Interstate Technology Regulatory Council - Decontamination and Decommissioning of Radiologically-Contaminated Facilities Guidance - 9118

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ABSTRACT

In January of 2008, the Radionuclides Team of the Interstate Technology Regulatory Council (ITRC) issued a technical and regulatory guidance document and related training titled, *Decontamination and Decommissioning of Radiologically-Contaminated Facilities*. It is intended to provide guidance on decontamination and decommissioning (D&D) to regulators, the public, project managers, cleanup contractors, and technology providers. It is further intended to educate interested parties in the concepts and processes involved with decommissioning and decontamination.

D&D of radiologically-contaminated facilities presents numerous challenges. At any given site, any D&D project may present complex overlaps with regulatory processes, stakeholder concerns, environmental issues, tribal concerns and treaty issues, monitoring and long-term stewardship and natural resources damage assessments. Attention to health and safety issues for workers and the public, monitoring and management of schedules and costs are also noteworthy. The objective is to reduce radiation risk to levels that are protective of workers and the public as well as the environment. In the ITRC document, "decontamination " means the removal or reduction of radioactive or other hazardous contamination from facilities, including both structural and non-structural materials and equipment. "Decommissioning" broadly refers to actions taken at the end of the life of a facility to enable its reuse or safe disposition. The decommissioning process generally incorporates some or all of the following activities: deactivation, waste management, decontamination, plant dismantling, demolition, and site remediation.

The document discusses major elements of the D&D undertaking – the regulatory framework (discussing the decommissioning requirements of the Nuclear Regulatory Commission, the Environmental Protection Agency, and the Department of Energy), costs, technologies, and health and safety. The document summarizes case studies of select closure sites, where some of the potential problems and decisions involved in the D&D process are explored. Stakeholder perspectives on the D&D process are also included. The document concludes by providing a distillation of lessons learned and factors for success during D&D. Both the D&D document and the training discuss EPA's tools for performing risk assessments for D&D types of activities.

INTRODUCTION

The purpose of this paper is to illustrate lessons learned from the decontamination and decommissioning (D&D) of radiologically contaminated facilities. These lessons were developed from an effort by the Radionuclides Team of the Interstate Technology Regulatory Council (ITRC) to compile and evaluate issues relevant to D&D activities in a technical and regulatory guidance. This guidance, *Decontamination and Decommissioning of Radiologically Contaminated Facilities*, was published in January 2008 and is available on the ITRC website (http://www.itrcweb.org/Documents/RAD5.pdf). This is the only document and training that we are aware of that address compliance with CERCLA when undergoing D&D activities.

The D&D of radiologically-contaminated facilities present numerous challenges. Many tasks are involved, each of which requires adherence to a complex array of federal and state regulations and policies, attention to health and safety issues for workers and the public, monitoring and management of schedules and costs, and interaction with a potentially large number of stakeholders who have an interest in the present activities and future plans for sites undergoing D&D. Even the terms "decontamination" and "decommissioning" are subject to variations of definition. For the purposes of this paper, "decontamination" refers to the removal or reduction of radioactive or other hazardous contamination from facilities, including both structural and nonstructural materials and equipment. The objective is to reduce radiation risk and/or exposure to be protective of public and worker health and safety and the environment. "Decommissioning" refers broadly to actions taken at the end of the life of a facility to retire it from service. The objective is to enable reuse or safe disposition of facilities and equipment. For radiologically-contaminated facilities, the decommissioning process generally incorporates some or all of the following activities: the deactivation and safe management of radioactive and other wastes; plant decontamination, dismantling, and demolition; and site remediation.

The size of the D&D task in the United States is enormous. The majority of decommissioning activities in the United States occur in two sectors: facilities licensed by the Nuclear Regulatory Commission (NRC) or agreement states and sites that come under the purview of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), including DOE and Department of Defense (DOD) sites. During the course of nuclear weapons research and development (R&D) and production activities, the federal government built and used more than 20,000 facilities, including production reactors, research reactors, chemical-processing facilities, uranium-production facilities, plutonium-production facilities, gaseous diffusion plants, hot cells, waste management facilities, and others. Some military bases were also contaminated as these weapons were deployed. Cleaning up the legacy left by nuclear weapons R&D and production is the largest and most expensive environmental project ever undertaken. More than 10,000 facilities are now surplus as the result of changes to the DOE mission and/or facility consolidation and obsolescence. More than 3,000 of these facilities have been decommissioned or are now slated for decommissioning within the DOE Environmental Management Program's life-cycle baseline, including some of the largest, most complex facilities in the world. Many are contaminated with both radioactive and hazardous substances, such as asbestos, beryllium, lead, and polychlorinated biphenyls (PCBs). Through 2006, more than 1,500 facilities had been decommissioned by DOE, including nuclear, radioactive, and industrial facilities.

The U.S. nuclear energy industry has considerable experience in decommissioning nuclear reactors. Nuclear energy provided the United States with nearly 21% of its electricity in 2002.
Presently, there are 104 operating nuclear power reactors in the United States, which produced 790 billion kilowatt-hours of electricity in 2004. The first commercial-scale nuclear plant was decommissioned in 1989. Since then, 14 nuclear plants, each greater than 100 megawatts, have been shut down and decommissioned. Currently, 16 power reactors and 14 test/research reactors are permanently shut down and undergoing decommissioning (IAEA 2006c).

COST AND PROJECT MANAGEMENT

According to DOE guidance, there are six major cost elements to consider in a D&D project (DOE 1995):

1. D&D Plan development
2. removal of materials and equipment from land and structures

3. construction and operation of support facilities
4. decontamination and/or removal of empty structures
5. waste management
6. contracting and project management

Prior to D&D actions occurring, detailed planning and the order of events must be set up in a D&D Plan and/or documents such as an Engineering Evaluation/Cost Analysis, Remedial Action Report, Waste Handling Plan and so on.

Document development can often account for 30% of total project costs (National Research Council 1996). The cost of documentation can be minimized by gathering as much knowledge about the site as practical in advance; planning for unknowns; planning for flexibility, including decision points throughout the process; and developing a team (regulatory and technical management) early. This approach will minimize potential work stoppage during D&D.

A well-developed D&D Plan requires input from several interested parties. The responsible party, in agreement with regulators and stakeholders, should analyze risks, costs, and social values (including future land use). The health and safety of the general workforce, as well as potential impacts to the local community and environment, need to be addressed. This process leads to wider public acceptance, which may minimize future costly delays. Numerous regulations and jurisdictions can lead to an agglomeration of requirements that must be clarified early on. Guidelines published by the NRC, DOE, and EPA provide assistance, regulatory coordination and compliance. State requirements and standards often also apply.

During the planning stage, the potential hazards of the various facilities should be identified and evaluated so that they can be prioritized according to their relative hazards. More hazardous facilities should generally be removed/mitigated first to lower maintenance costs and risks posed to workers, the public, and the environment. In some cases, factors such as availability of waste disposal sites, the location or physical relationship of facilities to one another, and continuing building usefulness may dictate the remediation of facilities in an order other than the hazard ranking. Likewise, maintenance and security expenses can be minimized by removing high-security features quickly, eliminating nonessential security activity. Personnel with lower clearance levels will be able to accomplish tasks without the need for escorts. This approach removes a layer of sometimes burdensome security. Finally, manpower needs can be reduced when high maintenance areas are addressed early.

The D&D Plan should consider previous D&D experience at the site or at other sites with similar problems. Taking time to compile process knowledge and to apply lessons learned can result in tremendous cost savings.

Clearly defining the future use of a facility is critical for estimating costs and developing a D&D Plan. As an example, cost estimates were developed for seven major plutonium buildings at the Rocky Flats Plant for attaining standby, restricted use, and unrestricted use conditions. A comparison of these estimates shows that the costs for performing the tasks required for a restricted use are about 4–5½ times the cost of a standby condition. At this facility for an incrementally small additional amount (approximately 10%) over the cost of a restricted use condition, an unrestricted use could be achieved (Rockwell International Energy Systems Group 1981).

The removal of equipment and materials from structures is the second cost topic to be considered. An active surveillance and maintenance program must exist at any radiologically contaminated structure until the contamination is controlled or contained. These expenditures can be saved with expedited equipment removal actions, performed in a safe and orderly manner. Decisions must be made whether and how to segregate and decontaminate the removed equipment and whether or not any of it can be recycled. The large amount of equipment from D&D structures can potentially result in large amounts of low-level waste. When economical, equipment and materials can be decontaminated for reuse. However, economics alone do not often justify the cost of decontamination. If items are not releasable to the public, they may still find a purpose on a controlled DOE site. Since the public and the regulatory community have a significant interest in how materials and equipment are disposed of or reused, effective communication greatly increases the likelihood of success. Further, as these communications can take a considerable amount of time, the process should be started early. Free-release standards should also be discussed with the regulatory community at an early stage to avoid any misinterpretations.

Construction and operation of support facilities is a third cost element. If at all possible, it is best to use existing buildings as support facilities for personnel and operations such as decontamination, waste segregation, waste packaging, etc. This approach may be impractical due to contamination or building logistics. In such cases, the construction of small, dedicated shops is preferred over the construction of large, multipurpose facilities. It is important to remember that the future cost of demolishing or decontaminating these newly constructed facilities must be considered in the total cost.

The question of whether or not to decontaminate and reuse or remove empty structures is an important decision point. If the planned future use is industrial, decontamination and reuse of existing facilities is a viable option. Costs must be weighed between the decontamination and handling of waste streams from the building or the demolition and removal of the structure.

The cost of waste management can have a significant impact on D&D projects since large quantities of low-level waste (LLW), hazardous waste, and mixed waste (MW) can be generated.. Waste management covers safe and economic disposal, including collection, separation, treatment, packaging, and transportation of the products generated from the D&D process. Costs can vary considerably depending on how efficiently a site's waste management strategy addresses each of these elements. A major decision at most sites is whether all wastes will be transported to an offsite disposal facility or if some wastes can be disposed of in facilities constructed on site.

Characterization of hazardous substances to determine their identities, forms, amounts, and locations is essential before, during, and after D&D operations. Sampling allows wastes to be segregated, determining how various waste streams need to be dispositioned. It is sometimes more cost-effective and safer to assume a whole structure or part of a structure is contaminated and dispose of it as such in an acceptable landfill rather than attempt to segregate the waste into component streams. Historical knowledge of the contaminated structure (to assist characterization), available landfill space, and disposal costs need to be considered.

If classified wastes are encountered, the site must be secure enough to handle, maintain, and protect those specific wastes. The facility must then incur the added cost of security (guards, fencing, and personnel security clearance) to handle classified waste on site or ship it off site to a secure facility.

An aggressive waste minimization effort applied to personal protective equipment (PPE), clothing, tools, chemicals, and supplies helps reduce waste disposal costs. The generation of mixed waste in particular should be kept to a minimum due to the expense and difficulty of locating an acceptable location for its disposal. Waste treatment sometimes allows less costly disposal; e.g., the cost of treating mixed waste might be warranted if it could be disposed of as low-level waste at a significant cost savings.

Although a consensus does not exist among the regulatory community, one means of reducing the quantity of waste produced is to decontaminate radioactive materials (primarily metals) to a level sufficient to permit sale to the commercial market. In addition to reducing wastes, this step produces revenue for the project. Recycling metals commonly found at radiologically contaminated sites (such as steel, stainless steel, nickel, copper, aluminum, mercury, and depleted uranium) can recoup costs, but release standards must still be met. Potentially recyclable products should be segregated into clean scrap, contaminated scrap that can be decontaminated economically, and contaminated scrap that cannot be decontaminated economically. A choice must sometimes be made between disposal costs and reducing volume. A great deal of consideration must be given to the cost and benefit of decontaminating materials to recycle and reuse since decontamination produces a waste stream that must be addressed. The cost of recycling is more than just a monetary issue since valuable space in landfills can be freed up if the choice is made to decontaminate or recycle materials

A number of components of the waste shipment process are capable of creating bottlenecks for the entire D&D process. Careful consideration and planning can reduce the potential for significant delays. Sufficient on-site storage capacity must be available, along with staging areas for loading waste containers. Containers must be compatible with transportation vehicles and unloading equipment at disposal facilities. Optimizing container size and purchasing containers in quantity can often yield significant discounts and reduce delays.

Finally, project management considerations must be evaluated for cost savings. Cost-effective management requires a management structure that is streamlined, orderly, responsive, and focused on safety and cost containment. Management layers need to be minimized using an integrating contractor or a single, independent contractor where possible. Multiple layers of management lead to added cost and a high ratio of management and professional services to cost of execution of the physical decommissioning.

The contractor should be given adequate responsibility and accountability in performing the operations. Fixed-price contracts with incentives for cost and schedule reduction should be used where possible. The roles of the contractor and any subcontractors should be well-defined.

Experience from various D&D projects has led to some general principles that are useful for contractors/project managers to consider:

- D&D planning should include the following:
  - project schedules with associated management details
  - a precleanup survey, including both radiological measurements and thorough documentation of the previous uses of the facility must be made to assist in planning
  - administrative activities for procurement
  - establishing equipment removal sequences for each area, taking into account the effects on building exhaust, air-supply, power, and communication systems
  - scheduling and supervision of work assignments for specific D&D tasks
  - allotment of sufficient storage space for equipment and materials awaiting disposition
- The early stages of D&D planning should incorporate environmental considerations along with technical and economic issues in decision making.
- Selection of suitable disposal or storage sites for contaminated materials is a critical step.
- Choosing personnel experienced in D&D processes will increase the efficiency of any task.
- D&D projects are labor-intensive; final costs are therefore very sensitive to changes in labor rates.
- Applying lessons learned from previous projects and from other sites makes a project more efficient and less costly.
- Early and frequent input from stakeholders will more likely result in a project that gains and maintains critical support from local governments and politicians.
- Consulting with regulatory agencies before and during D&D efforts will save time and effort in the long run.
- Close coordination with regulators can allow decisions to be made in the field.

• Resources are used more efficiently when similar remediation tasks are done simultaneously.
• Plans need to be open to ideas and scrutiny throughout the entire D&D process.
• Environmental efforts must be evaluated to ensure that soils and groundwater are not recontaminated during the process (e.g., contaminated soil should not be staged in an area already remediated).
• Delays in the waste shipment process are capable of creating bottlenecks for the entire D&D process.
• Optimize the use of automation and robotics in repetitive operations, taking into consideration factors such as reliability, decontamination needs, additional waste generation, etc. Robotics minimizes the potential exposure and radiation dose to the worker, thus reducing the amount of person hours and health and safety monitoring as well.
• Optimize the use of heavy equipment for similar operations. The high cost of leasing heavy equipment dictates its prudent use. Leased equipment must be decontaminated or purchased if the equipment cannot be cleaned for free release.
• Focused demonstrations are necessary to determine which technology is best suited for a particular site and particular project. Major R&D programs usually are not beneficial at this stage.
• Sacrificing attention to health and safety requirements may result in costly delays if incidents lead to violations and work stoppages.
• Removing classified or high-security items early in the process minimizes the need for specialized security monitoring.
• Waste-reduction efforts can result in tremendous cost savings.
• All D&D operations from initial cleanup to the final radiological certification survey must be thoroughly documented.
• Mock-ups should be used as decommissioning trials to account for missed procedures.

CERCLA Approach to D&D

The United States Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI) is responsible for implementing the long-term (non-emergency) portion of a key U.S. law regulating cleanup: the Comprehensive Environmental Response, Compensation and Liability Act, CERCLA, commonly known as “Superfund.” The purpose of the Superfund program is to protect human health and the environment over the long term from releases or potential releases of hazardous substances from abandoned or uncontrolled hazardous waste sites.

While every Superfund site is unique, and thus cleanups must be tailored to the specific needs of each site, there are two requirements that must be met at every site. CERCLA requires that all remedial actions at Superfund sites must be protective of human health and the environment. Therefore, cleanup actions are developed with a strong preference for remedies that are highly reliable, provide long-term protection and provide treatment of the principle threat to permanently and significantly reduce the volume, toxicity, or mobility of the contamination. In addition, CERCLA specifically requires Superfund actions to attain or waive the standards and requirements found in other State and Federal environmental laws and regulations. This mandate is known as compliance with “applicable or relevant and appropriate requirements” or ARARs.

To help meet the Superfund program’s mandate to protect human health and the environment from current and potential threats posed by uncontrolled hazardous substance releases (both radiological and nonradiological), EPA has developed a human health evaluation process as part of its remedial response program. The process of gathering and assessing human health risk information is adapted from well-established chemical risk assessment principles and procedures. The Superfund Baseline Risk Assessment provides the EPA's estimate of the likelihood and magnitude of health problems occurring if no cleanup action is taken at a site.

Cleanup levels for radioactive contamination at CERCLA sites are generally expressed in terms of risk levels, rather than millirem or millisierverts, as a unit of measure. CERCLA guidance recommends the use of slope factors in the EPA Health Effects Assessment Summary Tables (HEAST) when estimating cancer risk from radioactive contaminants, rather than converting from millirem. HEAST is based on risk coefficients in Federal Guidance Report 13.

Compliance with the requirements of other Federal environmental laws, more stringent State environmental laws, or State facility-siting laws is often the determining factor in establishing cleanup levels at CERCLA sites. However, where ARARs are not available or are not sufficiently protective, EPA generally sets site-specific remediation levels for: 1) carcinogens at a level that represents an upper-bound lifetime cancer risk to an individual of between 10^{-4} to 10^{-6}; and for 2) non-carcinogens such that the cumulative risks from exposure will not result in adverse effects to human populations (including sensitive sub-populations) that may be exposed during a lifetime or part of a lifetime, incorporating an adequate margin of safety. The specified cleanup levels account for exposures from all potential pathways, and through all media (e.g., soil, ground water, surface water, sediment, air, structures, and biota).

The 10^{-4} to 10^{-6} cancer risk range can be interpreted to mean that a highly exposed individual may have a one in 10,000 to one in 1,000,000 increased chance of developing cancer because of exposure to a site-related carcinogen. Once a decision has been made to take an action, EPA prefers cleanups achieving the more protective end of the range (i.e., 10^{-6}). EPA uses 10^{-6} as a point of departure and establishes Preliminary Remediation Goals (PRGs) at 1×10^{-6}.

To assess the potential for cumulative noncarcinogenic effects posed by multiple contaminants, EPA has developed a hazard index (HI). The HI is derived by adding the noncancer risks for site contaminants with the same target organ or mechanism of toxicity. When the HI exceeds 1.0, there may be concern for adverse health effects due to exposure to multiple contaminants. Radioisotopes of uranium are generally the only radionuclides for which EPA will evaluate the HI.

Excess cancer risk from both radionuclides and chemical carcinogens should be summed to provide an estimate of the combined risk presented by all carcinogens. Exceptions would be cases in which a person cannot reasonably be exposed to both chemical and radiological carcinogens. Similarly, the chemical toxicity from uranium should be combined with that of other site-related contaminants in calculating the HI.

There are generally several differences between cancer slope factors (the cancer risk (i.e., proportion affected] per unit of dose used in EPA's Integrated Risk Information System chemical files) for radionuclides and chemicals. However, similar differences also occur between different chemical slope factors. In the absence of additional information, it is reasonable to assume that excess cancer risks are additive for purposes of evaluating the total incremental cancer risk associated with a contaminated site.

PRGs are used for site "screening" and as initial cleanup goals if applicable. PRGs are not de facto cleanup standards and should not be applied as such. The PRG's role in site "screening" is to help identify areas, contaminants, and conditions that do not require further federal attention at a particular site.

PRGs not based on ARARs are risk-based concentrations, derived from standardized equations combining exposure information assumptions with EPA toxicity data. PRGs based on cancer risk are established at 1×10^{-6}. PRGs are identified early in the CERCLA process. PRGs are modified as needed based on site-specific information.

EPA has recently completed one risk assessment tool, and is close to completion of another that are particularly relevant to decommissioning activities conducted under CERCLA authority. EPA developed the Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) electronic calculator to help standardize the evaluation and cleanup of radiologically contaminated buildings at which risk is being assessed for occupancy. BPRGs are radionuclide concentrations in dust, air and building materials that correspond to a specified level of human cancer risk. The BPRG calculator may be found at: http://epa-bprg.ornl.gov/.

The intent of the draft Preliminary Remediation Goals for Radionuclides in Outside Surface SPRG calculator is to address hard outside surfaces such as building slabs, outside building walls, sidewalks and roads. SPRGs are radionuclide concentrations in dust and hard outside surface materials. The BPRG and SPRG calculators include both residential and industrial/commercial exposure scenarios.

To facilitate compliance with dose-based ARARs while conducting decommissioning activities under CERCLA, EPA is developing two electronic calculators. These are the Radionuclide Building Dose Cleanup Concentrations (BDCC) and the Radionuclide Outside Hard Surfaces Dose Cleanup Concentrations (SDCC) electronic calculators. Both of these ARAR dose calculators are set up in a similar manner to the BPRG and SPRG calculators. They include the same exposure scenarios. Also, the equations in the scenarios are essentially the same except the ARAR dose calculators use: dose conversion factors instead of slope factors, and a year of peak dose instead of risk over a period of exposure such as 30 years. When finalized, all four of these calculators will found at the following webpage: http://www.epa.gov/superfund/health/contaminants/radiation/radrisk.htm.

D&D TECHNOLOGY

Technology plays an important part in the D&D process. Throughout D&D, needs arise that must be met through innovative techniques or equipment. Types of technologies that are applicable to D&D include:

- Site Characterization and Verification Sampling
- Decontamination
- Contamination Control
- Cutting and Sizing
- Solids Removal
- Liquids Removal
- Robotics
- Large Structure Demolition
- Waste Sampling for Disposition
- Packaging and Transportation
- Work Monitoring

A few technologies taken from the ITRC D&D document are included below as examples of these types of technologies.

Characterization and verification sampling is intended to provide an understanding of the nature and extent of contamination sufficient to assess potential risks to human health and the environment. Verification sampling is conducted following D&D activities to demonstrate that specific remediation goals or waste acceptance criteria have been met.

A wide range of tools is available for characterization and verification sampling. How these tools are applied is also important to the quality of the characterization and verification process. Strategies such as Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM 2001) provide recognized approaches for determining which data need to be gathered, selecting what level of detail is required, and guiding the analysis and interpretation of the data.

The horizontal directional drilling (HDD) and environmental measurement while drilling (EMWD) provides an example of the one of the tools available. These two technologies were brought together to meet the need of remotely characterizing subsurface soil contamination under structures.

Surface Decontamination is important for cost saving disposal options. Technologies that have been successfully used on radiologically contaminated surfaces include both wet and dry methods of physically removing surface layers. Other methods, such as chemical peeling and chemical applications, can work well on steel surfaces but are limited on porous surfaces such as concrete. EPA's *Technology Reference Guide for Radiologically Contaminated Surfaces* (EPA 2006) provides a comprehensive listing of available decontamination technologies and describes several. Chemical decontamination with cerium nitrate or acids and hydrolasing using high pressure water are example technologies.

Contamination control minimizes the uncontrolled distribution of radioactive material in a given environment. For highly radioactively contaminated rooms, a two-step process using an aerosol sugar fog has been used to remove the contamination from the air and then seal it in place on the floor and walls of the room. The continued success of room fogging has resulted in avoiding countless hours of potential worker exposure to airborne radioactive particles. In many applications, entry requirements could be downgraded to standard air-purifying respirators after the fixative was applied, resulting in a cost savings. A lower derived air concentration also eliminated the need for multiple entries in expensive and cumbersome supplied air suits.

Cutting and sizing is important for limiting void space in disposal and for easy removal. Technologies used in this process include plasma-arc cutting, ultra-high pressure water jet and explosive cutting.

Solids Removal Systems incorporate vacuums and pumping systems to remove contamination while reducing worker exposure. A **liquid removal** technology has cost effectively used biodegradation reagents to metabolize oily sludges in areas with radiological contamination.

Robotics is a branch of engineering that involves the conception, design, manufacture, and operation of robots. For purposes of D&D, a robot is a machine designed to execute one or more tasks repeatedly, with speed and precision.

Two robotic technologies that clean up high-level hazardous/radioactive storage tanks and facilities are the Houdini and the Modified Light-Duty Utility Arm (MLDUA). Houdini is a remotely controlled (through a tether), hydraulically powered, folding vehicle that can pass through 24-inch openings in tanks ("risers") and then open to a 4 × 5 foot mini-bulldozer, complete with a plow blade; a dexterous, high-payload manipulator; and remote camera system.

The MLDUA is a large, robotic manipulator with seven degrees of freedom. It can deploy a 200-pound payload through risers as narrow as 12 inches in diameter. The MLDUA is equipped with a gripper end-effector that allows the arm to grasp other tools. The MLDUA is also equipped with two cameras located at the mast and arm junction and an additional camera in the gripper. It is skid-mounted so a crane can position it on the tank platform where it rests on adjustable outriggers.

Explosives have been utilized to accomplish large-structure demolition more cost-effectively and safely. Harmonic delamination is a technique used to fracture concrete away from rebar in thick hardened-concrete buildings. A building is prepared by drilling from the roof down to make hollow openings in the thick walls. Small amounts of explosives are placed in the holes and detonated sequentially. When the charges are detonated, high-velocity detonation waves move through the walls, separating the concrete from the rebar reinforcement. These pressure or sonic waves are tuned to the rebar/concrete laminate to literally shake up the building and make conventional mechanical demolition feasible. Explosive demolition can be used to more safely topple stacks and towers and to collapse large buildings in on themselves.

The aim of **waste sampling** is to determine the proper waste disposition method by obtaining one or more samples representative of the waste stream. The first step is to identify what questions need to be answered about the site and why. The next step is to develop an initial sampling plan to produce the data needed to answer those questions. The final steps include incorporation of sampling design, quality assurance/quality control (QA/QC), and statistical considerations. MARSSIM provides some very good information on sampling design. Combining field instruments with new decontamination techniques can dramatically reduce waste shipments.

The requirements for **packaging and transportation** of each waste type should be determined as early as possible. Packaging and transportation requirements are affected by the type of waste, type and level of contamination, waste acceptance criteria of the disposal site, and the method of transportation. Several technologies are available to simplify the process of meeting packaging and transportation requirements for specific wastes and sites. A good example is dispersible polyurethane foam, which has been used as a block and brace media for waste shipments.

Work monitoring technologies are important for the health and safety of the worker. For instance, mobile lung counters allows a site to maintain a lung-counting capability on site after existing medical facilities have been removed by D&D operations. Also a wireless alarm system has been developed to replace existing safety systems in buildings undergoing D&D where electrical power has been terminated. The system consists of individual wireless transmitters reporting to repeaters, which in turn, report to head-end equipment integrated with a fire alarm system.

HEALTH AND SAFETY

Health and safety issues associated with D&D of nuclear facilities are addressed by a complex set of technical and managerial practices. The protection of workers, the environment, and the public against radiation exposure is obviously a critical aspect of D&D and usually dominates public concern. However, it is important to keep in mind that the broad range of activities involved in decommissioning a nuclear facility includes a host of risks that are nonradiological in nature; such risks are covered by OSHA regulations and state occupational safety and health program regulations. It is widely accepted that the radiological hazards associated with a nuclear facility undergoing decommissioning are substantially less than those that pertain when it was in its operating state. Even so, it is also clear that D&D activities, which tend to involve a set of contractors and workers who are new to the facility and operating in a temporary mode, bring risks that were not planned for in the course of routine operations.

Both radiological and nonradiological hazards need attention during D&D. In general, radiological hazards fall into four categories: external exposure, ingestion and inhalation of radionuclides, criticality, and breach of containment., overall radiological risks can be lower during D&D than during regular operation. However, the nature of D&D activities can mean that there is an enhanced risk of exposure for some workers during this phase. Remote handling and robotics technologies can greatly mitigate these risks, but when these are unavailable, worker exposure must be carefully managed. Similarly, the ingestion and inhalation of radionuclides from surface contamination present a genuine risk that must be clearly addressed by standard worker protection measures. The potential for criticality and breach of containment are usually of less concern, but in some scenarios—such as the case where fissile material remains in process equipment—the possibility must be recognized and field activities planned accordingly. Containment systems can be particularly problematic. Those used during operation may no longer be working, and even if they are, there is no assurance that they can match the increased and varying demands of D&D activities. Radiological protection against these hazards is provided by a number of technical and managerial measures, including isolation and removal of radioactive material, spill prevention and dust/aerosol suppression techniques, bulk shielding of workers, discrete individual shielding through personnel protective clothing etc., training, air filtering, wastewater treatment, and appropriate waste-disposal techniques.

Nonradiological hazards include fire (the most common risk due to presence of flames in cutting technologies coupled with the accumulation of potentially combustible wastes), explosions (originating in dusts produced), toxic materials (particularly in aged facilities where material no longer allowable [e.g., asbestos] may be present), and electrical and physical hazards (e.g., noise, confined space risks, impact trauma from falling objects, etc). Standard industrial and commercial safety practices should be employed to address these concerns.

Safety in D&D can best be ensured by having the broad range of individual safety issues properly sequenced and addressed in a manner that progressively removes hazards. These issues are collected in a project-specific Health and Safety Plan (HASP). The HASP identifies potential safety and health hazards associated with D&D activities and sets forth a comprehensive set of procedures and controls to mitigate and eliminate the hazards. The major D&D activities addressed by the HASP include sampling; characterization; removal of chemical, hazardous, and radiological materials and associated equipment; major decontamination activities; dismantlement; and remediation of the contaminated environment. An effective and high-quality HASP must provide a clear chain of command for safety and health activities, accountability for safety and health performance, well-defined expectations regarding safety and health, well-defined task and operational hazards/risks, comprehensive hazard prevention and control methods, and recordkeeping requirements to track program progress.

DOE developed an approach called Integrated Safety Management (ISM) to address safety.
ISM is a process for systematically integrating safety awareness and good practices into all phases of work throughout DOE. It emphasizes safety as an integral part of each activity as opposed to being a stand-alone program and requires all personnel to conduct their work in such a manner that protects themselves, other workers, and the public and does not cause harm to the environment. ISM is defined by a continuous five-step process:

- **Define the scope of work:** Missions are translated into work, expectations are set, tasks are identified and prioritized, and resources are allocated.
- **Analyze the hazards:** Hazards associated with the work are identified, analyzed, and categorized.
- **Develop and implement hazard controls:** Applicable standards, policies, procedures, and requirements are identified and agreed upon; controls to prevent/mitigate hazards are identified; and controls are implemented.
- **Perform work within controls:** Readiness is confirmed, and work is performed safely.

• **Provide feedback and continuous improvement:** Information on the adequacy of controls is gathered, opportunities for improving the definition and planning of work are identified, and line and independent oversight is conducted.

LESSONS LEARNED

In conclusion, the team developed a lessons learned which is probably the most important outcome of this paper in relation to D&D activities. Considerable experience and knowledge has been gathered over the recent years in the United States regarding D&D activities at radiologically contaminated facilities. In a review of the cleanup at Rocky Flats, the GAO observed that DOE has no process for ensuring that all lessons are captured and implemented at other DOE sites. The GAO concluded that DOE may be losing the chance to save both time and money in its ongoing site cleanup efforts (GAO 2006).

The ITRC Radionuclides Team summarized "lessons learned" in undertaking the effort to survey the current status of D&D activities.. The following factors are offered for consideration in making D&D more successful.

• End-States—The anticipated future site use should be established before implementing D&D activities.
• Unexpected Issues—In all stages of D&D, one should expect the unexpected and hence plan for contingencies. D&D projects vary greatly, and unique situations occur frequently.
• Documentation—Thorough documentation is very important since the final activities of a D&D project may take place years after the first.
• Communication—All responsible parties should be involved early in the process.
Stakeholders and regulators are important and should be kept up to date with ongoing plans. The D&D plan should have well-defined goals and mutually agreed-upon end-points.
Documentation is an important part of the process and the final record. Former employees are an asset; their knowledge of the facility can be very useful in planning and other activities.
• Planning—Early planning is essential and should incorporate environmental considerations along with technical and economic issues in decision making.
• Removal Actions—At CERCLA sites, D&D can be expedited by using removal authority, also known as "accelerated cleanup." It is a joint policy between DOE and EPA to use removal authority to perform D&D. • Residual Material—If in-process material is allowed to remain in the various production facilities' tanks and pipelines, D&D is greatly complicated and future risks and liabilities can be greatly increased.
• Information exchange—Learn from other D&D activities and identify processes that may solve problems at the current site. Technical workshops or public meetings dealing with D&D in other areas should be sought out. Pilot studies and case studies are good sources of knowledge.
• Innovative Technologies—Innovative technologies should be evaluated and can result in lower life-cycle costs, accelerated schedules, and reduced worker exposure. Established technologies from other sites should be reviewed.
• Site History—Past history of the site must be reviewed. Documentation that lays out the purpose, function, and events associated with the site should be gathered, and personnel present during prior operations at the site should be used. Data gaps can then be addressed.
• Characterization—Characterization is a continuous process. It is conducted to understand health and safety concerns for workers, protect human health and the environment, understand the nature and extent of contamination, and anticipate the disposition of waste.
• Cleanup Levels—Standards for acceptable levels of residual contamination must be developed for equipment, soil, and any recyclable resources before release for restricted or unrestricted use. Appropriate decontamination levels may vary from site to site and depend on future site uses, the controlling authority (EPA CERCLA risk range, NRC dose limits, guidelines in DOE Orders, state standards or

decommissioning criteria, etc.), stakeholder input, and other site-specific factors. See *Determining Cleanup Goals at Radioactively Contaminated Sites: Case Studies* (ITRC 2002).

• Waste Management—Expertise on regulations for handling and packaging the waste allotments should be available. Waste destination, containers, transportation issues, and cost involved with disposal methods should be evaluated. Uncertainty about waste disposal availability is expected to continue, and decommissioning plans must adapt to changing conditions regarding this important step in the process. Waste reduction, both during operation of the facility and decommissioning, should be an important feature.

• Recycling/Reuse—From a practical point of view, though recycling is commendable, cost and liability considerations often mean that only clean, segregated material can be recycled. If there is an on-site disposal facility, then recycling is unlikely to be cost-effective and is thus unlikely to be chosen as an option, particularly when there is a cost-performance contract in place. If there is no on-site disposal facility, then recycling becomes a more viable option.

• Safety—It is essential to have a good safety program that informs the workers, regulators, and the public of site hazards and either contains or eliminates them. Improved safety performance results from top-management involvement, planning, training, and allocating responsibility to first-line supervisors.

• Detection Limits—If field equipment is not sufficiently sensitive to detect contamination at levels as low as the cleanup criteria, it may be necessary to send samples to an off-site laboratory for analysis. For information on real-time field-detection methods, refer to *Real-Time Measurement of Radionuclides in Soil: Technology and Case Studies* (ITRC 2006).

• Labor/Costs—A contractor with previous knowledge and experience with the D&D process should be hired. To include all goals associated with D&D of the facility, all responsible parties should be involved with planning. A project team with the proper resources and experience to evaluate the task should be assembled. Potential problem areas should be envisioned early so as not to hinder the project target dates. Decommissioning is intensive; thus final costs are very sensitive to changes in labor rates. Cost savings can result from the following:

− operating efficiencies that result from eliminating unnecessary duplication of management at multiple project sites
− subcontracting for multiple scopes of work
− retaining an experienced workforce
− avoiding demobilization and remobilization

• With experience, there should be operational efficiencies generally consistent with a learning curve. Cost reductions should accompany this increase in efficiency.

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