surface tools to develop improved understanding of long-term performance.
	Develop techniques to remotely and non-invasively provide subsurface hydrology, chemistry, and structural conditions	Implement more cost-effective non-intrusive tools to develop improved understanding of subsurface long-term performance.

Table 1. Listing of the LTM Paradigm Improvement Background Description, Initiative Details, and Outcome and Benefits (Continued).

Background Description	Initiative Details	Outcome and Benefits
Technical Focus Area: LTM Information Management Tools (Continued)		
Ecological LTM tools should include bioindicators, which are temporally robust, measure cumulative impacts, and have relevance to stakeholders. However, at present, bioindicators are limited in their ability to serve as leading indicators and represent an indirect measurement of the system	Improve/study bioindicators as leading and long-term indicators	Utilize bioindicators as advanced indirect monitoring tools to evaluate long-term performance of the waste closure site within an ecosystem perspective.
LTM systems need to move from point measurement to entire ecosystem monitoring with leading indicators, bio-indicators, remote sensing and other tools	Develop, demonstrate and validate an LTM Approach that transitions from point measurements to integrate landscape scale measures	Improve the methods of increasing the scale of LTM measurements and the criteria that would be used for leading indicators that would integrate landscape scale measures e.g., ecological parameters that could serve as leading indicators for remedy systems.
Technical Focus Area: LTM Systems		
LTM systems need to shift from compliance monitoring to natural system (e.g., watershed, disposal facility plus ecosystem) performance monitoring of a remedy system	Field demonstrate a shift from current compliance-driven LTM to ones that provide the ability to refine long-term remedy system performance monitoring and to evaluate the accuracy or validity of predictive tools	Refine long-term performance monitoring to evaluate the accuracy or validity of predictive tools using a systematic review of existing data for continuous LTM improvement, periodic remedy (e.g., 5-year remedy reviews), and LTM performance model validation/calibration.
Technical Focus Area: LTM Information Management		
Identify and build on existing information infrastructures	Identify and build on existing information infrastructures	Identify and build on existing information infrastructures
Review and revise governing DOE orders related to information management	Review and revise governing DOE orders related to information management	Review and revise governing DOE orders related to information management
Develop a distributed data search engine with comprehensive coverage of DOE complex environmental information and relevant sources outside of DOE	Develop a distributed data search engine with comprehensive coverage of DOE complex environmental information and relevant sources outside of DOE	Develop a distributed data search engine with comprehensive coverage of DOE complex environmental information and relevant sources outside of DOE

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APPENDIX A

**List of Participants
Contact Information**

**2009 DOE-EM
Long-Term Monitoring (LTM) Technical Forum
February 11-12, 2009**

**List of Participants
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APPENDIX B

Summary of Participant Evaluation Forms

**2009 DOE-EM
Long-Term Monitoring (LTM) Technical Forum
February 11-12, 2009**

**Summary of
Participant Evaluation Forms**

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The following is a compilation of the rated item grades and comments from an evaluation form completed by 15 of the Technical Forum's participants. This information will be used to plan future meetings of this type and scope.

Rating Items	Session Grade 1 (Lowest) to 5 (Highest)	
	Range	Mean Score
1. Facilities	3-5	4.20
2. Planning and Organization	3-5	4.20
3. Program Format	3-5	4.27
4. Effectiveness of Presentations	3-5	4.13
5. Clarity of Information Presented	3-5	4.07
6. Quality of Presentations	3-5	4.13
7. Time Devoted to Questions and Participant Discussion	3-5	4.67
8. Choice of Material Selected for presentations	3-5	4.00
9. Overall Value of the Conference	3-5	4.33

- More information should have been sent out ahead of time on what the final product of the working group would be. In addition, ahead of time there could have been better definition of the scope of each group. Lastly, the information management system became too focused on specific hardware rather than effective use of the LTM data.

- Needed more info before.
- Tools Group was a bit too large (20 - 25 people). Some of the presentations were not relevant to the discussion.
- Well done! Interesting and valuable results.
- Hydrologist academic perhaps equal representation of disciplines giving presentations. In my session there was a strong bias in biology in the voting items generated by the break out groups showed this bias.
- Good examination of issues. Structured but not limiting. Liked the bucks exercise. I think it was good to include folks from outside DOE. Facility was great. Very nice conference rooms.
- Very effective. Could have more interface between groups before investment exercise. Also, could have a little more existing practice for kick off, other wise an A. Co-breakout chairs did a terrific job. Kudos Would be nice to have travel funds, this is out of my pocket.
- Needs facilitators. Better skeletal structure. Free Thinking is great but could have focused on end result of recommendations for investment. The money game was a great way to help that!
- “Tools” Session was poorly led. Fewer presentations should have been given & session leads should have had a pre-conceived plan for leading discussions. The group was too large for free-form discussions to be useful; discussions tended to be dominated by a few individuals. Adequate time was given to breakout sessions. A gathering of the entire group after a couple hours of breakout discussions could have been useful (instead of the session leads going group-to-group).

APPENDIX C

List of Ideal LTMS Attributes

Long-Term Monitoring System (LTMS) Breakout Session**List of
Ideal LTMS Attributes**

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This list is a compendium of attributes provided by a range of participants in the workshop. Minimal editing was done to enhance clarity and to remove duplication, but in general this is the list as it was drafted by the participants.

An ideal LTMS should:

- Be driven by fundamental understanding of critical processes;
- Measure and validate system performance;
- Use decision support tools, risk and site conceptual models to inform design and operation of LTMSs;
- Predict system behavior in the short and long term through combinations of analog sites, conceptual or numerical models;
- Periodically and structurally use data and novel insights to provide improvement to models of the system;
- Shift focus from compliance failure to system understanding and performance monitoring;
- Be designed to consider contaminated sites as an integral part of the overall site “ecology;”
- Be designed to provide critical system information and understanding (not just data); and
- Be linked into decision support systems (additional remedy, fix engineered systems, change predictions) and into risk estimates.

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APPENDIX D

**LTM "Bucks" Investment Exercise
Demographic Data Sheet**

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**Long-Term Monitoring Technical Forum
LTM "Bucks" Investment Exercise
Demographic Data Sheet**

No. _____

Affiliation: (Check One)

Government ^a - _____ Academia - _____ Industry - _____ Other: _____
^a Includes government contractors

Focus: (Check One)

Basic Research - _____ Applied Research - _____ EM/Administrative - _____
Regulatory - _____ Other (Please specify): _____

Discipline: (Check One)

Geology/Hydrology - _____ Geophysics - _____ Biology - _____ Chemistry - _____
Engineering - _____ Other (Please specify): _____

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