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DEMONSTRATION RECOMMENDATIONS FOR ACCELERATED TESTING OF CONCRETE DECONTAMINATION METHODS

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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ACRONYMS, ABBREVIATIONS, AND INITIALISMS

ANL	Argonne National Laboratory
BCL	Battelle Columbus Laboratories Decommissions Project
BEMR	Baseline Environmental Remediation Report
BNL	Brookhaven National Laboratory
D&D	deactivation, decontamination, and decommissioning
DOE	U.S. Department of Energy
EM	Office of Environmental Restoration and Waste Management
ETEC	Energy Technology Engineering Center
ft	feet
FY	fiscal year
gal	gallons
h	hour
in.	inch
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory
lb	pound
LBL	Lawrence Berkeley Laboratory
m	meter
METC	Morgantown Energy Technology Center
min	minute
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
ppm	parts per million
psi	pounds per square inch
R&D	research and development
RFETS	Rocky Flats Environmental Technology Site
s	second
SFIA	Surplus Facility Inventory Assessment

SRS	Savannah River Site
TRU	transuranic (elements)
TTP	technical task plan
UV	ultraviolet
WSS	Weldon Spring Site Remedial Action Project
WVDP	West Valley Demonstration Project

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ABSTRACT

A large number of aging U.S. Department of Energy (DOE) surplus facilities located throughout the U.S. require deactivation, decontamination, and decommissioning. Although several technologies are available commercially for concrete decontamination, emerging technologies with potential to reduce secondary waste and minimize the impact and risk to workers and the environment are needed. In response to these needs, the Accelerated Testing of Concrete Decontamination Methods project team described the nature and extent of contaminated concrete within the DOE complex and identified applicable emerging technologies. Existing information used to describe the nature and extent of contaminated concrete indicates that the most frequently occurring radiological contaminants are ^{137}Cs, ^{238}U (and its daughters), ^{60}Co, ^{90}Sr, and tritium. The total area of radionuclide-contaminated concrete within the DOE complex is estimated to be in the range of 7.9×10^8 ft^2 or approximately 18,000 acres.

Concrete decontamination problems were matched with emerging technologies to recommend demonstrations considered to provide the most benefit to decontamination of concrete within the DOE complex. Emerging technologies with the most potential benefit were biological decontamination, electro-hydraulic scabbling, electrokinetics, and microwave scabbling.

1. INTRODUCTION

The end of the Cold War and the decision to reduce the size of the nuclear weapons production complex have created a need for the deactivation, decontamination, and decommissioning (D&D) of a large number of aging, surplus facilities by the U.S. Department of Energy (DOE) (U. S. DOE 1994). These facilities, located throughout the U.S., require a monumental effort for cleanup, with the goal of minimal impact and risk to the workers and the environment. The nature and magnitude of D&D problems require the development and application of technologies that will address the problems quickly and cost-effectively.

In many cases, closure and/or transition of the facility cannot take place until contaminated concrete is either disposed of or decontaminated. Methods and technologies used in past efforts were adequate on a small scale and may still be appropriate for some tasks; however, exclusive reliance on these technologies could result in deficiencies such as high costs and large waste volumes in the expanding D&D program (U. S. DOE 1994). In addition, current technologies tend to be labor-intensive and expensive, produce large volumes of secondary waste, and may expose workers to radiation and hazardous substances unnecessarily.

A technical task plan (TTP) entitled Accelerated Testing of Concrete Decontamination Methods was submitted by Oak Ridge National Laboratory (ORNL) responding to these needs for decontamination of concrete-contaminated facilities. The goals and objectives of the TTP will be accomplished through several interrelated tasks (Fig. 1.1). Task 1 describes the nature and extent of contaminated concrete within the DOE complex and identifies applicable emerging and commercial technologies. Task 2 consists of matching technologies to problems to provide recommendations for concrete decontamination demonstrations. Task 3 will initiate and implement up to four demonstrations in fiscal year (FY) 1995 and FY 1996. Task 4 will be to continue work on electrokinetic investigations initiated in FY 1994.

The purpose of this report is to recommend technologies for demonstration. The information providing the basis for the recommendations (task 1 and 2 efforts) is found in *Contaminated Concrete: Occurrence and Emerging Technologies for DOE Decontamination* (Dickerson et al. 1995).

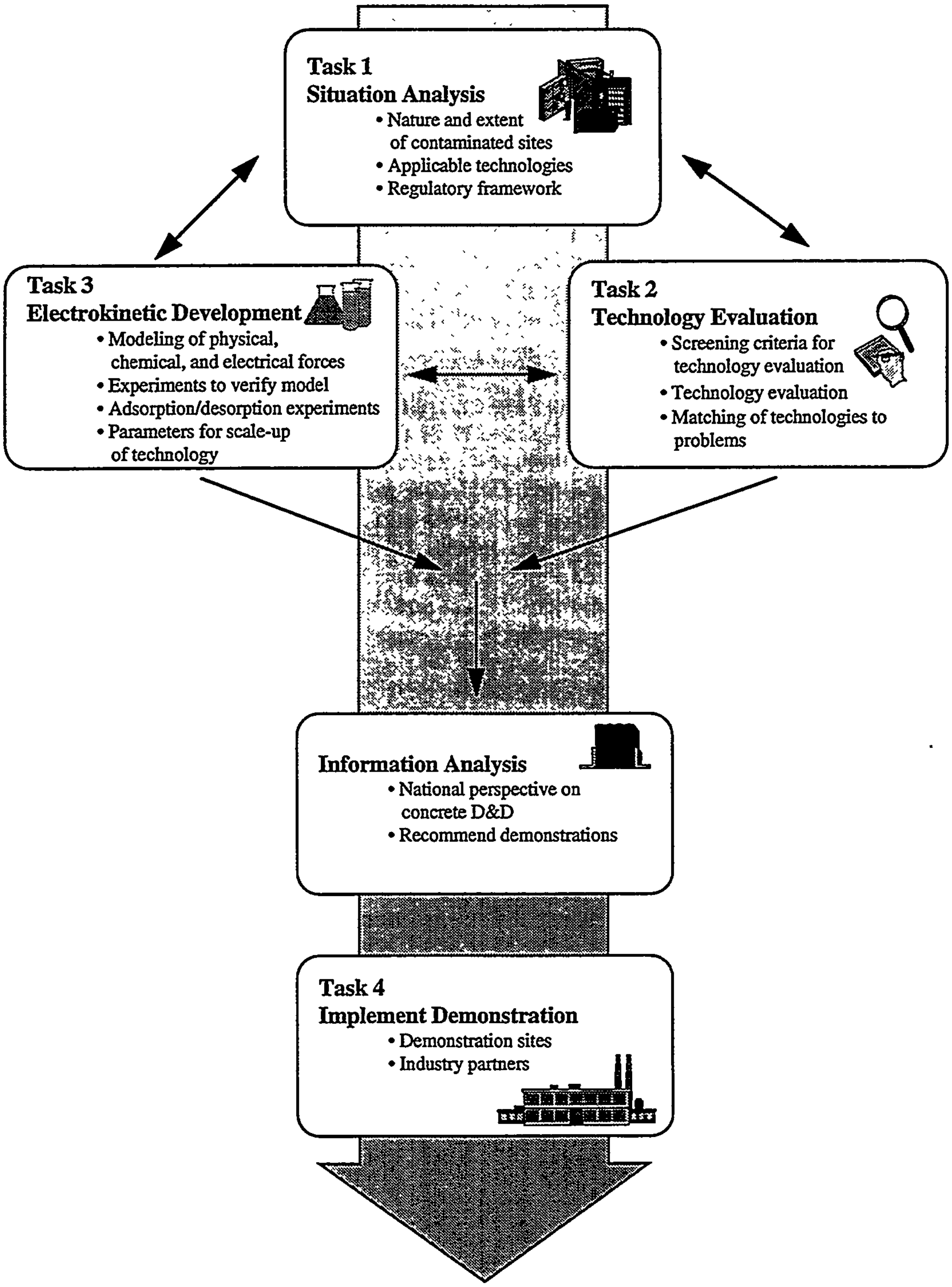

Fig. 1.1 Project conceptual framework.

2. NATURE AND EXTENT OF CONCRETE CONTAMINATION

The first work element of this project involved problem definition through description of the nature and extent of concrete contamination throughout the DOE complex. This was completed through various information-gathering activities, including database searches, acquisition of numerous sources describing site histories and characterization, and phone and written inquiries conducted with knowledgeable staff at the individual DOE sites.

2.1 RESULTS

As stated previously, concrete D&D has been identified by DOE as a major area of concern, requiring technologies that provide better and faster decontamination of the sites (U. S. DOE 1993a). Indeed, concrete was identified as the fourth most serious D&D problem following (1) establishing *de minimis* levels, (2) decontamination of metals, and (3) the need for improved characterization techniques. In a technology assessment developed by the DOE Office of Environmental Restoration and Waste Management (EM) and experts from across the country, the severity of concrete problems was ranked on a scale of 1 to 10, from no problem to major problem (Table 2.1). Sites were ranked qualitatively and independently. For example, experts knowledgeable about the Oak Ridge K-25 Site deemed contaminated concrete a major problem and, therefore, assigned a ranking of 10. These rankings cannot be compared between sites [e.g., Paducah Gaseous Diffusion Plant (Paducah) vs. Idaho National Engineering Laboratory (INEL)] because the ranking was not considered to be relative across the DOE complex but rather an indication of the severity of contaminated concrete at that site.

A large volume of documentation pertaining to the nature and extent of concrete contamination in the DOE complex was gathered (Dickerson et al. 1995). For a number of reasons, contaminant extent is site-specific in nature and difficult to generalize across the DOE complex (e.g., variety of facilities, different facility histories and uses, varying stages of characterization). However, several general trends were observed. The observations and generalizations of contaminant occurrence and potential extent of contaminated concrete are based on limited data and are not meant to be exact inventories of the entire DOE complex.

2.1.1 Extent of Concrete Contamination

Table 2.2 provides a summary of the generic types of facilities in the DOE complex and the typical concrete problems associated with each type. A facility is defined as a functional unit (e.g., building, structure, section of a structure, containment, or equipment) that requires D&D. Concrete with high-level contamination (typically associated with reactors, hot-cells, fuel-fabrication, and canyon facilities) is most often dismantled and disposed of; the decontamination is costly and creates a risk of increased worker exposure. If high-level contamination areas require decontamination, remote methods are typically used.

Concrete with low-level contamination, typically found in research and development (R&D), weapons materials production, and enrichment facilities, may be decontaminated to minimize waste disposal. Larger sites, such as the Oak Ridge Reservation (ORR) and the Savannah River Site (SRS), contain many types of facilities and a large variety of concrete conditions, hence the difficulty in gathering volume estimates.

Data from the BEMR Database

The Baseline Environmental Remediation Report (BEMR) database provided estimates on the total square footage and the percentage of contaminated floor space for each facility in the database. This information, which was restricted to buildings and did not include containments such as basins or pools, is useful, assuming that the buildings have at least as much contaminated concrete as the estimated percent of contamination. The concrete thickness in the walls and ceilings was considered in the reported percent of contamination, but an exact volume of concrete was not available. Furthermore, characterization at many sites is in the early stages, and the site could not yet be included in the database. Therefore, estimates in the BEMR database do not completely reflect the extent of contaminated concrete throughout the DOE complex.

When all buildings with available information were considered, a total of 689 facilities were evaluated, representing an estimated total of 0.79 billion ft^2 of potentially contaminated concrete. This estimate is equivalent to approximately 18,000 acres. Although there are many unknowns associated with the estimate, it provides an order-of magnitude estimate of the extent of contaminated concrete. While it is likely that the sites with the largest square footage will also have large volumes of contaminated concrete, ranking based on square footage of potentially contaminated floor (i.e. Hanford > ORR) is not possible because information is not available for all sites. Larger sites that have incomplete data in the database are expected to exceed the largest single current estimate (i.e., INEL, Oak Ridge K-25 Site).

Data from Site Queries

Information obtained from site queries generally agrees with the BEMR database regarding which sites have the largest extent of contaminated concrete. However, the order of sites varies. For example, site queries indicated that the top five sites with the greatest extent of contamination were Fernald, Hanford, Oak Ridge K-25 Site, Lawrence Berkeley Laboratory (LBL), and INEL. That LBL is surprisingly in this category is attributed to the fact that LBL provided contaminant extent estimates while other larger sites reported the estimated extent as undefined (e.g., Paducah, ORNL, SRS). Thus, given the information to date from either the BEMR database and site queries, sites cannot be accurately ranked based on the extent of contamination. However, these data are useful in identifying broad estimates of the extent of contaminated concrete by indicating where the problem is most prevalent in the DOE complex. Information from site representatives is summarized in Table 2.3 (a more detailed discussion may be found elsewhere [Dickerson et al. 1995]).

Site queries at the Weldon Spring Site Remedial Action Project (WSS), Rocky Flats Environmental Technology Site (RFETS), and SRS provided general information only, since detailed inventories of contaminated concrete are not available at this time. These facilities undoubtedly contain large quantities of concrete contaminated with a wide range of substances. Enrichment facilities such as the Paducah and Portsmouth Gaseous Diffusion Plants (Portsmouth), although not fully characterized at this time, also have potentially large volumes of contaminated concrete. Paducah and Portsmouth will likely have concrete contamination similar to the Oak Ridge K-25 Site, currently estimated at 16.7 million ft^2 resulting in approximately 500,000 ft^3 of rubble from decontamination (Dickerson et al. 1995). These facilities are also subject to a variety of contaminants, primarily U, with some ^{99}Tc and transuranic (TRU) elements.

Finally, as previously mentioned, many sites did not have volume information available due to the lack of characterization or because depths of contamination vary and precise volume estimates are unpredictable. In general, the sites did not provide information on the depth of concrete contamination. Battelle Columbus Laboratories Decommissions Project (BCL) reported that contamination depth varies from 1/16 in. to 5 to 6 in. Energy Technology Engineering Center (ETEC) reported from previous experience that contamination is generally < 1 in. deep. Additional information on estimated volumes and areas of contaminated concrete at DOE sites may be found elsewhere (Dickerson et al. 1995).

2.1.2 Nature of Concrete Contamination

To supplement the information on contaminant extent obtained from the BEMR database, the Surplus Facilities Inventory Assessment (SFIA) database, which contained more detailed information on specific contaminants associated with each of the DOE facilities, was searched. The results yielded 211 records where radiological contamination was confirmed, providing information on 19 DOE sites.

A general breakdown of radiological contaminants as reported in the SFIA database is provided in Fig. 2.1. Contaminants for individual sites are presented elsewhere (Dickerson et al. 1995). Non-radiological contaminants were not included because their presence in concrete was found to be limited and not well characterized (compared to the radiological contaminants) and may pose different decontamination issues (e.g., mixed waste). More than a quarter of the facilities did not specify the contaminant isotopes. Of the facilities identifying specific isotopes, ^{137}Cs was the most abundant, followed by ^{238}U, ^{60}Co, ^{90}Sr, and tritium, all of which account for only ~30% of the total occurrence. It is important to note that 24% of the contaminants are listed as unknown, indicating a lack of characterization information. Furthermore, an additional 25% are classified as other contaminants: over 100 isotopes with less than 1% occurrence per isotope.

The SFIA data are slightly different from the U. S. Nuclear Regulatory Commission (NRC) research findings on contamination associated with nuclear power plants, where the most abundant long-lived radioisotopes associated with contaminated concrete for times ranging from 10 to 20 years after shutdown were ^{60}Co, ^{55}Fe, ^{73}Ni and ^{137}Cs (Abel et al. 1984). In this study, contamination residues normally contained very low concentrations of ^{90}Sr, ^{904}Nb, Pu, Am, and Cm. However, the study was primarily of reactor facilities; DOE facilities are more diverse, as demonstrated in Table 2.2. Based on available information, it can be assumed that concrete in DOE facilities is commonly contaminated with ^{137}Cs, ^{238}U, ^{60}Co, ^{90}Sr, tritium, and TRU isotopes (Fig. 2.1).

As with the extent of contamination, the information from site queries (Table 2.3) generally agrees with the nature of concrete contamination indicated in the SFIA database. In addition, this information provides an indication of the frequently occurring contaminants throughout the DOE complex. The SFIA and BEMR data included only general information, and data were missing for several sites (e.g., Fernald). However, the site queries, obtained from telephone interviews with site personnel, provided information that was not included in the SFIA or BEMR databases.

Based on site queries, radiological contamination was more significant than non-radiological contamination. Cesium-137- and ^{60}Co-contaminated concrete associated with reactors and their supporting structures was found at Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), ETEC, INEL, LBL, Nevada Test Site (NTS), ORNL and the West Valley Demonstration Project (WVDP). Isotopes and daughter products of uranium were concrete contaminants at BCL, Fernald, INEL support facilities, Los Alamos National Laboratory (LANL), Oak Ridge K-25 Site, Oak Ridge Y-12 Site, Paducah, Portsmouth, RFETS, and WSS. TRU contamination in concrete was reported at ETEC, Hanford, INEL, LANL, Mound Plant, NTS, Oak Ridge K-25 Site, ORNL, Paducah, Portsmouth, and RFETS. Many sites had not yet isolated the contaminating isotopes and reported having mixed fission products, gross alpha, or gross beta. This is shown as the "Unknown" contaminants in Fig. 2.1, 24% of the occurrence. Some sites, such as SRS, have a large array of contaminants, making a determination of a "primary" contaminant difficult at this point in time.

2.1.3 Previous DOE Experience with Concrete Decontamination

When evaluating the nature and extent of contaminated concrete, valuable information can be obtained from past experiences. For example, past experiences at a site may indicate that contamination was typically confined to the surface 1/8 in. or that cracks and joints presented a major problem but were encountered only rarely. Additionally, useful information can be gleaned from past experience with decontamination technologies.

Information relating to past experiences in concrete decontamination was solicited from 40 sites. Typically, facilities with the largest volumes and many types of contamination had undergone more D&D activities using more diverse technologies (Table 2.4). ORR, INEL, Hanford, and SRS, for example, had each tried several conventional technologies. D&D programs at some locations were not sufficiently developed to provide information for the survey. Other facilities had not yet begun pre-D&D site-characterization studies, usually because the sites were still active. The remainder either had no contaminated concrete or had already completed D&D.

It should be noted that most contamination associated with concrete is surficial (within the top inch) (DePaoli et al. 1995). More mobile radionuclides such as ^{99}Tc and tritium are expected to migrate deeper into the concrete than less mobile radionuclides such as ^{238}U and ^{90}Sr. Also, migration of radionuclides into the concrete structure of buildings was almost completely avoided if a coating was applied to the concrete prior to a spill or contamination (Deguchi et al. 1992). However, bare concrete, concrete where the integrity of the coating is lost, or cracked and pitted concrete becomes subject to contamination at depth. However, experiments with ^{60}Co indicate that radioactivity decreases rapidly with depth near the surface, decreasing more slowly after about 4 in. in depth (Deguchi et al. 1992). Radioactivity at a depth of about 8 in. was found to be about five orders of magnitude lower than at the surface. Cesium was found to migrate at a similar rate. In general, characterization of concrete does not include depth measurements. DOE primarily uses floor monitors and surface probes to measure exposure rates. Rarely is concrete cored and analyzed as part of D&D scoping and characterization surveys. Therefore, information on contaminated depth is primarily from measurements taken during and after decontamination at DOE facilities.

Past experiences indicate that the effectiveness of a decontamination method is often related to the presence of sealant coatings and paint. If the concrete had a previous coating, decontamination was generally more successful than if the coatings were damaged or the concrete was bare. This is attributed to the fact that most contaminants are less likely to penetrate sealants as compared to the more porous surface of concrete.

Traditional concrete decontamination methods include shot blasting, mechanical scabbling, detergent scrubbing, high-pressure washing, chemical treatments, strippable coatings, clam-shell scrapers, brushing, vacuuming, and attacking cracks with jack-hammers. The use of explosives, jack-hammers, etc., has been a problem because of the high worker exposure to contamination suspended in dust. This is well demonstrated in experiences at Mound and during the cleanup of reactors in the 1970s.

In general, the present technology needs for decontamination arise from past experience. It is also evident from past experience that (1) the primary decontamination methods used to date have been pressure-washing techniques and various types of scabbling, and (2) the majority of concrete decontamination experience is associated with the D&D of reactors by NRC.

2.1.4 General Concrete Decontamination Technology Needs at DOE Sites

Based on the nature and extent of contaminated concrete, DOE previously conducted a general D&D technology assessment where specific D&D needs were identified for DOE facilities (U.S. DOE 1993a, 1994). Additionally, CROSSWALK, a database for technology needs assessment, was designed to match technology needs with existing technologies. The information gleaned from a search of the database was useful in providing a basis for evaluating the needs of the entire DOE complex. However, some of the needs may be obsolete because the deadlines for technology needs at many of the sites has passed. The needs identified by the above sources were both reiterated and expanded upon during the site queries (Table 2.4) and in the Technology Logic Diagrams (INEL 1993, 1994; ORNL 1993; Oak Ridge K-25 Site 1993). Several problems and needs associated with in situ and ex situ concrete decontamination were identified. Technology needs are summarized in Table 2.5.

2.2 DISCUSSION

Concrete was widely used to build the facilities that support the nuclear fuel cycle in the DOE complex. The concrete associated with these facilities has been found to contain a myriad of contaminants, varying from site to site depending on the facility type. The nature and extent of contaminated concrete in the DOE complex cannot be comprehensively defined until characterization of these facilities is complete. The majority of DOE sites do not have a volume inventory of contaminated concrete because they are still in active use or in the initial stages of characterization. Inventories of contaminated buildings in the SFIA and BEMR databases suggest the potential for an enormous amount of contaminated concrete, but show that the majority of facilities are in the early assessment stage of the D&D process. The BEMR data indicated that only 19% of the buildings in its inventory were surplus and 1% were surplus with cleanup approved. Sixty-one percent of the buildings were active. SFIA data were similar, showing that only 2% of the data set was in the D&D process. Therefore, it is not surprising that approximately 40% of the sites surveyed in this study were unsure of technology selection because they were not yet at the D&D development phase. However, based on the amount of the floor space of contaminated buildings that have not been characterized, it is likely that concrete decontamination technology selection will be an important process in the future of DOE D&D. Indeed, floor space in uncharacterized concrete buildings at sites such as Portsmouth, RFETS, and SRS may exceed the total of all concrete decontaminated to date.

The available information provides a general perspective on the nature of concrete contamination in the DOE complex. It is evident from the variety of facility types that contaminants in concrete are wide-ranging. At sites where characterization has been conducted, radionuclides are more abundant than non-radiological contaminants in concrete. For example, the BEMR database indicated that 86% of the known contamination associated with buildings was radiological.

When the occurrence of isotopes is examined, ^{137}Cs and ^{238}U and its daughters are closely followed by ^{60}Co, ^{90}Sr, and tritium in frequency (Fig. 2.1). It should be noted that there is very limited information on radionuclide concentrations in concrete from NRC and virtually none from DOE facilities. Most data are from surface measurements of alpha, beta-gamma, and gamma radiation exposure rates. The common finding is that most concrete contamination is surficial in nature and decreases with depth. Past D&D experiences confirm this, where scabbling and sandblasting methods have been required only to depths of 1 in. or less during projects at ORNL, LANL, and the Three Mile Island nuclear power plant (Dickerson et al. 1995). This may account for the reason that over 17% of DOE sites queried indicated that they had no need for new technology or that traditional methods were satisfactory.

Although not the primary type of contamination, contamination of concrete at depth by association with cracks and joints does occur and poses one of the most difficult problems in decontamination. This has been demonstrated at BCL, where surface methods were not effective in decontaminating deep cracks (contaminants were ultimately removed by jack-hammering). Experience in the D&D of reactors has also shown that traditional methods for removing deep contamination result in high worker exposure and are time-consuming and costly. Time and costs are further increased when the work must be accomplished remotely, such as at Hanford and INEL. Tritium, a deeply penetrating contaminant, poses problems at SRS, LANL, and other sites (U.S. DOE 1993a).

Probably the most common issue in concrete decontamination is the need for reduction of waste volume and secondary waste. Scabbling, while reducing the volume of concrete requiring disposition (1 mm of slab vs the entire slab thickness), produces large amounts of contaminated rubble that must be disposed of. Pressure washing minimizes the volume of concrete for disposal, but produces large amounts of waste water. In addition, regulatory restraints may make disposal of secondary waste costly; therefore, its reduction is an important need. Facilities such as Fernald, where waste must be shipped off site, have an economic interest in reducing the volume of final waste (it is estimated that 3.3 million ft^3 of concrete require decontamination). LANL, in addition to exploring the costly option of disposing of concrete rubble at NTS or Envirocare of Utah, is also considering decontamination of rubble for reuse as construction aggregate. Experience at LBL demonstrates the value of recycling and reuse of contaminated rubble as waste containers. Indeed, concrete decontamination was a topic in the Waste Recycling Workshop held by the Alliance of Ohio Universities and Fernald Environmental Management Corporation in 1994 (AOU 1994). A major conclusion from the workshop was that recycled concrete might best be used within the DOE complex. This is based on the difficulty of proving that concrete rubble is clean and the lack of applicable standards. Also, decontamination of rubble might not be economical for sites where on-site waste burial is available and associated costs are low, such as NTS or INEL. Finally, it should be noted that 71% of DOE waste management costs are associated with the disposal of contaminated metals and concrete (Allen et al. 1988). Major cost savings could be realized by substantially reducing waste volumes.

Another need related to secondary waste is the reduction of liquid waste associated with pressure washing and chemical methods. As an example, secondary waste produced by decontamination efforts at the INEL Idaho Chemical Processing Plant produced large amounts of radioactive, sodium-bearing liquid waste that posed a disposal problem for the facility. Furthermore, the generation of mixed wastes produced by the use of solvents and acids used for decontamination have posed disposal problems at sites such as Oak Ridge K-25 Site. Experience with pressure washing at Hanford shows that large amounts of liquid waste are associated with this method.

As indicated by Table 2.1, site representatives perceive concrete contamination as a problem of varying severity at their respective sites. Oak Ridge K-25 Site, Paducah, and Portsmouth all rated the problem as the most severe. Indeed, these enormous enrichment facilities will likely present a large portion of the concrete decontamination challenges in the future. Other facilities may have rated concrete as a lower priority based on the severity of other problems.

Finally, variations of concrete scabbling have been the most common methods of decontamination. The bulk of technology demonstrations and associated needs for new technologies have occurred at the larger sites, such as INEL, Oak Ridge K-25 Site, and ORNL, where characterization is in the final stages. These sites also have detailed logic diagrams for technology selection and detailed inventories of waste. This should not be confused with having the largest "concrete problem" based on the fact that most facilities are in early characterization stages and do not have the information available.

2.3 CONCLUSIONS

The results of the first project task have provided a broad perspective on the nature and extent of contaminated concrete throughout the DOE complex. Assimilation and evaluation of existing information obtained from the SFIA, BEMR, and CROSSWALK databases and personnel communication with D&D representatives at the majority of the sites delineated the primary occurrence of contaminants and the locations of the greatest amount of contaminated concrete. Because concrete characterization is in initial stages at many sites, the information available is incomplete. Assimilation of the available information into one location is helpful in identifying areas that require more data and potential areas of concern in the future (Dickerson et al. 1995).

The following are conclusions from this effort:

- The most frequently reported contaminants are ^{137}Cs and ^{238}U and its daughters, closely followed by ^{60}Co, ^{90}Sr, and tritium. Approximately 25% of the contaminants identified during characterization are estimated to occur less than 1% of the time. Because characterization information is not available for several sites (including the gaseous diffusion plants), the order of the frequency of these contaminants in expected to change. For example, ^{238}U may have a greater occurrence than ^{137}Cs. However, it is expected that ^{137}Cs, ^{238}U, ^{60}Co, ^{90}Sr, and tritium will remain the most commonly occurring isotopes within the DOE complex.

- The total area of contaminated concrete within the DOE complex is estimated to be in the range of 7.9×10^8 ft^2 or approximately 18,000 acres. The volume of contaminated concrete is estimated at 6.7×10^6 ft^3. These estimates do not represent the complete extent of contamination because they are based on incomplete and differing data available from the sites. The sites identified as having the most contaminated concrete are Hanford, Fernald, and ORR. These estimates are assumed low because they do not include complete information from INEL, SRS, Portsmouth, Paducah, and RFETS, all of which are expected to have similar amounts of contaminated concrete.

- Concrete decontamination needs were identified as: (1) reduction of secondary waste (rubble and liquid), (2) cost- and schedule-effective technologies, (3) more efficient removal of the concrete surface layer, (4) innovative technologies for floor and wall decontamination, and (5) unknown. When sites were asked which decontamination problems they faced, most replied with unknown. This is attributed to the fact that decontamination is still in preliminary stages at many sites.

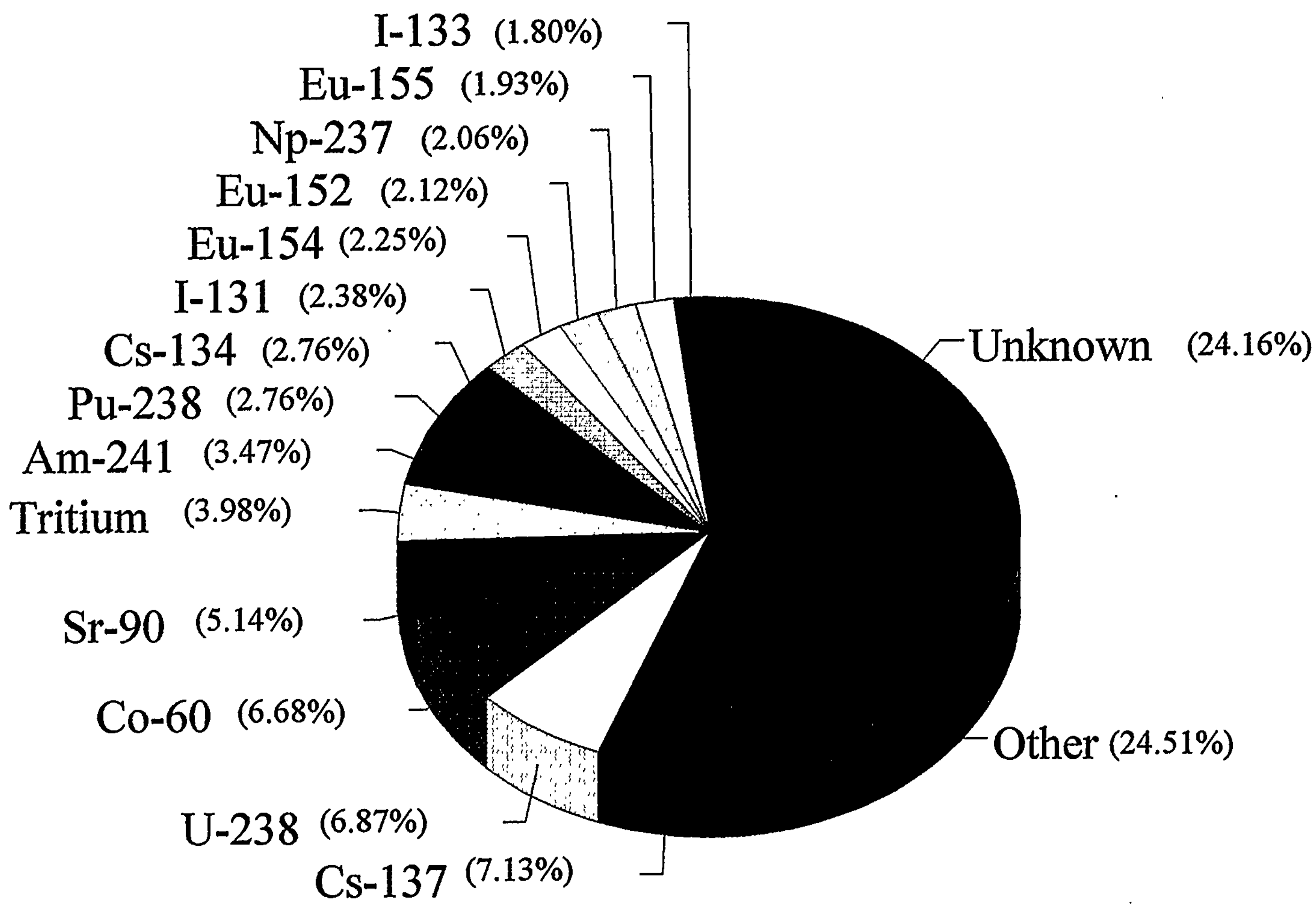

Fig. 2.1. Occurrence of contaminants representative of the DOE complex.

Table 2.1. Ranking of concrete problems at DOE facilities

Sites	Ranking
Oak Ridge K-25 Site	10
Paducah	10
Portsmouth	10
Hanford	9
Oak Ridge Y-12 Site	9
Argonne National Laboratory East	8
ETEC	8
ORNL	8
LANL	7
Formerly Utilized Sites Remedial Action Program	6
Fernald	6
INEL	6
SRS	6
Lawrence Livermore National Laboratory	5
Mound Plant	5
WSS	3

Table 2.2. Concrete contamination in DOE facilities

Facility Type (Site Examples)	Description of Concrete Contamination	Decontamination Comments
Reactors (ANL, Hanford, INEL, SRS, ORNL, ETEC, LANL, Lawrence Livermore National Laboratory)	HLR (induced) in reactor vessel walls and internals, biological shields, and beam tubes/ports.	Remote methods required; radiological contamination often remains after surface decontamination is performed.
Canyon buildings (Hanford)	HLR compounded by spills and leaks; wide variety of potential contaminants in the concrete structure of the canyon.	Remote methods required; large volumes of concrete produced for disposal.
Separation facilities (ETEC, Hanford, LANL, ORNL)	HLR associated with structure; wide variety of contaminants; similar to canyon facilities.	Remote methods required.
Fuel fabrication facilities	HLR from fissile production material and widely dispersed material (fines) associated with concrete structures. Possibility of creating a critical mass.	High worker exposure; alpha contamination and criticality control are major considerations.
Fuel reprocessing facilities (Hanford, ORNL, SRS, INEL)	LLR and hazardous material associated with concrete floors and walls.	Selection of decontamination method difficult due to wide variety of potential contaminants. Selection dependent on physical structure housing the facility.
Hot cells (INEL, Pacific Northwest Laboratory, ORNL)	HLR associated with walls of hot cells and embedded in cell drains and ventilation systems.	Remote methods required; embedded drains difficult to access.
Analytical and R&D facilities (ORNL, LANL)	LLR for the most part associated with floors and walls.	A wide range of equipment must be removed before decontamination of concrete.
Weapons materials production facilities (Oak Ridge Y-12 Site, Oak Ridge K-25 Site, Fernald, Formerly Utilized Sites Remedial Action Program, LANL, INEL)	LLR alpha-emitting contamination (machining waste) associated with floors and walls. Tritium is present and penetrates deeply into concrete.	Methods needed that penetrate deeply to reach tritium and mercury contamination.
Uranium enrichment facilities (Oak Ridge K-25 Site, Portsmouth, Paducah)	LLR; wide variety of potential contaminants associated with floors and walls.	Facilities are large, with enormous amounts of concrete for potential decontamination; most of these facilities are in the characterization process.

HLR: high-level radiation
LLR: low-level radiation
R&D: research and development

Sources: U.S.DOE 1993b, 1994

Table 2.3. Summary of nature and extent of concrete contamination based on site queries

Site	Type of Contaminated Concrete	Primary Radionuclide Contaminants	Estimated Extent
Argonne National Laboratory East	Containment structures, rod storage area	Co, Cs, some tritium	1400 ft^2 285 ft^3
BCL	Undefined	U, Th, some mixed fission products	Unknown (200,000 ft^2 to a depth of 1/16 to 6 in. has been decontaminated to date)
BNL	Buildings, storage tanks, reactor, canals, concrete surfaces surrounding duct work	U oxide, Pu, tritium, Co, Cs, Sr, Fe, Bi, Na	9000 ft^3 (reactor only)
ETEC	Building, fuel storage vaults	Co, Cs, Sr, Y, Eu, U, TRU, mixed fission products	10,400 ft^2 240 ft^3
Fernald	Buildings, silos	U, Th	3,300,000 ft^3
Grand Junction Projects Office	Concrete floors	U (mill tailings in concrete matrix)	300 ft^2
Hanford	Buildings (reactor and support), laboratories, canyon facilities, underground storage tanks	Sr, Cs, Pu, U, Tc, Co, ^{14}C, Am, others	1,737,000 ft^3 (100 and 200 Areas)
INEL	Reactors and associated structures (canals), hot cells, chemical processing plants	Co, Cs, Eu, U, Sr, Pu, Am, others	278,354 ft^3 (161,087 ft^3 rubble)
Kansas City Plant	Manufacturing buildings	No rad contamination	No rad contamination
Oak Ridge K-25 Site	82 facilities slated for D&D	U, Tc, TRU	16,700,000 ft^2 (generating ~500,000 ft^3 rubble)
LANL	Floors and walls, one reactor	Pu, U	6000 yd^3 (162,000 ft^3)
LBL	Concrete blocks used for shielding	Co, Eu	500,000 ft^3
Lawrence Livermore National Laboratory	No concrete D&D planned	NA	NA
Mound	Buildings	Pu, tritium, Th, others	161,000 ft^3 (50,000 to 100,000 ft^3 rubble generated)
NTS	Buildings	U, Pu, Am, Sr, Co	Undefined

Table 2.3. (continued)

Site	Type of Contaminated Concrete	Primary Radionuclide Contaminants	Estimated Extent
ORNL	Reactors, buildings, storage tanks	Cs, Co, Sr, U, Th, Eu, Pu, Am, numerous others	Undefined
Pantex	No concrete D&D to date nor planned	NA	NA
Pinellas	No concrete D&D to date nor planned	Tritium	NA
Pacific Northwest Laboratory	Included with Hanford	Included with Hanford	Included with Hanford
Portsmouth	Buildings	U, Tc, TRU	Undefined
Princeton Plasma Physics Laboratory	Tokamak Fusion Test Reactor scheduled for D&D in 9/95	Activation products, some tritium	Very little D&D planned
RFETS	Buildings	Pu, U	Undefined (116 buildings identified as contaminated)
RMI Titanium, Inc.	Buildings	U	15,000 ft^3
Sandia National Laboratories	D&D delayed to FY96	No characterization to date	Undefined
WSS	Building	U, Th	Undefined
WVDP	Chemical process cell	Cs, Sr, Am, Pu	D&D completed generating 30,000 ft^3 waste (plus 7800 ft^3 secondary waste)
Oak Ridge Y-12 Site	Buildings	U, Th	153,000 ft^3
TOTAL			**~6.7×10^6 ft^3**

Note: This table was generated from information provided in the site queries. Condensing contaminants, extent, and contaminant type has resulted in a loss of more detailed information, which is presented in Appendix A of *Contaminated Concrete: Occurrence and Emerging Technologies for DOE Decontamination* (Dickerson et al. 1995).

NA: not applicable

Table 2.4. Summary of technology assessment based on site queries

Site	Type of Contaminated Concrete	Technologies Under Consideration	Technology Needs as Identified by the Site
Argonne National Laboratory East	Containment structures, rod storage area	Mechanical demolition and abrading, scabbling, abrasive cleaning, pneumatic demolition	Unknown
BCL	Undefined	Vacuum blasting and scabbling, jackhammers for deep cracks	None
BNL	Buildings, storage tanks, reactor, canals, concrete surfaces surrounding duct work	Undefined	Any cost-effective methods to manage long-term risks and to decontaminate prior to disposal
ETEC	Buildings, fuel storage vaults	Mechanical scabbling, hydraulic hammers and jackhammers	Unknown
Fernald	Buildings, silos	Performance criteria provided to subcontractor who then selects an appropriate technology	Unknown
Grand Junction Projects Office	Concrete floors	Needle scabbling	None
Hanford	Buildings (reactor and support), laboratories, canyon facilities, underground storage tanks	Dry-ice blasting, arc saw, fixatives, water cannon, concrete spalling, high-pressure hot water jet, laser ablation, chemical methods, needle guns, shot blasting	None, technical approach has been developed
INEL	Reactors and associated structures (canals), hot cell, chemical processing plants	Numerous technologies (INEL 1994)	Further R&D, testing, and evaluation needed for numerous technologies
Kansas City Plant	Manufacturing buildings, no rad contamination	NA	NA
Oak Ridge K-25 Site	82 facilities slated for D&D	Numerous technologies (Oak Ridge K-25 Site 1993)	More efficient concrete surface layer removal, reduction of secondary wastes, innovative systems for floor and wall decontamination, reduction of rubble waste
LANL	Floors and walls, one reactor	Mechanical scabbling, solvents, microwave, laser technologies	Unknown

Table 2.4. (continued)

Site	Type of Contaminated Concrete	Technologies Under Consideration	Technology Needs as Identified by the Site
LBL	Concrete blocks used for shielding	Recycle and reuse; concrete shipped to ORR will be pulverized and reused as aggregate in new concrete for waste burial boxes	None
Lawrence Livermore National Laboratory	No concrete D&D planned	NA	NA
NTS	Buildings	None to date; previous concrete D&D used chipping and scabbling	Unknown
ORNL	Reactors, buildings, storage tanks	Numerous technologies (ORNL 1993)	More efficient concrete surface layer removal, reduction of secondary wastes, innovative systems for floor and wall decontamination, remote decontamination, and decontamination of rubble
Pantex	No concrete D&D to date nor planned	NA	NA
Pinellas	No concrete D&D to date nor planned	NA	NA
Pacific Northwest Laboratory	Included with Hanford	Included with Hanford	Included with Hanford
Portsmouth	Buildings	None; D&D is in planning stage	Unknown
Princeton Plasma Physics Laboratory	Tokamak Fusion Test Reactor scheduled for D&D in 9/95	Very little D&D planned	None
RFETS	Buildings	Scabbling, strippable coatings, CO_2 blasting	Unknown
RMI Titanium, Inc.	Buildings	Scabbling and vacuuming, chemical, mechanical, and electrical technologies	Technologies with cost and schedule reductions
Sandia National Laboratories	D&D delayed to FY96	Unknown	Unknown
SRS	Reactors, buildings, canyons, waste tanks	Conventional technologies	Unknown
WSS	Buildings	High-pressure water, vacuums	None

Table 2.4. (continued)

Site	Type of Contaminated Concrete	Technologies Under Consideration	Technology Needs as Identified by the Site
WVDP	Chemical process cell	D&D completed used high-pressure detergent washing and vacuuming	Unknown
Oak Ridge Y-12 Site	Buildings	High-pressure water jet, pelletized CO_2	More efficient concrete surface layer removal, reduction of secondary wastes, innovative systems for floor and wall decontamination

Note: This table was generated from information provided in the site queries. Condensing technologies under consideration and contaminant type has resulted in a loss of more detailed information, which is presented in Appendix A of *Contaminated Concrete: Occurrence and Emerging Technologies for DOE Decontamination* (Dickerson et al. 1995).

NA: not applicable

Table 2.5. DOE concrete decontamination technology needs

Technology Need	Explanation	Applicable Sites
Reduction of secondary waste	Large volumes of scabbled material created by decontamination pose disposal problems. Technologies capable of washing and leaching contamination from rubble are desired.	Fernald Oak Ridge K-25 Site ORNL
Less labor-intensive, time-consuming methods	Labor involved in the traditional scabbling methods creates high costs in decontamination.	All sites
Recycling of concrete	Potential to reuse concrete rubble requires technologies to ensure that the material can be released.	INEL LBL
Remote decontamination	In order to reduce worker exposure to high levels of radiation present at facilities, remote methods are desired.	Hanford INEL reactors ETEC
Size reduction of large blocks of concrete	Unlike rubble, which has various potential reuses, large blocks of concrete must be reduced before any potential reuse.	Hanford
Decontamination of deeply contaminated concrete, including joints and cracks	The majority of traditional concrete decontamination methods are not effective for deep contamination.	Fernald ANL BCL
Decontamination of mercury-contaminated concrete	Mercury penetrates concrete to depths where traditional methods are not effective.	SRS Mound LANL INEL Princeton Plasma Physics Laboratory ORNL Oak Ridge Y-12 Site
Characterization/separation/ segregation process	A process where contaminated concrete is identified, segregated, and cleaned during dismantlement for recycling/reuse is needed.	LBL LANL

Source: U. S. DOE 1993a

3. CANDIDATE TECHNOLOGIES FOR CONCRETE DECONTAMINATION

Prior to screening candidate technologies and matching these to concrete problems, development of a candidate technology list was required. This list was developed through literature reviews, personal inquires with commercial technology vendors and technology researchers and developers, and prior experience of individual project team members. The task focused on assimilating existing information to minimize duplication of past efforts. Key DOE sources of information include the ORNL, Oak Ridge K-25 Site and INEL Logic Diagrams (ORNL 1993; Oak Ridge K-25 Site 1993; INEL 1993, 1994), the *Decommissioning Handbook* (U.S. DOE 1993b), and previous DOE-funded efforts such as technology feasibility studies. The focus of this task was emerging and innovative technologies; commercially available technologies were used as baselines for comparison.

Based on initial responses from vendors and technology developers and on literature reviews, a preliminary list of emerging technologies with purported application to concrete decontamination was developed (Table 3.1). At this point, information on technologies was simply obtained; no attempt was made to screen these technologies on factors such as time before technology is ready for field application, likelihood of implementation, cost, etc. Fact sheets describing the various technologies, equipment, and services were prepared to enable rapid review and understanding of the technologies (Dickerson et al. 1995). The detailed information obtained during this task includes: process description, secondary waste generation, treatment efficiencies, limiting conditions, processing rates, cost and unusual environmental and worker health and safety concerns (summarized in Table 3.2). (Brief descriptions of the technologies may be found elsewhere [Dickerson et al. 1995].)

Table 3.1. Emerging candidate concrete decontamination technologies

Technology	Description
Biological	
Biological decontamination (microbially influenced degradation)	Microorganisms used to dissolve or disintegrate the concrete matrix. Organisms are applied to the surface, and conditions such as nutrients, temperature, and relative humidity are maintained. The biomass etches the concrete surface, removing the contaminants. After terminating organism growth, the remaining biomass is removed by brushing or vacuuming.
Chemical	
Chemical gels	Uses a gel as a carrier of chemical decontamination agents. The gel is applied to the surface and then scrubbed, wiped, rinsed, or peeled off. Several applications may be required.
Decontamination and recycle of concrete	Decontamination of concrete by foam cleaning agents, low- and high-pressure surface rinsing, and surface concrete removal using high-pressure water. The waste is then separated by using screens and microfiltration for fines removal and using activated carbon for organic compound removal.
Electro-hydraulic scabbling	Scabbling of concrete based on the generation of hydraulic shock waves by means of an electric discharge. Process minimizes secondary waste generation.
Electrokinetics (electromigration and electroosmosis)	Removes contaminants using an electric potential to cause ion migration from the pores of the concrete into an electrolytic solution that may be subsequently treated.
Solvent washing	Based on washing contaminated items in solvent, with an automated system to spray and recover the solvent. It is a waste reduction and separation process in which radionuclides are extracted from the media (e.g., soil, concrete) by use of solvents.
Strippable foil	Removal of contaminants through chemical interactions of the foil applied to the surface. The dried coating (foil) is then removed.

Table 3.1. (continued)

Technology	Description
Mechanical	
Centrifugal cryogenic CO_2 blasting	Uses high-speed, rotating wheel to accelerate CO_2 pellets and is more efficient than compressed air. Pellets evaporate to gaseous CO_2 upon impact, minimizing secondary waste.
Compressed-air cryogenic CO_2 blasting	Similar to traditional sand blasting except that pellets are made of solid CO_2 (dry ice). The dry ice pellets evaporate on contact with the contaminated surface, minimizing secondary waste.
Concrete milling	Shaves away the top layer of the concrete. Large milling vehicles have been used commercially for paving and potentially may apply to concrete floors.
Remotely operated dry ice pellet decontamination system	Decontamination of concrete by dry ice (CO_2) blasting linked with a remotely operated vehicle to reduce worker exposure and costs.
Supercritical CO_2 blasting	Uses supercritical CO_2 (>87.8°F) pressurized up to 55,000 psi to generate high velocity CO_2 jets at speeds up to 3,000 ft/s. The jets remove surface contaminants without damaging the clean substrate.
Thermal	
Dry heat (roasting)	Currently at the problem definition stage. The technology is simple in concept, well developed, and accepted by industry. Its application in surface decontamination has not been demonstrated.
Flashlamp cleaning	Uses energy absorbed from a high-energy xenon flashlamp to cause rapid temperature rises, creating decomposition or evaporation of material to a particulate residue.
Laser etching and ablating	Uses energy from pulsed laser beams to create a combination of photochemical and photothermal effects beneath the surface, causing thin layers of material to be ejected from the surface.

Table 3.1. (continued)

Technology	Description
Laser heating	Energy from a continuous-wave or pulsed laser is absorbed at the surface, and the rapid temperature rise causes material to evaporate or decompose to a carbonaceous residue.
Microwave scabbling	Microwave energy heats the free water present in the concrete matrix, producing thermal and steam pressure-induced mechanical stresses that cause the concrete surface to burst. The loosened particles may then be collected by a vacuum system.
Plasma torch	Uses an inert gas passing through a high-power arc discharge to produce a very high temperature gas stream that is capable of melting nearly all uncooled material. Potential use for rapid spalling of concrete.

Sources: ORNL 1993; Oak Ridge K-25 Site 1993; INEL 1993, 1994; U.S. DOE 1993b

Table 3.2. Summary of candidate technologies for concrete decontamination

Technology	Stage of Development	Processing Rates	Secondary Waste Generation	Estimated Cost per ft^2	Removal Efficiency[a]	Limiting Conditions	Comments
Automated brushing	Demonstration	Unknown	Variable, high-efficiency particulate air filters and brushing	$300.00	Unknown	Not effective in decontamination of fixed contaminants	High-efficiency particulate air filtering system is integrated into this technology
Automated grinding	Conceptual	15 ft^2/min	Surface layer plus grinding media	Unknown	Unknown	Development of vacuum system	Effective for surface contaminants only
Biological (microbially influenced degradation)	Experimental/ developmental	4.7 mm/year	Approximately half the waste produced by conventional technologies	$1.00-3.00	Unknown	Nutrient availability	Reduced risks compared to conventional technologies; passive process
Detergent (caustic) treatment	Commercial	Unknown	Caustic solutions	>$1.00	Variable	Labor-intensive	Surface decontamination only; used extensively at gaseous diffusion plants
Centrifugal cryogenic blasting CO_2	Developmental	0.50 ft^2/min	Variable	$0.90-26.00	Unknown	Surface decontamination only; waste handling of contaminated water	Current system is not suited for rad decontamination; has been demonstrated at several sites; robotics and water reuse/recycling system is needed; used commercially to decontaminate hand tools
Chelation	Demonstration	Variable	Waste stream must be oxidized	$1.00	Excellent	Selection of chelating agents	Easy to apply
Chemical extraction	Demonstration	100 ft^2/h	0.03-0.06 gal/ft^2	$4.00-50.00	Up to 99%	Depth of contaminants	Several demonstrations have been conducted with mixed results
Chemical foams	Commercial	Variable	Rinse water and residuals	$0.50-2.00	75-90%	Ineffective with cracked or convoluted surfaces	Primarily used as a pretreatment

Table 3.2. (continued)

Technology	Stage of Development	Processing Rates	Secondary Waste Generation	Estimated Cost per ft^2	Removal Efficiency[a]	Limiting Conditions	Comments
Chemical gels	Demonstration	Unknown	Rinse water and residuals	$0.50-2.00	Up to 100%	Complex chemical system	Costly and time consuming
Chipping hammer/paving breaker	Commercial	20 yd^3/day (90-lb hammer)	Variable	Variable	Variable	Leaves surface very rough; a large amount of dust is produced	Used to decontaminate small inaccessible areas
Compressed-air cryogenic blasting CO_2	Demonstration	0.50-1.5 ft^2/min	Variable	$8.00-26.00	Unknown	Surface decontamination only; waste handling of contaminated water	Robotics and water reuse/ recycling system is needed
Concrete milling	Conceptual	Unknown	Top 6-25 mm of concrete removed	$0.75	Unknown	Suited for horizontal surfaces only	Equipment is available, but has not been used for decontamination purposes
CO_2 blasting	Commercial	10-90 ft^2/h	Variable	$0.90-1.75	Surface contaminants	CO_2 in confined area; depth of contamination	CO_2 vaporizes, reducing secondary waste
Electro-hydraulic scabbling	Developmental	20-40 ft^2/h	0.5-1 gal/ft^2 (liquid solid mixture)	$0.65-1.85	100% up to 1-in. deep	Currently applicable to floors only	Initial design for floors only; removes ~1 in. of surface concrete per pass; airborne particulates are minimal
Electrokinetic	Developmental	Not yet determined	Liquid used during process, volume not yet determined	Not yet determined	65->90%	Currently applicable to floors only	Developmental/ optimization stage
Explosives	Commercial	Variable	~0.25 ft^3/ft^2	$50.00	Up to 100%	Dust containment	Top 3 to 4 in. of concrete are removed per detonation
Flame scarification	Commercial	Unknown	Unknown	Unknown	Unknown	Produces radioactive airborne particulates	Concrete is heated to cause differential expansion and spalling

Table 3.2. (continued)

Technology	Stage of Development	Processing Rates	Secondary Waste Generation	Estimated Cost per ft^2	Removal Efficiency[a]	Limiting Conditions	Comments
Flashlamp cleaning	Demonstration	Up to 120 ft^2/h	Ash from coating	\$4.50-25.00	Unknown	Surface decontamination only	Input from xenon vendors is critical
Grit blasting (sand blasting)	Commercial	~47 ft^2/h, dependent on grit used	0.03 ft^3/ft^2 (solids)	~\$5.00-10.00	Up to 100%	Waste-processing system	Waste production rates depend on media/surface combinations
Hand brushing	Commercial	Variable	~0.003 ft^3/ft^2	Up to \$82	Variable	Labor-intensive	Cost includes labor
Hand grinding, honing, scraping	Commercial	Variable	Variable	\$0.50-1.00	Variable	Limited to decontamination of small areas	Remote operation will improve efficiency
High-pressure water	Commercial	~370 ft^2/h	0.03 ft^3/ft^2, 4-100 gpm liquids	\$0.06-2.00	Variable	Uses large amounts of water	Water reuse/recycling system is needed
Ice blasting	Commercial	Similar to other blasting technologies	~15 gal/h waste-water generation rate	\$1.00	Unknown	Limited to surface decontamination	Remote operation will improve efficiency
Laser ablation	Developmental	85 ft^2/h	75% waste reduction is projected	~\$1.00	Unknown	None identified	Currently building a full-scale prototype
Laser heating	Developmental	2.5 ft^2/min	Unknown	\$1.00	Unknown	Currently used to decontaminate metallic surfaces	Decontamination of large surface areas with minimum amount of waste generation
Microwave scabbling	Demonstration	40 ft^2/h	0.15 ft^3/ft^2 solids	~\$2.00	100% 2 in. per pass	Removes top layer of concrete	Technique has not been optimized. Not available in the private sector
Multi-unit scarification	Commercial	20-300 ft^2/h	0.078 gal/ft^2 solids at 1/16-in. removal; needle gun only, 0.03 gal/ft^2	\$1.85-2.50	1/16 in. per pass	Noise pollution	Integration of several pieces of scabbling equipment

Table 3.2. (continued)

Technology	Stage of Development	Processing Rates	Secondary Waste Generation	Estimated Cost per ft^2	Removal Efficiency[a]	Limiting Conditions	Comments
Plasma torch	Developmental	Unknown		~$1.00	Unknown	Spalling of concrete	Technology currently used to decontaminate hazardous surfaces
Plastic pellet blasting	Commercial	4 ft^2/min	Similar to other scabbling/blasting processes	$0.20-2.15	Unknown	Demonstration of specific medium needed	Pellets need to be optimized; widely used as an alternative to grit blasting
Scarification	Commercial	200-400 ft^2/h	0.078 gal/ft^2 at 1/16-in. removal	$1.85-2.50	1/16 in. per pass	Noise pollution	Collects 99.5% of all debris
Shot blasting	Commercial	30-3000 ft^2/h	Variable	$0.04-5.02	10-100%	Airborne debris; system for processing waste needed	Conventional decontamination equipment, removes ~1/4 in. of concrete per pass
Soda blasting ($NaHCO_3$)	Demonstration	120-240 ft^2/h	0.007 ft^3/ft^2 (solids), 1.9 gal/ft^2 (liquid)	$5.00-7.00	95-99 %	Multiple units required for secondary-waste processing	Commercially available for non-rad cleanup
Soft media blasting	Commercial	60-100 ft^2/h	0.001-0.01 ft^3/ft^2 (solids)	$10-12	90-99 %	Uses large amounts of water	Successful in mixed waste decontamination
Solvent washing	Conceptual	Unknown	Unknown	Unknown	Unknown	Applicable only to smearable contamination	Limited to small areas of contamination
Steam cleaning	Commercial	Unknown	Condensed steam	$0.50-2.00	Variable	Uses large amounts of water	Not effective for removing fixed contaminants
Strippable coating	Commercial	Up to 100 ft^2/h	Coating residuals	$1.00-1.40	Variable	Cost of strippable coating	Application and removal times are long

Table 3.2. (continued)

Technology	Stage of Development	Processing Rates	Secondary Waste Generation	Estimated Cost per ft^2	Removal Efficiency[a]	Limiting Conditions	Comments
Strippable coating (SensorCoat)	Developmental	Undetermined	Undetermined	Undetermined	Undetermined	Depth of contamination	Proof of process has been shown but development is required
Supercritical CO_2 blasting	Developmental	Unknown	Variable, spent grinding media	Unknown	Unknown	Optimizing pressure and speed of cleaning head	System optimization is required for commercialization
Superheated water	Commercial	Variable	0.4-2 gal/min liquids	$0.50-2.00	Variable	Uses large amounts of water	Robotics and water reuse/recycling system are needed
Ultra-high-pressure water	Commercial	1 ft^2/min	3-5 gal/ft^2 liquid	~$2.00	Unknown	Water recycling system	Robotics control is in development; numerous non-rad decontamination
Vacuum cleaning	Commercial	40-54 ft^2/h	Dependent on depth of removal	$2.00-11.00	Variable	Limited to confined areas	This is a pre- and/or post-treatment process; surface decontamination
Water flushing	Commercial	Variable	Variable	~$1.00	Variable	Uses large amounts of water	Readily used to pre-treat surfaces

[a] Based on unpainted surfaces

4. SCREENING AND MATCHING PROBLEMS WITH EMERGING TECHNOLOGIES

After assimilating information on the contaminated concrete problem (nature and extent) and candidate technologies for decontamination, efforts to screen and match emerging technologies to concrete contamination problems began. Initially it was envisioned by the project team that the Kepner-Tregoe (Kepner and Tregoe 1973) screening and evaluation process would be used to provide a systematic approach for recommending technology demonstrations. However, early in this process several problems arose.

First, it was difficult to compare technologies based on some set of criteria when the technologies are at different stages of development. For example, technologies in early development stages may be removed from further consideration when compared to well-established and demonstrated technologies. This would imply that the most important criteria for a technology is the stage of development, thus eliminating potentially promising technologies that may have application to problems that are not adequately addressed by existing technologies (cracks and penetrations). Second, much of the specific data required for comparison to screening criteria such as cost, processing rates, secondary waste generation, etc. is not well defined or known for technologies in the earlier stages of development. It is this type of data that is intended to be obtained from the demonstrations. Finally, because specific sites for conducting the demonstrations have not been identified, several of the evaluation criteria used in a more rigorous screening process cannot be defined with certainty. For example, although there are broad considerations that can be taken into account for implementability, many aspects of the criteria are directly related to the site (contaminant concentration and depth, limiting conditions impacting equipment operation, site safety support, worker and environmental risk). The project team recognized that a more rigorous screening process (such as Kepner-Tregoe) is appropriate and should be used when a technology is being selected for a specific application for cleanup (e.g., treatability demonstrations or decontamination of a specific facility). However, the goals of this project are to identify and demonstrate promising technologies for application to a wide variety of concrete problems throughout the DOE complex.

A process for evaluating technologies entitled Managing Technology for Development was presented by Joseph Paladino at the March Facility Deactivation, Decommissioning, and Material Disposition Focus Area monthly meeting (Paladino and Longsworth 1995). To summarize, the process evaluates technologies based on the ability of an action (in this case, a demonstration) to further the development of a technology toward implementation and technology transfer. The technology development and implementation continuum is broken into several stages of development, each separated by a decision-point (i.e., a gate). A technology is evaluated based on a set of decision-point criteria that are appropriate for the technologies at various stages of development. If a demonstration of the technology meets these criteria (i.e., provides the information that is appropriate for the stage of development, see Figure 4.1), the technology passes the decision point (gate) and moves to the next stage of development. Because of the applicability of the process to meet project goals by allowing review of technologies at different stages of development, it was used by the team for technology screening.

A team meeting was held on April 17 and 18 to conduct the screening process. Team members included representatives familiar with engineering, technology development, using decontamination technologies, implementing demonstrations, and health and safety. Based on the results of the first project task (see Sections 2 and 3), which focused on definition of the nature and extent of concrete contamination, concrete problems across the DOE complex were identified and categorized, emerging technologies with potential applicability to addressing the problems were listed, and DOE sites with representative problems as potential demonstration sites were identified (Table 4.1).

For the purposes of this evaluation, contaminated concrete was broken into four categories: (1) transferrable surface areas containing removable contamination on the concrete surface and not within the concrete matrix; (2) fixed surface areas containing contaminants in the concrete matrix at a depth of 1/8 in. or greater; (3) deep contamination, including contaminants that had migrated beyond the surface due to cracks and penetrations; and (4) bulk contamination, which was assumed to be activated concrete and, therefore, not appropriate for decontamination processes. The fixed surface area category was subdivided to take into account different conditions that impact decontamination, including bare floors, painted floors, bare walls, painted walls, and containments such as basins and pools. It was recognized by the team that hot cells could be considered separately. However, it was assumed that decontamination of the hot cell could be conducted by considering a combination of the other fixed surface area subcategories.

Following team consensus on definition of the problem, screening of candidate technologies began. This project focused on emerging technologies. Commercially available technologies (such as scabbling) were used as baseline technologies for comparison. The preliminary list of candidate technologies (Table 3.1) was screened based on factors such as time before the technology was expected to be ready for field application (must be ready for demonstration by FY96 for inclusion in this project) and the likelihood of implementation (regulatory and safety issues must be addressed). Several technologies were removed from further consideration at this time. Next, the stage of development for each technology potentially applicable to a problem was identified, and the usefulness of a demonstration to move the technology through a "gate" and to the next stage of development was evaluated (Figure 4.1 and Table 4.2). A relative rank (high, medium, low) was given to each technology within a problem area based on the probability of a demonstration to move the technology through a gate and provide new information to DOE for addressing the concrete problem. Other considerations given during ranking included previously conducted demonstrations, need for a technology to move to the next stage or be removed from the development process (i.e., technologies that have stalled out in the development process), and if the technology addresses a need that is not addressed by other technologies. For example, for surface areas with transferrable contamination, chemical extraction was ranked low because the technology is considered to be in the commercial stage and a demonstration of the technology for this problem would not move the development through a gate. However, for deep contamination in cracks and penetrations, chemical extraction was rated high because a demonstration for this problem may move the technology through a gate to implementation for a problem that is not adequately addressed by other technologies. A record of the comments and considerations during ranking for each technology was kept and is summarized in Table 4.2. The assumptions made during the evaluation were verified with the vendors and technology developers to ensure the team had an accurate understanding of the technology and its applicability to the problem. Additionally, specific information for conducting demonstrations and identification of leveraging opportunities were pursued.

The results from this screening process provided information on the breadth of problems for which a technology has application (a measure of the fraction of concrete within the DOE complex that the technology has the potential to address) and a relative perspective on the value added to development of a technology if a demonstration were to be conducted. It should be noted that based on the uncertainties of the data describing the extent of contamination (Sect. 2), it is not possible to accurately estimate the percentage of the total contaminated concrete represented by each specific problem area (e.g., 75% of the contaminated concrete within the DOE complex is associated with bare floors). However, general trends indicate that bare and painted floors are likely to represent the largest areal extent of contaminated concrete, followed by bare and painted walls and ceilings, then containments, and, finally, cracks and penetrations representing the smallest fraction of the problem. The difficulties associated with decontamination of the various problem areas were also considered. For example, cracks and penetrations may account for only a small portion of the problem but are the most difficult problem area to decontaminate, while floors may account for the largest portion of the problem but are the easiest to decontaminate. As mentioned previously, these factors were taken into consideration when ranking the technologies specific to problems.

Technologies with potential application to the problems were further evaluated based on estimated cost, secondary waste generation, and processing rates. Again a relative rank (high, medium, low) was assigned to each technology based on a qualitative comparison of the criteria to the baseline technology. A high ranking indicates additional benefit of the technology over the baseline (i.e., lower cost or secondary waste generation, faster processing rates), medium indicates little or no added benefit, and low indicates a higher cost or secondary waste generation rate or a slower processing rate when compared to baseline technologies. The reported cost data used for evaluation are expected to be low due to the variations in how the data were reported and because capital costs cannot be apportioned as unit costs until the size of the demonstration (or ultimate use by the site) is determined. When capital costs are apportioned it may change the individual cost rankings listed in Table 4.3. Secondary waste generation rankings were typically high. This was assumed to be a reflection of the fact that emerging technologies are conceived and developed in part based on the ability of a process to reduce secondary waste. It is also interesting to note that the processing rates were typically slower than baseline technologies and, therefore, received low rankings. It is likely that processing rates will increase as the technology is streamlined during development and commercialization.

Table 4.3 summarizes the results of the screening and evaluation process. In all cases, adequate technology performance was assumed. Additionally, it was assumed that unit disposal costs for liquid and/or solid secondary waste streams would be the same for each technology application. Due to the uncertainties associated with cost information for technologies that have not been commercially developed, the best available cost information is reported for comparison (Table 4.4), but only a relative ranking was assigned based on the comparison between the emerging technology and the baseline technology. Cost data was solicited from private industry and technology developers and confirmed with information published in the open literature and DOE reports. For comparison and evaluation of cost, secondary waste generation, and processing rates, the baseline technologies were assumed to be washing for transferrable surfaces, mechanical scabbling for floors (bare and painted) and containments, needle gun scabbling and/or high pressure washing for walls and ceilings (bare and painted), and jack-hammering for cracks and penetrations. Parameters used during the comparison for the baseline technologies are included in Table 4.3.

	Basic Research	Applied Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration	Implementation
Technology Maturation Stages	Idea generation		Proof of technology		Engineering prototype	Production prototype	Utilization by end-user
	No need	Need	Product definition Non-specific applications Bench-scale	Working model Reduction to practice Specific applications Bench-scale	Scaled-up version to test design features and performance limits Pilot-scale Field testing	End-user validation Full-scale "Beta" site testing	Utilization by end-user
Gates		1	2	3	4	5	6
Expectations			Address priority DOE need Knowledge of similar efforts	Show clear advantage over available technology	Meet cost/benefit requirement Demonstrate significant end-user demand	Technology ready for end-user	End-user deploys technology
End-user Input	←Needs→ ←Requirements→ ←Specifications→						
Information Required for Subsequent Gate Decisions	Establish programmatic fit		Preliminary utilization plan addressing: - Technical - Programmatic - Market - Financial - Regulatory - Public - Legal - Health and safety factors Communications plan	Detailed utilization plan with: - Elements of preliminary utilization plan *plus* - Partnership assessment - Cost/benefit analysis Initial performance/cost data package	Final utilization plan with: - Elements of detailed utilization plan *plus* - Cost-sharing and partnership agreements in place Final performance/cost data package	Signed contract with end-user(s)	

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Fig. 4.1. Managing technologies for deployment. *Source:* Paladino, J., and P. Longsworth. *A Common Framework for Managing Technology Development in DOE's Environmental Cleanup Program* (draft). Office of Technology Development, Office of Environmental Management. U.S. Department of Energy. Used with permission.

Table 4.1. Matching of concrete decontamination problems with emerging technologies

Problem	Surface Areas (Transferrable)	Surface Areas (Fixed)					Deep Contamination (Cracks and Penetrations)
		Bare floors	Painted floors	Bare walls/ceilings	Painted walls/ceilings	Containments (basins/pools)	
Technology	Biological CO_2 blasting Chemical extraction Electro-hydraulic scabbling Flashlamp Ice blasting Laser ablation Soda blasting Soft media blasting Strippable coatings	Biological Chemical extraction Electrokinetics Electro-hydraulic scabbling Flashlamp Laser ablation Microwave Plasma torch Soft media blasting	Biological Chemical extraction CO_2 blasting Electro-hydraulic scabbling Flashlamp Ice blasting Laser ablation Microwave Plasma torch Soda blasting Soft media blasting	Biological Chemical extraction Flashlamp Laser ablation Soft media blasting	Biological Chemical extraction CO_2 blasting Flashlamp Ice blasting Laser ablation Soda blasting Soft media blasting	Biological Chemical extraction Electrokinetics Electro-hydraulic scabbling Flashlamp Laser ablation Microwave Plasma torch Soft media blasting	Chemical extraction Electrokinetics Honing
Site and Contaminants	All Sites	Fernald (U, Th) Hanford (Sr, Cs, Pu, U, Tc, Co) INEL (Co, Cs, Eu, U, Sr, Pu) Oak Ridge K-25 Site (U, Tc, TRU) Mound (Pu, tritium, Th) NTS(U, Pu, Am, Sr, Co) Portsmouth (U, Tc, TRU) Paducah (U) RMI Titanium, Inc. (U) SRS (U, Pu, Cs, tritium)	ANL (Co, Cs) Hanford (Sr, Cs, Pu, U, Tc, Co) INEL (Co, Cs, Eu, U, Sr, Pu) LANL (Pu, U) ORNL (Cs, Co, Sr, U, Th) RFETS (Pu, U)	Fernald (U, Th) INEL (Co, Cs, Eu, U, Sr, Pu) Oak Ridge K-25 Site (U, Tc, TRU) Portsmouth (U, Tc, TRU) Paducah (U) SRS (U, Pu, Cs, tritium)	ANL (Co, Cs) Hanford (Sr, Cs, Pu, U, Tc, Co) INEL (Co, Cs, Eu, U, Sr, Pu) LANL (Pu, U) ORNL (Cs, Co, Sr, U, Th) RFETS (Pu, U)	BNL (U oxide, Pu, tritium) Hanford (Sr, Cs, Pu, U, Tc, Co) SRS (U, Pu, Cs, tritium)	All Sites

Note: Bulk contamination was assumed to be activated concrete associated with reactors and, therefore, not considered appropriate for decontamination processes.

Table 4.2. Evaluation of potential demonstration usefulness

Problem Area	Potential Candidate Technology	Stage of Technology Development[a]	Usefulness of Demonstration[b]	Comments
Surface Area (transferrable)	Biological	Applied research	High	Potential to leverage with demo planned for 1995. May progress development through gate 2 to exploratory development.
	Chemical extraction	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted.
	Chromagraphic strippable coatings	Exploratory development	High	Demo may assist development through gate 3. Benefit of technology may be in characterization.
	CO_2 blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Must consider waste containment problems
	Electro-hydraulic scabbling	Advanced development	High	Potential to leverage with demo planned in FY95. May progress development through gate 3 to engineering development.
	Flashlamp	Advanced development	Medium	Demo may assist development through gate 4. Must show clear advantage over other numerous alternative technologies applicable to this problem.
	Ice blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Extensively used commercially.
	Laser ablation	Advanced development	High	Demo may assist development through gate 4. Proof of technology to date has been on a very small scale. Potential bathtub ring (non-smearable) application to remove shine (see containments).
	Soda blasting	Engineering development	Medium	Demo may assist development through gate 5. Need to show application to radionuclides and clear advantage over numerous alternative technologies applicable to this problem.
	Soft media Blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Extensively used commercially for non-radiological contamination.

Table 4.2. (continued)

Problem Area	Potential Candidate Technology	Stage of Technology Development[a]	Usefulness of Demonstration[b]	Comments
Surface Area (fixed) Bare Floors	Biological	Applied research	High	Potential to leverage with demo planned for 1995. May progress development through gate 2 to exploratory development. Must identify DOE need due to required decontamination time.
	Chemical extraction	Implementation	Low	Demo will not assist development through a gate. Several demonstrations have been conducted.
	Electrokinetics	Exploratory development	High	Demo may assist development through gate 3. Potential to leverage with N reactor pool.
	Electro-hydraulic scabbling	Advanced development	high	Potential to leverage with demo planned in FY95. May progress development through gate 4 to engineering development.
	Flashlamp	Advanced development	Medium	Demo may assist development through gate 4. Must show clear advantage over other numerous alternative technologies applicable to this problem.
	Microwave	Advanced development	High	Demo may assist development through gate 4. Potential leveraging may assist with field testing. Must show cost/benefit ratio.
	Plasma torch	Exploratory development	Low	Unclear if demo will assist development through a gate. Interest in development is not clear.
	Soft media blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Extensively used commercially for non-radiological contamination.
Surface Area (fixed) Painted Floors	Biological	Applied research	High	Potential to leverage with demo planned for 1995. May progress development through gate 2 to exploratory development. Must identify DOE need due to required decontamination time.
	Chemical extraction	Demonstration	Medium	Demo may assist development through gate 6 to commercialization. Must consider containment and neutralization of chelators.

Table 4.2. (continued)

Problem Area	Potential Candidate Technology	Stage of Technology Development[a]	Usefulness of Demonstration[b]	Comments
	CO_2 blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Must consider waste containment problems
	Electro-hydraulic scabbling	Advanced development	High	Potential to leverage with demo planned in FY95. May progress tech development through gate 4 to engineering development.
	Flashlamp	Advanced development	Medium	Demo may assist development through gate 4. Must show clear advantage over other numerous alternative technologies applicable to this problem.
	Ice blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Extensively used commercially.
	Laser ablation	Advanced development	Medium	Demo may assist development through gate 4. Proof of technology to date has been on a very small scale. Must show clear advantage over other technologies.
	Microwave	Advanced development	High	Demo may assist development through gate 4. Potential leveraging may assist with field testing. Must show cost/benefit ratio.
	Plasma torch	Exploratory development	Low	Unclear if demo will assist development through a gate. Interest in development is not clear.
	Soda blasting	Engineering development	Medium	Demo may assist development through gate 5. Need to show application to radionuclides and clear advantage over numerous alternative technologies applicable to this problem.
	Soft media blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been previously conducted. Extensively used commercially for non-radiological contamination.

Table 4.2. (continued)

Problem Area	Potential Candidate Technology	Stage of Technology Development[a]	Usefulness of Demonstration[b]	Comments
Surface Area (fixed) Bare Walls/Ceilings	Biological	Applied research	High	Potential to leverage with demo planned for 1995. May progress development through gate 2 to exploratory development. Must identify DOE need due to required decontamination time.
	Chemical extraction	Implementation	Low	Demo will not assist development through a gate. Several demonstrations have been conducted.
	Flashlamp	Advanced development	Medium	Demo may assist development through gate 4. Must show clear advantage over other numerous alternative technologies applicable to this problem.
	Soft media blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Extensively used commercially for non-radiological contamination.
Surface Area (fixed) Painted Walls/Ceilings	Biological	Applied research	High	Potential to leverage with demo planned for 1995. May progress development through gate 2 to exploratory development. Must identify DOE need due to required decontamination time.
	Chemical extraction	Demonstration	Medium	Demo may assist development through gate 6 to commercialization. Must consider containment and neutralization of chelators.
	CO_2 blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Must consider waste containment problems.
	Flashlamp	Advanced development	Medium	Demo may assist development through gate 4. Must show clear advantage over other numerous alternative technologies applicable to this problem.
	Ice blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been previously conducted. Extensively used commercially.

Table 4.2. (continued)

Problem Area	Potential Candidate Technology	Stage of Technology Development[a]	Usefulness of Demonstration[b]	Comments
	Laser ablation	Advanced development	Medium	Demo may assist development through gate 4. Proof of technology to date has been on a very small scale. Must show clear advantage over other technologies.
	Soda blasting	Engineering development	Medium	Demo may assist development through gate 5. Need to show application to radionuclides and clear advantage over numerous alternative technologies applicable to this problem.
	Soft media blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Extensively used commercially for non-radiological contamination.
Surface Area (fixed) Containments (basins/pools)	Biological	Applied research	High	Potential to leverage with demo planned for 1995. May progress development through gate 2 to exploratory development. Must identify DOE need due to required decontamination time.
	Chemical extraction	Implementation	Low	Demo will not assist development through a gate. Several demonstrations have been conducted.
	Electrokinetics	Exploratory development	High	Demo may assist development through gate 3. Potential to leverage with N reactor pool.
	Electro-hydraulic scabbling	Advanced development	High	Potential to leverage with demo planned in FY95. May progress development through gate 4 to engineering development.
	Flashlamp	Advanced development	Medium	Demo may assist development through gate 4. Must show clear advantage over other numerous alternative technologies applicable to this problem.
	Laser ablation	Advanced development	Medium	Demo may assist development through gate 4. Proof of technology to date has been on a very small scale. Potential bathtub ring (non-smearable) application to remove shine.

Table 4.2. (continued)

Problem Area	Potential Candidate Technology	Stage of Technology Development[a]	Usefulness of Demonstration[b]	Comments
	Microwave	Advanced development	High	Demo may assist development through gate 4. Potential leveraging may assist with field testing. Must show cost/benefit ratio.
	Plasma torch	Exploratory development	Low	Unclear if demo will assist development through a gate. Interest in development is not clear.
	Soft media blasting	Implementation	Low	Demo will not assist development through a gate. Numerous demonstrations have been conducted. Extensively used commercially for non-radiological contamination.
Deep Contamination (cracks and penetrations)	Chemical extraction	Demonstration	High	Demo may assist development through gate 6 to commercialization. Must consider containment and neutralization of chelators. Few technologies address this problem.
	Electro-hydraulic scabbling	Advanced development	High	Potential to leverage with demo planned in FY95. May progress development through gate 4 to engineering development. Containment of the water must be considered for application to this problem.
	Electrokinetics	Exploratory development	High	Demo may assist development through gate 3. Potential to leverage with N reactor pool. Few technologies address this problem.
	Microwave	Advanced development	Medium	Demo may assist development through gate 4, but it is unclear if the technology will be applicable to this problem (technology will require modification for this application). Potential leveraging may assist with field testing. Must show cost/benefit ratio.
	Honing	Implementation	Low	Demo will not assist development through a gate. Applicable to penetrations such as borings, etc.

[a] Stage of development is defined on Fig. 4.1.
[b] Rank was based on the usefulness of a demonstration to move the technology along on the implementation continuum (i.e., benefit from a demonstration to assist a technology through a "gate" and to the next stage of development, Fig. 4.1).

Table 4.3. Results from technology demonstration evaluation

Technology	Number of Applicable Problems[a]	Usefulness of Demo[b]	Estimated Cost[c]	Secondary Waste Generation[d]	Processing Rates[e]	Comments
Biological	6	High	High	High	Low	Waste volumes are assumed to be slightly less than the baseline technology primarily due to smaller particle size compared to the size of scabbled concrete. Advantages include low worker exposure, low labor requirements, controlled removal, the fact that the process does not drive the contaminant farther into the concrete, and application to a wide variety of problems and configurations. Limitations include slow processing rates and careful control of the operating conditions (relative humidity and nutrients).
Chemical extraction	7	Medium	Medium high	High	Medium	Several vendors have completed or are in the process of conducting demonstrations; thus the technology may be considered as a commercial process with low benefit for additional demonstrations. It might be considered as an enhancement to the electrokinetic process. Advantages of the process are minimal worker exposure, minimization of secondary waste, and the fact that the concrete surface is not harmed or destroyed. Limitations include depth of chemical penetration for decontamination and disposal of secondary waste (may be considered as a mixed waste).
Chromographic strippable coatings	1	High	Unknown	High	Unknown	Technology is a variation of strippable coatings and is in the early stages of development. Bench-top experiments have shown "proof of principle", but more specific information is not available. Advantage is identification of hot spots during application, thus minimizing extent of the area treated.

Table 4.3. (continued)

Technology	Number of Applicable Problems[a]	Usefulness of Demo[b]	Estimated Cost[c]	Secondary Waste Generation[d]	Processing Rates[e]	Comments
CO_2 blasting	3	Low	Medium low	High	Medium	Several variations of the technology are being developed. However, CO_2 blasting is considered to be commercially available, thus a demonstration would provide limited benefits.
Electrokinetics	3	High	Unavailable	High	Low	Cost estimates are not available at this time. Additionally, secondary waste volumes are expected to be minimized compared to baseline technologies but have not yet been quantified. Advantages of the process are minimal worker exposure, minimization of secondary waste, and the fact that the concrete surface is not harmed or destroyed. Disadvantages include slower processing rates.
Electro-hydraulic scabbling	5	High	High	Medium	Low	This technology is expected to be sold as a service; therefore, capital costs are not applicable. Operating costs may vary as development of the process continues. Secondary waste is slightly higher than the baseline due to the use of water for scabbling. However, water recycling and dust minimization (i.e., reduced worker exposure to dust) may offset the limitations.
Flashlamp	6	Medium	Medium	High	Medium	This technology is expected to be sold as a service; therefore, capital costs are not applicable. Essentially this process would be used to remove surface coatings only, but may also fix contamination in place (e.g., vitrification of concrete). It produces an ash waste of ~ 25% of the baseline technology-generated waste volume. Advantages include low waste volume and the fact that it does not drive contaminants into the concrete nor damage the surface. Limitations include difficulty of maneuvering the equipment to decontaminate corners and tight places.

Table 4.3. (continued)

Technology	Number of Applicable Problems[a]	Usefulness of Demo[b]	Estimated Cost[c]	Secondary Waste Generation[d]	Processing Rates[e]	Comments
Ice blasting	3	Low	Medium	Low	Medium	Ice blasting is considered to be commercially available; thus a demonstration would provide limited benefits.
Laser ablation	4	Medium	Medium low	High	Low	This technology is expected to be sold as a service; therefore, capital costs are not applicable. Essentially this process would be used to remove surface coatings only. It produces an ash waste of ~ 25% of the baseline technology-generated waste volume. Advantages include low waste volume and the fact that it does not drive contaminants into the concrete nor damage the surface. Limitations include difficulty of maneuvering the equipment to decontaminate corners and tight places.
Microwave scabbling	4	Medium high	Medium low	Medium	Low	Although the technology has been used internationally (Japan) it is considered to be available only through the DOE system in the United States. Secondary waste may be slightly higher than the baseline due to the larger size of the scabbled concrete. Advantages include minimization of air-borne particles and applicability to high radiation areas if remotely operated. Modifications to the system may have application to decontamination of walls. Limitations include difficulty of maneuvering the equipment to decontaminate corners and tight places.

Table 4.3. (continued)

Technology	Number of Applicable Problems[a]	Usefulness of Demo[b]	Estimated Cost[c]	Secondary Waste Generation[d]	Processing Rates[e]	Comments
Plasma torch	3	Low	Medium	High	Low	This process would be used to remove surface coatings only. Produces an ash waste of ~ 25% of the baseline technology-generated waste volume. Advantages include low waste volume and the fact that it does not drive contaminants into the concrete nor damage the surface. Limitations include development costs and difficulty of maneuvering the equipment to decontaminate corners and tight places.
Soda blasting	3	Medium	Medium	High	Medium	Although secondary waste volumes will be slightly less than baseline technologies, treatment of the waste may be a limitation. The technology has been demonstrated at numerous non-radioactive sites and has been modified for decontamination of radioactive surfaces (recently demonstrated at K-25); therefore, additional demonstrations may provide limited benefits.
Soft media blasting	6	Low	Medium low	Medium	Medium	This technology is expected to be sold as a service; therefore, capital costs are not applicable. Waste volumes will be slightly less than baseline technologies depending on the efficiency of recycling the soft media. The technology has been applied to non-radioactive contamination and is being modified for decontamination of radioactive surfaces; therefore, the technology is considered to be commercially available. A demonstration would provide limited benefits.

Table 4.3. (continued)

Technology	Number of Applicable Problems[a]	Usefulness of Demo[b]	Estimated Cost[c]	Secondary Waste Generation[d]	Processing Rates[e]	Comments
Mechanical	Baseline	NA				Baseline technology for fixed contamination in floors (bare and painted) and containments problem areas.
scabbling			$7-12.6 /ft^2$	$0.083\ ft^3/ft^2$	315-323 ft^2/h	
Scarifier			$6.65 /ft^2$	$0.031\ ft^3/ft^2$	47 ft^2/h	
Grit blasting			$0.31-5.02 /ft^2$	0.003-0.029 ft^3/ft^2	Variable	
Shot blasting						
Needle gun scabbling	Baseline	NA	$13.06 /ft^2$	$0.0026\ ft^3/ft^2$	Unavailable	Baseline technology for fixed contamination in walls and ceilings (bare and painted).
High-pressure washing	Baseline	NA	$16.91/ft^2$	$0.028\ ft^3/ft^2$	377 ft^2/h	Baseline technology for fixed contamination in walls and ceilings (bare and painted).
Washing/scrubbing	Baseline	NA	<$1/ft^2	Variable	Variable	Baseline technology for transferable contamination.

[a] Seven problems areas were identified and used for comparison (see Table 4.1).
[b] High ranking indicates an assumed greater benefit from a demonstration (see Table 4.2).
[c] High ranking indicates an assumed process operation cost savings compared to baseline technologies, medium indicates minimal (or no) benefit, and low indicates a higher process operation cost per unit. Capital cost was not included in the evaluation because these costs can not be evaluated as unit costs until a specific application (extent of contamination to be decontaminated) is identified.
[d] High ranking indicates an assumed reduction in secondary waste compared to baseline technologies, medium indicates minimal (or no) benefit, and low indicates increased secondary waste generation.
[e] High ranking indicates a faster processing rate compared to baseline technologies, medium indicates minimal (or no) benefit, and low indicates a slower processing rate.
NA: not applicable

Table 4.4. Estimated costs for emerging concrete decontamination technologies

Technology	Estimated Capital Cost, $	Estimated Operating Cost, $/ft^2	Estimated Labor Costs, $/hr	Comment
Automated brushing	250K	300	Variable	
Automated grinding	Up to 500K	Unknown	Variable	
Biological (microbially influenced) degradation	Unavailable	1-3	Included in operating cost	
Centrifugal cryogenic CO_2 blasting	100-200K	0.075-0.75	Unknown	Technology may require up to ~$750K for concrete application development.
Chelation	Unavailable	<1	Unknown	
Chemical extraction	<5K	4-5	Up to 43.75[a]	Assumes 2-person team for application.
Chemical foams	<50K	0.5-2	43.75[a]	Assumes 2-person team for application.
Chemical gels	<50K	0.5-2	43.75[a]	Assumes 2-person team for application.
Chromographic strippable coatings	Unavailable	Unavailable	Unavailable	Cost information is not available due to the early development stage of the process.
CO_2 blasting	300K	0.90-1.75	15-300 (includes operating cost)	Higher cost range estimates are for application to radioactive contaminants.
Compressed-air cryogenic CO_2 pellet blasting	Unavailable	8-26	Unknown	Operating cost includes energy requirements.
Concrete milling	11K	0.75	43.75[a]	
Detergent (caustic) treatment	<10K	>1.00	Variable	
Electro-hydraulic scabbling	Unavailable	0.65-1.85	Included in operating cost	Assumed that the process would be provided as a service by private industry.
Electrokinetics	Unavailable	Unavailable	Unavailable	Cost information will be available from the vendor by mid-June.
Explosives	50K	50	Unknown	
Flame scarification	Unavailable	Unavailable	Unavailable	
Flashlamp	500K	4.5-25	Included in operating cost	Assumed that the process would be provided as a service by private industry.
Grit (sand) blasting	Unavailable	5-10	43.75[a]	
Hand grinding, honing, scraping	Unavailable	0.5-1	Variable	
High-pressure water	50-75K	0.06-2	43.75[a]	
Ice blasting	60-155K	1	43.75[a]	

Table 4.4. (continued)

Technology	Estimated Capital Cost, \$	Estimated Operating Cost (\$/ft^2)	Estimated Labor Costs (\$/hr)	Comment
Laser ablation	~700K (up to 1M to develop prototype)	Unavailable	Unknown	It is likely that the process will be provided as a service by private industry.
Microwave scabbling	150K	2	43.75[a]	
Plasma torch	<100K	1	<100	
Plastic pellet blasting	Unavailable	0.20-2.15	43-63	
Scarification	110K	5-12.6	43.75[a]	
Shot blasting	4M	0.04-5.02	43.75[a]	Capital cost estimate is based on the cost to design and build a pilot facility.
Soft media blasting	20K	2, 10-12	43.75[a]	Higher cost range includes labor costs when assumed the process is provided as a service by private industry.
Soda blasting	Unavailable	5-7	43.75[a]	Operation cost estimated at \$5.62/ft^2 at Oak Ridge K-25 Site demonstration.
Steam cleaning	50-75K	0.05-2	43.75[a]	
Strippable coatings	<10K	1-1.4	43.75[a]	Assumes 2-person team for application. Capital cost is for the spraying unit.
Supercritical CO_2 blasting	150K	1	43.75[a]	
Superheated water	175K	0.05-2	43.75[a]	
Ultra-high-pressure water	>500K	>2	43.75[a]	
Water flushing	<5K	<1	variable	

[a] Labor cost estimate based on a 2-person team at \$40K/year/person.

Sources: Technology logic diagrams (INEL 1993, 1994; Oak Ridge K-25 Site 1993; ORNL 1993) Vendor responses (Dickerson et al. 1995; Neiswander 1995).

5. DEMONSTRATION RECOMMENDATIONS

Candidate technologies were qualitatively ranked based on the relative ranking for each criteria (Table 4.3), resulting in three groupings: (1) demonstration is recommended, (2) demonstration may be considered, and (3) remove from further consideration. The evaluation process and criteria are discussed in Sect. 4. Technologies in the first group are considered to potentially provide the most benefit to decontamination of concrete within the DOE complex and include biological decontamination, electro-hydraulic scabbling, electrokinetics, and microwave scabbling. Biological decontamination is recommended for demonstration because it has the potential to solve a wide range of contamination problems (a large fraction of contaminated concrete), fits a niche that is not currently addressed (long-term passive treatment), and may offer potential cost savings and waste reduction. Similarly, electrokinetic processes are recommended for demonstration because of their potential to decontaminate a large fraction of contaminated concrete within the DOE complex and their application to a niche that is not currently addressed (cracks and penetrations, contamination at depths greater than the surface inch), as well as their potential for waste reduction. Electro-hydraulic scabbling ranked high for all criteria and, therefore, is recommended for demonstration. A demonstration of this technology at Fernald is currently funded by Morgantown Energy Technology Center (METC). However, preliminary discussions with technology developers indicated an interest in additional demonstrations of this technology as applied to other problem areas. Finally, microwave scabbling is recommended for demonstration to determine the feasibility of the technology.

Technologies in the second group were considered to provide benefits to concrete decontamination but with specific application: chemical extraction, for application to cracks and penetrations or coupled with electrokinetic processes to determine if the processes can be optimized; chromographic strippable coatings, a process that although is in early development stages, may provide characterization and waste minimization benefits; and flashlamp, for the potential to significantly reduce secondary waste and as a decontamination service, to reduce costs.

Technologies in the third group are not recommended for demonstration and include CO_2 blasting (and variations of the process), ice blasting, laser ablation, plasma torch, soda blasting and soft media blasting. The primary reason for removing these technologies from further consideration is that they are essentially variations of baseline scabbling technologies and may be considered commercially available (at least for non-radiological contamination), therefore adding little benefit to decontamination of concrete if demonstrated. Both the laser ablation and plasma torch technologies are not recommended for demonstration because they address, without reducing cost, problem areas (transferrable contamination and painted surfaces) that currently have numerous commercial technology solutions. However, both of these technologies have the potential to significantly reduce waste generation compared to baseline technologies. Table 5.1 is a summary of the demonstration recommendations.

Discussions have been initiated with several DOE sites, technology developers, and private industry vendors to identify potential demonstration sites. Several potential locations have been identified and are listed on Table 5.1. The next phase of the project will focus on selection of a demonstration site and private industry partner. The selection of a demonstration site will be based on leveraging opportunities, benefit to the site (e.g., will the technology address problem areas at that site, is the site currently working to partner with the vendor), and ease of implementing the demonstration. When a private industry partner is not currently working with the technology developer, selection will be based on responses to a solicitation for participation.

Table. 5.1. Summary of recommended demonstrations

Technology	Potential Industry Partner	Potential Demonstration Site	Problem Area	Recommendation
Biological decontamination	British Nuclear Fuels PLC	INEL EBR-1 Historical Site RFETS Hanford	Transferrable and fixed surfaces	Demonstrate
Chemical extraction	Corpex Environmental Engineering Technology Corporation	Hanford Purex (EM-40) ORNL Bldg. 2026	Penetration Hot cell	Consider demonstration (potential to optimize electrokinetics)
Chromographic strippable coatings		LANL RFETS	Transferrable and fixed surfaces	Consider demonstration
CO_2 blasting	Commercially available		Transferrable and painted surfaces	Remove from further consideration
Electro-hydraulic scabbling	Textron	Fernald ORNL	Fixed surfaces (floors)	Demonstrate (demonstration is currently funded through METC)
Electrokinetics	ISOTRON	Hanford N Reactor Pool (EM-40)	Fixed surfaces (containments and floors)	Demonstrate
Flashlamp	Polygon	Ashtabula (EM-40)	Fixed surfaces (floors and walls)	Consider demonstration
Ice blasting	Commercially available		Transferrable and fixed surfaces	Remove from further consideration
Laser ablation	F2 PENTEK		Painted surfaces	Remove from further consideration
Microwave scabbling	PENTEK		Fixed surfaces (floors and walls)	Demonstrate
Plasma torch			Transferrable and painted surfaces	Remove from further consideration
Soda blasting	OBG Technical Services		Transferrable and painted surfaces	Remove from further consideration
Soft media blasting	GenCorp Aerojet	RFETS Fernald Hanford	Transferrable surface (fixed and/or painted surfaces)	Remove from further consideration

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