TECHNICAL INFORMATION FOR LONG TERM SURVEILLANCE AND MONITORING

Mitchell D. Erickson and Alfred J. Cavallo

Environmental Measurements Laboratory, U. S. Department of Energy,
201 Varick Street, New York, NY 10014-4811

ABSTRACT

Even after the U.S. Department of Energy's Office of Environment Management cleanup program has ended, there will be areas that will need to be monitored and maintained for the foreseeable future. This need reflects a fundamental obligation on the part of the DOE and the Federal Government to protect future generations from any residual hazards at these locations. Such a monitoring program must be designed to be cost-effective and to enjoy the highest level of trust of the general public. Thus, not only will the monitoring data need to be gathered efficiently, but also these will need to be presented in a manner that is both easily accessible and understandable to the general public. The program certainly must have a rigorous and visible QA Program with oversight at the national level to insure that the data, as well as the decisions and actions made using these data, are reliable. The experience gained by DOE in this enterprise will be widely applicable, since many other governmental and private sector organizations have similar, if less widely publicized, issues to address.

The technical information needed for long term surveillance and monitoring (LTSM) includes monitoring data, QA, data quality objectives, and decision criteria. Proper development, collection, visualization, and management of these technical data are critical to LTSM success. Planning for LTSM involves identification of the technologies needed to make the measurements, development of data collection networks, planning for data transmission and storage, and protocols for data review and validation. Once collected, the data need to be converted into information for the user and integrated with other LTSM systems to provide timely and transparent access to federal managers, stakeholders, and regulators. Finally, record retention policies and data management must be planned.

INTRODUCTION

For over 50 years, the U. S. Department of Energy (DOE) and its predecessor agencies of the U. S. Government employed a vast network of industrial facilities and laboratories dedicated to the design, development, testing and production of nuclear weapons. Uranium ore was a raw material for these weapons factories, and uranium mining and milling became booming industries in Colorado, Utah, and New Mexico. The fissionable isotope of uranium was extracted from natural uranium in immense gaseous diffusion plants in Tennessee, Ohio and Kentucky, and plutonium for weapons was produced in several nuclear reactors in Washington State. Large automated chemical plants were built to extract plutonium from the highly radioactive nuclear fuel rods. Other reactors were built in South Carolina to produce tritium, an isotope of hydrogen, for thermonuclear and boosted nuclear weapons. Ultimately, tens of thousands of nuclear weapons were manufactured and more than one thousand nuclear weapons were tested in the air and underground in Nevada, and at other testing ranges in the Pacific Ocean.

During this era, the environmental impact of weapons production and waste disposal was managed by DOE under its own internal rules and did not receive the highest priority for management attention and budgets. About a decade ago, as a result of court orders following suits brought by various public interest groups, the Department (1) became subject to legislation regulating the generation and disposal of waste. Environmental assessments indicated that many DOE sites had environmental problems of a magnitude and character not encountered anywhere else. It was also realized that it would require decades of effort and enormous financial and technical resources to stabilize the waste and clean up the environmental contamination.

A few examples will illustrate the enormity of the undertaking. Uranium mine waste and mill tailings could leach contaminants into ground and surface waters, and emit radon to the atmosphere. Chemical reprocessing produced a highly radioactive mixture of organic and inorganic liquids; these were stored in large tanks, some of which are now leaking and threatening to contaminate the Columbia River. Thousands of pounds of mercury were released during lithium isotope enrichment at Oak Ridge, Tennessee. Thousands of tons of uranium hexafluoride, having been passed through the enrichment plants, are now stored in deteriorating tanks. In addition, large quantities of radioactive and hazardous waste were disposed on site in inadequate containers or in landfills that are unacceptable by current standards. This waste needs to be retrieved, converted to a stable form, and then disposed of properly.

Since 1989, DOE's Environmental Management Program has made significant progress in dealing with these challenges. Abandoned uranium mines have been sealed, mine and mill tailings piles removed or capped, and transuranic waste is now being emplaced in a deep geologic repository at the Waste Isolation Pilot Plant in New Mexico. Contaminated buildings have been decontaminated and demolished with the rubble deposited in carefully designed isolation cells that will be sealed and capped.

However, much more remains to be done. In many cases, cleanup does not necessarily mean that a site will be restored to its original pristine condition. Some contamination is so difficult to remove that the best that can be done is to stabilize the waste and provide for monitoring for the indefinite future. Some lands, such as that portion of the Nevada Test Site where underground tests were conducted, must essentially be regarded as national sacrifice zones, impossible to decontaminate and to be permanently excluded from unrestricted access. Other areas, for example those at which all contaminated waste can be entombed in a disposal cell, may only require the most rudimentary control and oversight. All of these properties will require what is known as long-term stewardship, which includes all activities necessary to ensure the protection of human health and the environment following the completion of cleanup, disposal or stabilization at a site or a portion of a site. Long term stewardship is composed of all engineered solutions and institutional controls designed to contain and prevent human exposure to contaminants, such as surveillance activities, record keeping, inspections, groundwater monitoring, pump and treat activity, barrier maintenance, and access control. As a result of a court decision following litigation by an environmental group (2) such a program has been started within DOE itself.

MONITORING REQUIREMENTS FOR LONG-TERM STEWARDSHIP

The media requiring long-term stewardship can be classified as follows:

Facilities. This is a site currently being utilized, and which will be decommissioned when no longer needed. An example is the spent nuclear fuel storage cell near what was once the Fort St. Vrain nuclear reactor in Colorado.
Engineered Unit. An example is a disposal cell.
Soils and Sediments
Ground Water
Surface Water

MAJOR CONTAMINANTS

Radionuclide contaminants of greatest concern are the mobile isotopes or those whose main decay mode is alpha and beta emission. The latter are more difficult to detect routinely, compared to gamma emitters. These include uranium, technetium-99, tritium, strontium-90, cesium-137, plutonium, and americium.

Metals that will be most important to monitor are mercury, hexavalent chromium, lead, and beryllium.

The most important volatile organic contaminants are metal cleaning solvents [TCE (trichloroethylene), dichloroethylene, chloroform, and carbon tetrachloride), while the most critical semivolatile organics are PCBs (polychlorinated biphenyls)], which were generally used in electrical equipment. Other contaminants include fuels (diesel and gasoline), lubricants (oils and kerosene), toluene, benzene, xylene, ethylene dibromide, and freons.

Each of these pollutants requires monitoring technology adapted to the special needs of the media and the environment. For example, the Colorado spent fuel facility listed above requires radiation and groundwater monitoring, as well as 24 hour on-site security guards, at a total cost of about $3M/year (3). Since there are hundreds of facilities – some smaller, some much larger – the annual monitoring costs could amount to hundreds of million per year. Proper design of our nation's LTSM can assure that these expenses are controlled while we conduct the right monitoring to meet our objectives.

GENERAL REQUIREMENTS FOR SENSORS

In general, all sensors must meet the following specifications, according to the Office of Environmental Management's Office of Science and Technology (OST) (4). They must be appropriate for the intended application and have adequate dynamic range, sensitivity, reliability under actual field conditions, and have a minimum maintenance schedule. They must also minimize any waste generation. Finally, they must be cost effective.

Requirements for Organic Sensors

Sensors for monitoring organic pollutants must be capable of in-well performance and in-ground performance. They must be able to monitor compounds of interest. It would be highly desirable if they could also monitor breakdown products for toxicology considerations, indicator species, and co-contaminants such as hydraulic fluids, lard, oil, and PCBs in oil.

The sensors must be capable of measurements in the presence of high levels of interferences. In addition, they must cost significantly less than the current systems, a maximum of $4,000 for a deployed system (current baseline of $500/sample is assumed with a technology replacement cycle of every two years) (4).

Requirements for Metals Sensors

Metal sensors must monitor for compliance (RCRA metals) and identify potential interferences.

Requirements for Radionuclide Sensors

Radionuclide contamination is more or less unique to DOE sites and is of enormous concern to the public, as the perceived risk from such contaminants is extremely high. Therefore, great care must be taken with the selection of this instrumentation. Radionuclide sensors must be able to monitor to regulatory levels with good accuracy and precision, be capable of automated measurements and remote telemetry, and must have lower overall cost than current instrumentation.

GENERAL SITE MONITORING STRATEGIES

Many issues are common to a wide selection of the DOE sites or areas that will require long-term monitoring.

Real-Time Versus Periodic Measurements

Considering the timescale for contaminant migration in soils, groundwater, or subsurface vapor, obtaining real-time data appears unwarranted in most cases where quarterly monitoring is the norm. While episodic events, such as flash floods or downpours, would require more frequent data collection, in general no real benefits would result from the requirement for real-time analysis. This is particularly true in cases where it is unlikely that the volume of data generated would be fully reviewed on a regular basis. Exceptions to this conclusion include:

- situations during which more frequent monitoring data would provide valuable information, such as monitoring rivers or other surface waters that are transient in nature,

- conditions when time-integrated information based on frequent data collection would provide a more accurate picture than quarterly information. In the vast majority of cases it appears that continuous monitoring of pollutant levels is not justified. However, since the public often may demand this, some compromise may have to be worked out, either using more frequent measurement intervals, or by using instrumentation that records the average values and minimum or maximum values only. Such performance is more easily obtained from gamma radiation monitoring equipment; in most cases a requirement for continuous monitoring is simply not feasible or is prohibitively expensive with current or foreseeable technology.

- situations where the costs or risks of obtaining samples are high and a relatively cheap monitor is available.

Standard Packaging and Architecture

To accelerate the sensor development cycle, consideration must be given to the entire system from the outset, including elements such as the deployment and sampling system, data acquisition and processing system, and data transmission systems integrated with new sensors. The development process may be expedited through use of standard packaging designed for common environmental field applications and emplacements. Additionally, standard, open-architecture data acquisition and transmission systems already commercially available should be used. These industry standards should be adopted wherever possible.

Moisture Data

A significant issue for environmental remediation projects is identifying the best way to detect early warning signs of system failures for containment or engineered isolation facilities, such as landfills, vaults, and caps. Monitoring the moisture content and flux is emerging as a baseline monitoring approach through negotiation with regulators regarding DOE engineered facilities. Because moisture sensors are commercially available, many site managers would like to focus on developing integrated systems that monitor moisture flux, water content, and soil water potential below and around remedial systems. The monitored moisture data not only give an early indication of potential system failure, but also facilitate specific site understanding of the transport pathways and processes that influence contaminant movement.

Surrogate Parameters

Many DOE monitoring needs include requests for real-time, *in-situ* sensors that measure contaminants to mandated detection levels reliably over extended periods via automated operations or in remote locations. Hence, meeting these requirements may not be possible or might be too expensive. However, designing sensors and integrated sensor systems for monitoring surrogate parameters that are good indicators of remedial system performance might be more easily achievable and therefore offer a satisfactory solution. Furthermore, surrogate measurements, such as moisture content, pH or redox conditions, and barometric pressure changes might be better indicators of early system failures than contaminant measurements.

CRITICAL INSTRUMENTATION NEEDS

New instrumentation and measurement techniques most urgently needed for the long term monitoring program include:

- Field deployable tritium analysis systems.
- Technetium-99 monitoring with auto-sampler, using EMPORE™ disks, and an automatic disk cartridge changer at the surface. (Chemical speciation is important for the technetium-99 measurement.)
- Integrated systems for monitoring soil water content, soil water tension (soil water flux), and contaminants (radionuclides). These systems should be compatible with cone penetrometer technology.
- Monitors for soil water movement as an indicator of likely contaminant transport.

Lower priority projects include:

- Deploying automated samplers in support of monitoring,
- Monitoring total gamma radiation levels as an indicator of contaminant transport,
- Using colloid-based collection technology for actinide monitoring,
- Testing the applicability of Cadmium Zinc Telluride (CZT) detectors for low-energy gamma-ray monitoring,
- Testing the applicability of Mercuric Iodide detectors for low energy gamma ray monitoring, and
- Testing the applicability of Portable Isotopic Neutron Spectroscopy (PINS) with a Xenon detector for gamma-ray measurements.

POLICY AND PROJECT PLANNING

Establishing both national and site LTSM programs requires key technical input into monitoring activities, monitoring frequency, action levels, and responses to an action-level. Decisions at this point have broad implications to public acceptance, cost, and operational effectiveness of LTSM. A large part of the LTSM policy emanates from the program management, generally located in agency headquarters. However, other organizations play a critical role in development of policy. For DOE, the Environment, Safety, and Health Office (EH) promulgates orders and directives that impact on LTSM. Other federal agencies, notably the Environmental Protection Agency's Federal Facilities Office and the cognizant Region can impose policy.

A list of some, but not all, of the programs that require long-term surveillance and monitoring are:

- Hazardous waste land disposal under the Resource Conservation Recovery Act (RCRA),
- Cleanup of sites contaminated with hazardous substances under Superfund (Comprehensive Environmental Response, Compensation, and Liability Act, CERCLA),
- Disposal of low level radioactive waste generated by nuclear facilities, Nuclear Waste Policy Act and the Atomic Energy Act,
- Decommissioned licensed nuclear power facilities, Atomic Energy Act, and
- Cleanup and disposal of uranium mill tailings, Uranium Mill Tailings Remedial Control Act.

Scientists can and should participate on consensus standards working groups, interagency committees, and other activities that develop the policies that we all must live with for years to come. Standards and policies rooted in good science can facilitate the LTSM program. Poorly written standards will increase costs through needless work, redoing faulty work, and litigation. A success story is the Multi-Agency Radiological Survey and Site Investigation Manual (MARSSIM) document, published in 1997. The MARSSIM (5) provides a unified approach for radiological surveys at contaminated sites. It provides guidance for planning conducting, evaluating and documenting environmental radiological surveys for demonstrating compliance with dose-based regulations for D&D of nuclear facilities. A team from DOE, EPA, NRC, and DoD created MARSSIM. The Environmental Measurements Laboratory (EML) scientists contributed the survey design, measurement methods and statistical analysis sections and continue to contribute to training and implementation projects across the DOE complex. Although MARSSIM was completed several years ago, improvements continue:

- EML and the University of Tennessee (UT) are developing survey and analytical techniques appropriate for determining by measurement, residual radioactivity levels that are at or near background radiation levels in subsurface regions of survey units and to integrate this technology with surface measurements. This work is necessary to establish a technical basis for demonstrating and validating compliance with a distinguishable from background criterion for clearance of materials.

- The EML/UT Team is also adding a Bayesian geostatistical analysis module to improve the Spatial Analysis and Decision Assistance (SADA) software used in MARSSIM planning.

Building on the success of MARSSIM, the same agencies have developed the Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) (6), which connects analytical measurement requirements to decision and data quality requirements. The goals of this manual are to improve uncertainty estimates conforming to National Institute of Standards and Technology (NIST) and ISO recommendations and to improve MDC estimates that realistically reflect actual capabilities. The manual has been completed and was submitted for public comment in September 2001.

DOE has established a Cleanup Criteria/Decision Document (C2D2) Database to record site-specific environmental contaminant concentration levels that the Department of Energy has agreed to cleanup. EML is responsible for the management and improvement of C2D2. Since cleanup criteria must be developed for every contaminant at each DOE cleanup site, the C2D2 database can be extremely useful to field offices as a resource to compare proposed values and to provide background data for negotiations. It can also be useful to DOE headquarters as a unique resource that tracks complex-wide parameters that can assess progress and reveal trends. EML has recently made significant modifications to the C2D2 database content and structure, has developed a user interface to improve accessibility, and has published analysis reports on cleanup data. In an ongoing effort to update the contents and improve data quality, EML will continue to work in collaboration with Argonne National Laboratory to add additional decision documents and review data. EML will also continue to work with field offices and headquarters to identify new data sources, application needs, and obtain feedback on interface developments.

QUALITY ASSURANCE (QA)

Currently, each site implements its own QA Program. However, as the cleanup program moves toward completion, some sites without an ongoing DOE mission will move into a long term monitoring that is part of another site's responsibility. Each site or subsite requiring long term monitoring must have its own QA project plan.

QA is central to the planning of LTSM as well as ensuring that all technical data are useable for making decisions. Most institutions, including DOE, have the appropriate high-level policies and guidance for QA. Over the past couple of decades, QA has been institutionalized at the project level with QA project plans, standard operating procedures, training and other appropriate measures. We need to work on improving the inclusion of QA at the programmatic level, especially in the planning. With LTSM, it is critical that we include QA principles in national and site planning.

Plan, Implement, Assess

This is embodied in virtually all QA programs and parallels the principles of good project management.

Data quality objectives (DQO) is a process of evaluating first what question is being addressed and then how to get the needed information. The rigorous process pioneered by EPA is designed to make sure that all involved parties decide during the planning phase what specific decisions will be made with the data collected and what the action levels are for those decisions. In addition, the cost of and tolerance for making the wrong decision are quantified so that the statistical design of the monitoring program can be scaled appropriately. The lower the tolerance for making the wrong decision, the more data is needed and thus the higher the cost of the program. Once a monitoring system has been designed (number of monitoring points, frequency of monitoring, analytes, precision and accuracy requirements), the DQO process should cycle back through the decisions with all involved parties to gain concurrence. This process is critical to LTSM planning because it gets buy in from the site owner (e.g., DOE), regulators, public interest groups, project management, and other stakeholders. Initial agreement on the decision rules and the actions to be taken if certain conditions are met forestalls expensive and protracted controversies during execution of the LTSM.

Data must be validated before using it to make a decision. Currently, data validation is cumbersome, time-consuming and costly. At some DOE sites, 100% of laboratory analytical data are validated by a third party, delaying access to the data by weeks or months and costing up to 2.5 times the original cost of the analysis. Appropriate application of scientific principles could provide a LTSM policy that would improve this process. We clearly need reliable data, but we also need it on time and within a reasonable budget. Among the opportunities for change include validation of a statistically based fraction of the data, changing the validation templates to focus on critical issues and not on formatting trivia and improved contract scopes to shift the responsibility for providing reliable data to the original analysis laboratory.

EML's Quality Assessment Program (QAP) is a performance evaluation (PE) program for environmental radiological measurements that substantiates the quality of the analytical techniques used by DOE's contractor laboratories. The program administered by EML and has been operational for over 25 years. In the most recent QAP distribution (QAP54, March 2001), 149 laboratories submitted over 3000 analytical results for evaluation. DOE contractors are required under DOE Orders 5400.1 and 414.1A to select laboratories that participate in an external QA PE program for radionuclide laboratory measurements. QAP provides the DOE facilities this external, independent evaluation of environmental radiological analyses by providing NIST traceable performance evaluation materials. The QAP PE materials consist of blind test samples (water, soil, air filters, and vegetation) that are sent to participating laboratories twice a year and analyzed by all the laboratories at the same time and within the same time constraints. Participation in a

DOE-wide program provides for uniform standards of measurement for DOE field management.

In addition, any external laboratory to which samples are sent must have its own QA Program that is certified by the Office of Long-Term Stewardship.

A visible, effective QA Program is an essential part of winning the confidence of LTSM stakeholders and the general public, which is critical to the overall success of any long term monitoring program.

INFORMATION MANAGEMENT SYSTEMS

Given the rapid changes in information management technologies, preserving data is a major issue in a program that must extend into the indefinite future. Many systems that were once considered high technology simply no longer exist, so that, for example, data stored on 5.25 inch "floppy disks" is now virtually useless. A similar future is in store for the 3.5 inch floppy. CD technology is also challenged by issues like media durability (disk delamination), and the changing wavelength of the light source used to read or write a disk. The problem of technical obsolescence and rapid technological change has been widely recognized and extensively discussed for many years, but without any agreement on how this should be resolved.

Information management systems will be necessary to store, preserve, and integrate information about a wide variety of issues associated with remaining site hazards. Information management systems must be capable of efficiently acquiring, displaying, and integrating new information while storing and preserving previously acquired data, and all information must be readily available to the general public in an easily accessible format. Maintaining operational and effective information management systems for such complex data over an indefinitely long period of time is unprecedented.

In addition to the technical challenges, there will be economic, political, and cultural changes that are not foreseeable and will complicate information management activities. Wars, civil unrest, economic recession or depression, growing public risk avoidance, and changes in language all must be considered. While the details of these threats cannot be specified, the institution in charge of LTSM must be sufficiently robust so that it is capable of carrying out its mission.

MODELS AND DECISION TOOLS

Models are needed to predict future adverse conditions at sites, pollutant transport scenarios, and durability of physical remedies.

The action levels must be clearly delineated and the actions to be taken if levels are exceeded must be agreed upon (see DQO discussion above). Minimization of human intervention and labor costs must be balanced with overconfidence in automated systems and the garbage in/garbage out phenomenon.

We need more robust models for future adverse conditions at sites, including scenario modeling (e.g., 100-y flood), changes in site conditions such as encroachment of population on the site boundary, and changes in legal requirements.

We need a better understanding of subsurface science and models for pollutant transport scenarios. We need improved models for the robustness of physical remedies (e.g., how long will that landfill liner remain intact?)

All models must be validated by laboratory experiments, mesoscale experiments, and carefully monitored field demonstrations. We also need to collect supporting data (e.g., site-specific physical properties) to reasonably bound assumptions on model input. The current lack of data to test subsurface transport models is particularly acute.

DESIGNING THE INSTITUTION

An overarching concern is the establishment of an organization (7) that is capable of dealing with the numerous challenges of LTSM. Such an entity must be invested with the appropriate legal authority and be allocated secure funding to accomplish its mission. As mentioned previously, DOE is only one of many organizations facing this identical issue. At this point, it is not clear how the problem is to be settled, but there are several possible candidates for this task. These might be:

- An Office of Long Term Stewardship within DOE;
- The Office of Emergency Response in the US EPA;
- The US Department of Defense Army Corps of Engineers;
- The US Department of Interior Bureau of Land Management.

There are advantages and disadvantages associated with each of these choices. Certainly, DOE is the most qualified technically, with extensive experience in all types of waste management, including radioactive waste management. DOE staff are already located at all of the contaminated sites, and there is already a small LTSM Program being run by the Grand Junction, CO, DOE field office, as well as an Office of Long Term Stewardship located in DOE Headquarters. DOE has managed and does successfully manage extremely complex technical programs around the country.

Yet technical competence is only one facet of the LTSM project. The ability to interact with the public and win its trust is also vital to the success of the entire enterprise. It is therefore important to acknowledge that DOE has had a deep-rooted culture of secrecy, problems maintaining its own infrastructure, and a history of placing production ahead of environmental and safety norms. Unless it overcomes these limitations it may not be the best institution to be entrusted with this mission in the long term. Much will depend on how the issues associated with LTSM are handled in the immediate future.

CONCLUSIONS

It appears that there are major challenges associated with the implementation of an LTSM Program not only at DOE sites, but also at sites for which many other organizations in the public and private sector are responsible. Some of the challenges are technical, such as development of new sensors that are stable, accurate and cost effective. Many other issues are non-technical, such as identifying mechanisms for stable funding and winning public trust, are in many ways much more intractable. How the United States meets these challenges in the future will have a significant impact on the public's attitude towards both governmental and private sector competence, fairness, and responsibility.

REFERENCES

1. Legal Environmental Assistance Foundation v Hodel, 586 F Supp 1163 (ED Tenn D Ct 1984); Natural Resources Defense Council (NRDC) v EPA, 824 F2nd 1258 (1st Cir 1987); NRDC v DOE, Cir Action No. 89-1835 (D Dc 1989).
2. NRDC v Richardson, (D DC 1998).
3. DOE/EM-0563, January 2001, A Report to Congress on Long Term Stewardship. Vol. 2, Site Summaries, Colorado, p 20, US GPO 2001: 472-252-00334.
4. Long Term Monitoring Sensor and Analytical Methods Workshop, Orlando, FL, June 13-15, 2001; Characterization, Monitoring, and Sensor Technology Crosscutting Program (CMST-CP) & Subsurface Contaminants Focus Area, Office of Science and Technology, Office of Environmental Management, U.S. Department of Energy.
5. MARSSIM, NUREG-1575, EPA 402-R-97-016; US GPO, PO Box 37082, Washington, DC 20402-9328.
6. MARLAP, Vol 1-II, NUREG-1576, EPA 402-B-01-003, NTIS PB2001-10675, NTIS, Springfield, VA.
7. Long-Term Stewardship and The Weapons Complex: The Challenge Ahead, K. N. Probst and M. H. McGovern, June 1998, Resources for the Future, 1616 P Street, NW, Washington, DC 20036-1400.