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Technology Reference Guide for Radiologically Contaminated Surfaces

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Office of Air and Radiation
Office of Radiation and Indoor Air
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Technology Reference Guide for Radiologically Contaminated Surfaces

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Radiation and Indoor Air
Radiation Protection Division
Center for Radiation Site Cleanup

EnDyna, Inc.
Under Contract No. 4W-2324-WTSZX

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Disclaimer

This Technology Guide, developed by USEPA, is meant to be a summary of information available for technologies demonstrated to be effective for radioactive surface decontamination. Inclusion of technologies in this Guide should not be viewed as an endorsement of either the technology or the vendor by USEPA. Similarly, exclusion of any technology should not be viewed as not being endorsed by USEPA; it merely means that the information related to that technology was not so readily available during the development of this Guide. Also, the technology-specific performance and cost data presented in this document are somewhat subjective as they are from a limited number of demonstration projects and based on professional judgment. In addition, all images used in this document are from public domain or have been used with permission.

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Preface

This *Technology Reference Guide for Radiologically Contaminated Surfaces* (Guide) is designed to help interested parties identify technologies that are potentially useful in removing radiological contaminants from surfaces as part of a site remediation. The Guide is a snapshot in time and may be updated in the future. If you have any comments on the document or suggestions for incorporation in future updates, please contact:

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List of Acronyms and Abbreviations

A	Ampere
AEC	U.S. Atomic Energy Commission
AECL	Atomic Energy of Canada Limited
ALARA	As low as reasonably achievable
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
AP	Alkaline-Permanganate
ARAR	Applicable or Relevant and Appropriate Requirement
ASME	American Society of Mechanical Engineers
Bq	Becquerel
BRC	Below regulatory concern
BRWM	Board on Radioactive Waste Management (NAS)
CANDEREM	Canadian Decontamination and Remediation Process
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (also known as Superfund; see also SARA)
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations
CITROX	Citric acid – oxalic acid process
CLU-IN	Hazardous Waste Clean-Up Information (EPA website)
cm	centimeter
CMS	Corrective Measures Study
CORD	Chemical Oxidizing Reducing Decontamination
D&D	Decontamination and Demolition (also can refer to Deactivation and Decommissioning or other combinations of these terms)
DECOHA	A fluoroboric acid process
DfD	Decontamination for Decommissioning Process (EPRI)
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
DPM	Disintegrations per Minute
DTPA	Diethylenetriaminepentaacetic acid
EC	European Commission or European Community
EDDS	Ethylenediaminedisuccinic acid
EDTA	Ethylenediamine tetra-acetic acid
EHS	Electro-hydraulic scabbling
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ERDF	Environment Restoration Disposal Facility (Hanford)
ERWS	En-vac Robotic Wall Scabbler
EU	European Union
FEMP	Fernald Environmental Management Project
FS	Feasibility Study
ft	foot
g	gram
gal	gallon
h	hour
HEDTA	Hydroxyethylenediaminetriacetic acid

HEPA	High efficiency particulate and aerosol (filter)
HPS	The Health Physics Society
HPWC	High-Pressure Water Cleaning
Hrc	Hardness on the Rockwell C Scale
Hz	Hertz
ICRP	International Commission on Radiological Protection
in	inch
INL	Idaho National Laboratory
ITSR	Innovative Technology Screening Report
kJ	kilojoule
kg	kilogram
kV	kilovolt
kW	kilowatts
L	Liter
LOMI	Low Oxidation State Transition Metal Ion Process
LSDDP	Large Scale Demonstration and Deployment Project
LSDP	Large Scale Demonstration Project
LTR	License Termination Rule
m	meter
MDA	Minimum Detectable Activity
MEDOC	Metal Decontamination by Oxidation with Cerium process
MID	Microbially Influenced Degradation
min	minutes
mm	millimeter
n	nano
NAS	National Academy of Sciences
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEA	Nuclear Energy Agency
NITROX	Nitric acid-permanganate-oxalic acid process (PN Services Inc)
NMSS	Nuclear Material Safeguards and Safety
NORM	Naturally occurring radioactive material
NP	Nitric acid-permanganate process
NRC	U.S. Nuclear Regulatory Commission
NUREG	Nuclear regulation (NRC)
OECD	Organization of Economic Cooperation and Development
OEDPA	Oxyethylidenediphosphonic acid
OMB	Office of Management and Budget
OPG	Oxalic acid-Peroxide-Gluconic acid process
OSC	On-Scene Coordinator
OSDF	Of-Site Disposal Facility
OSHA	Occupational Safety and Health Admistration
p	pico
PCB	Polychlorinated biphenyl
PH	Person Hour
PICS	Personal Ice Cooling System
PLF	Productivity Loss Factor
PNNL	Pacific Northwest National Laboratory
PPE	Personal Protective Equipment
PWR	Pressurized Water Reactor
psi	pounds per square inch

R&D	Research and Development
RCT	Radiological Control Technician
RAPIC	Remedial Action Program Information Center
REDOX	Reduction-Oxidation process
RBMK	Reactor Bolshoy Moshchnosty Kanalny (Soviet Nuclear Reactor)
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
rpm	revolutions per minute
s	second
SABAR	Steel Abrasive Blasting and Recovery System
SARA	Superfund Amendments and Reauthorization Act of 1986 (also known as Superfund)
scfm	standard cubic feet per minute
SCIRUS	A specialized science based search engine (http://www.scirus.com/srsapp/)
SODP	Strong Ozone Decontamination Process
SITE	Superfund Innovative Technology Evaluation
SRS	Savannah River Site (DOE)
TEDE	total effective dose equivalent
TENORM	technologically enhanced naturally occurring radioactive material
TMS	Technology Management System
TUCS	Thermally Unstable Complexing Solutions
USACE	U.S. Army Corps of Engineers
UV	Ultra violet
V	Volt
VAC	Volts AC
VISITT	Vendor Information System for Innovative Treatment Technologies
yr	year

Executive Summary

The U.S. Environmental Protection Agency (EPA), Office of Radiation and Indoor Air (ORIA) developed this *Technology Reference Guide For Radiologically Contaminated Surfaces* (Guide) to help identify surface decontamination technologies that can effectively remove radiological contaminants from building, structure, and equipment surfaces. These technologies may also be useful in the removal of non-radiological contaminants, such as hazardous metals, from surfaces. This Guide is designed to provide easy access to critical information on technologies that are commercially available. This information is presented in technology profiles that can be used to compare technologies for site-specific application. The technologies selected for presentation in this Guide include those that could be considered for response actions.

The technology profiles are categorized under two general classifications:

- Chemical Decontamination Technologies
- Physical Decontamination Technologies

Chemical decontamination technologies include those technologies that involve placing a liquid chemical or chemical solution in contact with a contaminated surface for a predetermined time and allowing the chemical properties of the chemicals, the contaminants, and the host matrices to effect the decontamination. Physical decontamination technologies involve mechanical action, such as abrasion, scrubbing or grinding of the surface, to remove the contaminant or the contaminant together with the host surface.

The technology profiles provide a consistent format for presentation of the information obtained from diverse reference sources. Each technology profile presents the relevant information under eight sections:

1. Description of Technology
2. Target Contaminants
3. Applicable Media and Surface Characteristics
4. Waste Streams and Waste Management Issues
5. Operating Characteristics
6. Performance
7. Capital and Operating Costs
8. Commercial Availability

The Guide is designed to be updated as necessary. A comprehensive review of available information was performed to identify technologies appropriate for reduction in the level of radioactive contaminants on building surfaces and equipment. It should be noted, however, that information was not readily available for all sections of all technology profiles. Reliable cost information was especially difficult to identify in some cases. However, this Guide summarizes pertinent available information that can be used for appropriate site response decisions. In addition, an attempt is made to see whether these technologies are applicable in situations of radioactive dispersion in urban settings.

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Chapter 1. Introduction

1.1 PURPOSE

This *Technology Reference Guide for Radiologically Contaminated Surfaces* (Guide) is designed to help site managers, Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), their contractors and others identify technologies that are potentially useful in removing radiological contaminants from building, structure, and equipment surfaces as part of a site remediation. The Guide is primarily targeted at sites subject to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), although it is hoped that it will be useful for other locations facing similar problems.

To make appropriate site response action decisions, site managers need pertinent technical information to help guide them. For this reason, the Guide provides basic information on technologies and references to further information sources. As such, this Guide is decision-focused to help the project manager select an appropriate technology for surface decontamination that will meet the cleanup criteria.

The Guide assumes that the site manager or other decision maker has had some Superfund experience, and is generally aware of the hazards associated with radiological contaminants, but does not necessarily have the expertise of a health physicist. The Guide has a singular focus on decontamination and does not address other aspects of decommissioning, deactivation or dismantlement. It assumes that a decision has been made to clean up the structure and that cleanup goals have already been established. It does not address shielding contamination to prevent exposure. EPA recognizes that site managers fulfill numerous technical, management, and regulatory responsibilities, all driven by the goal of making expedient, yet careful, decisions about their actions. In planning and implementing response actions, this document can be used in the Remedial Investigation/Feasibility Study (RI/FS) or Proposed Plan processes. In addition, Superfund administrators, EPA site manager counterparts in federal facilities, site managers outside of EPA, EPA Regional Radiation Program staff, and technology vendors can use the Guide to evaluate technology options. The Guide is designed to be a resource, not a teaching tool.

The Guide is meant to be an aid to decision making and is not meant to replace other procedures that are acknowledged as critical to the decision-making process. It may be appropriate to gather information to support remedy selection and implementation through a small-scale engineering study. Such small-scale engineering studies are often laboratory based tests that provide critical information on how a proposed technology will perform under particular real-world conditions. They are relatively low cost and are often used to provide better data support remedy selection and valuation. Small-scale laboratory tests may be followed up with advanced or pilot scale tests if more remedy design information is needed.

When properly designed a treatability study should yield information on seven remedy selection criteria:

- Overall protection of human health and the environment,
- Compliance with applicable or relevant and appropriate requirement (ARAR)
- Long-term effectiveness,
- Reduction of toxicity, mobility and volume,
- Short term effectiveness,
- Implementability, and
- Cost.

Recognition of the value of this approach will allow the project manager to budget early in the planning process for decontamination treatability studies, screen for potentially applicable decontamination technologies, develop remedial alternatives incorporating other considerations such as protective cleanup levels and waste disposal options, and perform a comparative analysis of alternatives to ultimately select the final remedial action technology. It is also important to realize that the results of treatability studies on technologies considered in this Guide are not only applicable to CERCLA remedial actions which typically address situations where there is a long term threat to human health or the environment, but can also be applied by On-Scene Coordinators (OSCs) to make selections for CERCLA removal actions, which are used in situations where there is an immediate threat to human health or to the environment.

Finally, it is appropriate to consider at the outset of the Guide the issue of “treatment.” Radioactive contamination may be treated by a variety of technologies. The concept of treatment is not solely dependent on whether contamination is destroyed (though obviously in the case of radioactive material, destruction as such is not possible), but may also involve removing or stabilizing the contaminant. This concept of treatment is discussed in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) under §300.5, provided in Appendix G of this document. Here, treatment is defined by whether the technology can or will alter “ ... the composition of a hazardous substance or pollutant or contaminant through chemical, biological, or physical means so as to reduce toxicity, mobility, or volume of the contaminated materials being treated.” Furthermore, such technology should generally achieve a standard of treatment of 90 to 99 percent reduction in concentration or mobility.

From an environmental media standpoint, treatment may include: stabilization (e.g., fixation), thermal treatment, dehalogenation, soil washing, etc. It typically does not include waste capping in place by itself. While this latter technology reduces the mobility of the contaminant, for the most part it does not do so by treating the actual contaminated media.

In a similar manner, treatment of surface contamination includes activities that remove or stabilize the material on the surface. These may include, for purposes of this guidance, the various washing or abrasive technologies that remove the contaminant from the surface. Applying shielding material, while a remediation technology that may facilitate achieving protectiveness or ARAR by limiting direct exposure and inhibiting resuspension of degraded material, normally would not be considered a treatment technology. Treatment may also include a stabilization or fixation technology in which an additive chemically or physically bonds with the contaminant and by immobilizing it prevents the contaminant from migrating. For nonradioactive contaminants the immobilization of contamination on a surface followed by removal of the entire structure from a site (“fixation and total removal”) is used at many residential Superfund sites. This document addresses only decontamination, but notes that fixation and removal should be explored as a potential option in cases where decontamination is not feasible.

Under CERCLA, the concept of treatment is the same for organic, inorganic or radioactive contaminants. While some forms of treatment may in fact be capable of destroying or modifying the chemical composition, other forms of treatment may immobilize the contaminant or may remove the contaminant from the media, and thus mitigate the former potential exposure pathway. Contaminated materials may be treated to remove the contaminant from the material. The contaminant and associated treatment residuals may require further treatment for final waste management.

1.2 REGULATORY BACKGROUND

For this document, decontamination is defined as the removal of radiological contamination from the surfaces of facilities and equipment by a variety of chemical and physical techniques (DOE 1994) with the objectives of:

- Reducing radiation exposure,
- Enabling reuse of facilities and equipment,
- Reducing the amount of material (equipment, construction and related debris) requiring expensive disposal,
- Restoring a site or facility to productive use,
- Removing contaminants prior to return to use, further treatment, modifications, protective storage, or longer-term management and disposal, and
- Reducing the amount of residual radioactivity to be protective of public and worker health and safety, and the environment.

The hazards associated with radiological contaminants include radiological exposure to personnel from three potential pathways: 1) direct exposure to external radiation emanating from radioactive contaminants on surfaces and in equipment; 2) radiation exposure due to inhalation of contaminants that are already airborne in the facility or are generated during the remediation activities; and 3) radiation exposure due to ingestion of radioactive contaminants. It should be noted that a technology that addresses one of these pathways need not necessarily address the others.

Decontamination is usually part of a larger cleanup activity often involving characterization, waste treatment, dismantlement, demolition, and disposal work. The decontamination activities *per se* require two main resources: clearly understood target cleanup levels and technologies to achieve the required level of cleanup. The technologies themselves, rather than the standards, are the subject of the following sections of this Guide. Please refer to CERCLA Section. 9621 - Cleanup Standards (42 USC §9621) and EPA guidance on radiation cleanup standards (EPA 1997).

Standards for radiological decontamination are the subject of much debate and study. Radiological decontamination may involve comparatively low levels of radioactivity. The situation parallels that of managing low-activity radioactive wastes where there is a broad spectrum of materials for which a regulatory framework has evolved in a piecemeal fashion since the late 1940s. This regulatory framework has often focused on the source rather than on inherent radiological properties or risk. At least 12 federal statutes apply to some types of, but not all, low-activity wastes. Radiation cleanup standards are set by the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), the Environmental Protection Agency (EPA), and by state regulators (NAS 2003). In addition, a number of other professional organizations have made recommendations.

Radiological decontamination is also an issue in the consideration of potential terrorist attacks using radioactive material. On January 3, 2006, the Department of Homeland Security (DHS) published a draft guidance (for interim use with request for comment), titled *Application of Protective Action Guides for Radiological Dispersal Devices (RDD) and Improvised Nuclear Device (IND) Incidents*. The draft is intended for use by Federal agencies, and as appropriate, State and local governments, emergency responders, and the general public who may find it useful in planning and responding to an RDD or IND incidents.

1.3 TECHNICAL APPROACH/DOCUMENT DEVELOPMENT

As a basis for selecting technologies to be included in this Guide, a technology, first and foremost, should be able to remove radioactive contaminants. It could also be useful to remove non-radioactive contaminants such as organic materials, metals or other inorganic materials. Second, a technology had to be commercially available from one or more vendors. Third, the technology should have a demonstrated history in removing contaminants.

It was originally intended that a technology should also be cost effective in its implementation indicating costs commensurate with decontamination effectiveness. However, technology implementation cost information and the corresponding details of its application have been extremely difficult to obtain, and therefore, determining "cost effectiveness" could not be estimated on a reliable basis. Cost data is included where available.

A comprehensive review of available information was performed to identify technologies appropriate for reduction in the level of radioactive contaminants on building surfaces and equipment. Details of the sources and approach are provided in Appendix D.

1.4 ORGANIZATION AND USE OF THE GUIDE

The technology profiles presented in this Guide have been divided into two main classes: chemical and physical technologies. Chemical decontamination technologies make use of manipulation of the chemical properties of the contaminants and their host matrices to bring about the decontamination. Physical decontamination technologies make use of some form of physical or mechanical abrasion of the contaminant or the host surface material to effect contaminant removal. Section 2.0 reviews the following five chemical decontamination technologies:

- Chelation and organic acids,
- Strong mineral acids and related materials,
- Chemical foams and gels,
- Oxidizing and reducing agents, and
- TechXtract.

Section 3.0 reviews the following thirteen physical decontamination technologies:

- Strippable coatings,
- Centrifugal shot blasting,
- The concrete grinder,
- The concrete shaver,
- The concrete spaller,
- Dry ice blasting,
- Dry vacuum cleaning,
- Electro-hydraulic scabbling,
- The En-vac robotic wall scabbler,
- Grit blasting,
- High pressure water,
- Soft media blast cleaning (sponge blasting), and
- Steam vacuum cleaning.

Each technology profile addresses either a single technology or a single technology type and is divided into the following eight sections:

- **Description of Technology**, where a brief, non-exhaustive outline of the technology is presented
- **Target Contaminants**, where, if appropriate, the specific radionuclide or contaminant host matrix is described,
- **Applicable Media and Surface Characteristics**, where the nature (e.g., porosity or chemical characteristics) and geometry of the surface hosting the contamination are described,
- **Waste Streams and Waste Management Issues**, where information on the primary and secondary waste-streams, quantities of waste, containment requirements, and any non-typical waste treatment, disposal, or other management issues are provided. It should be noted that certain items, such as used personal protective equipment, are common waste stream elements for almost all technologies and have not been included in every section except where the vendor specifically noted the issue.
- **Operating Characteristics**, where information on worker considerations (e.g., any non-typical or specialized worker skills or training needed, any non-typical worker safety requirements), any necessary surface pretreatments, equipment portability or mobility, equipment weight, power requirements, installation requirements, other complementary technologies usually applied in conjunction with the subject technology, special regulatory issues or permit requirements, or any other operating constraints or concerns are presented,
- **Performance**, where information on documented performance (through treatability studies or other radiological decontamination projects); performance measures (e.g., setup time, decontamination factors, removal efficiencies, depth of contamination or surface removal, number of operating personnel required, ability to clean around encumbrances, ease of technology equipment decontamination after use); documented applications of NCP criteria; impacts on performance; and any other technology limitations or needs for future development are presented,
- **Capital and Operating Costs**, where information on purchase, rental, operating costs, quotes from actual projects, comparisons with a baseline technology, and waste management costs are presented, and
- **Commercial Availability**, where contact information for technology vendors is presented.

Eight appendices augment the information in the technology profiles:

- Appendix A contains all references cited in the document.
- Appendix B gives the list of contacts/vendors associated with technologies described.
- Appendix C provides basic terms and units of radiation.
- Appendix D gives the additional sources of information for technologies.
- Appendix E provides information related to the applicability of these technologies in situations of radioactive dispersion in urban settings.
- Appendix F presents capsule summaries of emerging decontamination technologies.
- Appendix G presents the National Contingency Plan definition of the term “treatment.”
- Appendix H provides the Chemical Abstracts Service Reference Number for all chemicals cited in the text.

A summary of the chemical and physical technologies appears in Exhibit 1-1 and Exhibit 1-2 below. Each exhibit includes an assessment of the quality of performance data available for the technologies. This assessment is not exhaustive and is provided for informational purposes only.

Exhibit 1-1. Chemical Decontamination Technologies

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data***	Cost*
Chelation & Organic Acids	Can be tailored to wide range of contaminants. Safer than other chemical techniques.	Requires considerable on-hand chemical knowledge for best application.	Contaminant solubilization requires great care in waste treament. Danger of mobilization of the contaminant.	Poor	$10.76/m^2$ ($1.00/ft^2)
Strong Mineral Acids & Related Materials	Can remove very stubborn deposits. Much operating experience from industrial cleaning.	Great care needed operationally due to safety considerations. Can destroy substrate.	Primarily used for metal corrosion products.	Poor	$21.53/m^2 ($2.00/ft^2)
Chemical Foams & Gels	Increased contact time aids performance. Can reach remote and hidden areas.	May require repeated applications to achieve maximum effectiveness.	Care must be taken when flushing since foams can travel to areas beyond the reach of liquids.	Adequate	$21.53/m^2 ($2.00/ft^2)
Oxidizing & Reducing Agents	Disrupts matrix where contaminants hide so small amounts can be very effective.	Must be targeted at appropriate situation. Will not work if redox chemistry is not suitable.	Often used as one step of a multiple step process.	Adequate	$21.53/m^2 ($2.00/ft^2) and above
TechXtract	Highly flexible. Can be tailored to specific contaminants.	Best for batch operation for small objects or for smaller areas.	Requires optimization for contaminant and substrate.	Good	$2.15/kg ($0.98/lb)

Exhibit 1-2. Physical Decontamination Technologies

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data***	Cost*
Strippable Coatings	Produce a single solid waste. No airborne contamination. No secondary liquid waste.	The spray gun nozzles clog. From a cost perspective, may be best suited for smaller decontamination activities.	Only works for easily removed (smearable) contaminants.	Good	\$52.20/m^2 (\$4.85/ft^2)
Centrifugal Shot Blasting	Especially good at removing paint and light coatings from concrete surfaces in open areas away from wall-floor interfaces.	Escaped shot may pose a hazard to workers. May require an air compressor, systems for dust collection and air filtration, a forklift, and a generator.	Can be limited by large size, hence unable to get into corners.	Good	\$368.66/m^2 (\$34.25/ft^2)
Concrete Grinder	Fast and mobile. Less vibration.	Small size limits utility.	Often best used in combination with other technologies.	Good	\$31.43/m^2 (\$2.92ft^2)
Concrete Shaver	Good for large, flat, open concrete floors and slabs. Fast and efficient.	Does not maneuver well over obstacles. Good only for concrete floors and slabs.	Attractive alternative to hand-held scabblers.	Good	\$14.21/m^2 (\$1.32/ft^2)
Concrete Spaller	Good for in-depth contamination. Fast.	Requires predrilling of holes. Leaves behind a rough, uneven surface.	Limited commercial availability.	Good	\$199.35 /m^2 (\$18.52/ft^2)

Exhibit 1-2. Physical Decontamination Technologies

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data***	Cost*
Dry Ice Blasting	CO_2 gas generates very little extra waste. Very good for contamination on a surface.	Cannot remove contamination more deeply embedded in the surface matrix.	Requires support systems: air-compressors, dryers and filters.	Adequate	N/A**
Dry Vacuum Cleaning	Readily available. Works well with other physical decontamination technologies.	Only good for loose particles.	Typically used in conjunction with other decontamination technologies	Adequate	\$21.53/m^2 (\$2.00/ft^2)
Electro-Hydraulic Scabbling	Generates less secondary waste than other technologies using water. Very efficient. Removes deep contamination.	Requires a skilled operator. Generates some secondary liquid waste.	Works best for horizontal surfaces.	Poor	\$107.64/m^2 (\$10.00/ft^2) and up
En-vac Robotic Wall Scabbler	Works well on large, open spaces, including walls and ceilings. Worker exposure to contaminants is limited: remote operation and integrated vacuum system.	Requires additional attachments to address irregular surfaces, obstacles, and tight places such as near wall-ceiling and wall-floor interfaces.	Remote controlled aspect allows operation in areas unsafe for humans.	Good	\$52.74 per hour; cost effective at approx. 139.35 m^2 (1500 ft^2)
Grit Blasting	Well-established technology. Different types of grit and blasting equipment are available for a variety of applications.	Generates large amounts of dust and particulates during operation.	Wide range of grits and abrasives available for special situations.	Good	Cost based on En-vac system.

Exhibit 1-2. Physical Decontamination Technologies

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data***	Cost*
High Pressure Water	High pressure systems are readily available.	Generates a significant secondary waste stream.	Can physically destroy substrate. Best used on sturdy structures.	Adequate	$39.07/m^2$ ($3.63/ft^2$)
Soft Media Blast Cleaning (Sponge Blasting)	Removes virtually all of the contamination from the surface.	Generates significant amounts of airborne contamination. Lower productivity.	Applicable to surface decontamination only.	Good	$49.51/m^2$ ($4.60/ft^2$)
Steam Vacuum Cleaning	Easy to use. Washed surfaces dry quickly. Good for large flat surfaces.	Not good for irregular surfaces. Not good for grease. Poor ergonomic design.	Not recommended for surfaces that can be damaged by steam temperatures.	Good	$146.82/m^2$ $13.64/ft^2$)
Piston Scabbler	Remotely operated and standard units are available. Good for open, flat, concrete floors and slabs.	The units are loud. Remote units cannot operate close to wall-floor interfaces.	Remote controlled aspect allows operation in areas unsafe for humans.	Good	$64.58/m^2$ ($6.00/ft^2$)

* Costs may vary widely depending on site specific conditions such as the size of the decontamination project.
** N/A: reliable cost information was not available.
*** The quality of performance is based on professional judgement made on the basis of data collected.

Chapter 2. Chemical Decontamination

2.1 INTRODUCTION TO CHEMICAL DECONTAMINATION

Chemical agents are widely used in the nuclear and related industries as decontaminants, primarily to remove fixed contamination. Chemical decontamination is the most versatile approach to radiological decontamination since it can draw on the entire discipline of chemistry to find agents able to chemically transform and remove contamination. Hence, it can, in theory, remove any contaminant. In practice, however, it is more limited since the same processes that attack the contaminant can also attack the surface material on which the contaminant resides. Therefore, not all surfaces (e.g., porous material) are amenable to its use.

Decontamination is essentially a cleaning operation, and chemical decontamination was developed from the chemical cleaning methods used to maintain large-scale industrial processes. Both cleaning and decontamination require similar technologies, methods, equipment, and procedures and draw from the same areas of fundamental chemical knowledge. However, due to concern over the health effects of radiation from a very small mass of radioactive material, the degree of removal of unwanted material necessary in decontamination is usually many orders of magnitude greater than in industrial cleaning since trace amounts of radionuclides present on a surface still render the surface as being "contaminated."

Three types of chemical phenomena account for most chemical decontamination techniques: acid or alkaline dissolution, oxidation/reduction (redox) reactions, and chelation (complexation, sequestration) reactions. These three are not mutually exclusive and, in fact, are often used together, both simultaneously and sequentially. This ability to combine techniques adds to the capabilities of chemical decontamination. However, it also adds complexity to its use and requires that a clear understanding of the advantages and disadvantages must be obtained.

The advantages of chemical decontamination are:

- In the right situation it can be relatively quick and simple.
- It is similar to classical cleaning in the general industry and can draw on much operational experience.
- It can be relatively inexpensive where additional equipment is not required.
- With proper selection of chemicals, almost all radionuclides can be removed from contaminated surfaces.
- Decontamination factors of over 10,000 may be achieved.
- It has the potential to remove contaminants from areas with restrictions to physical access, such as interior surfaces, crevices, joints, piping, remote internal volumes, hidden parts, complex geometries.
- It usually involves little or no airborne contamination.
- When properly performed, it can have minimal effects on equipment and surfaces thus allowing easy reuse.

At the same time, the disadvantages of chemical decontamination can be significant:

- Chemical decontamination generates liquid waste streams that require treatment (neutralization, ion exchange, precipitation, filtration, evaporation) and, in turn, can generate further secondary waste streams such as spent ion exchangers. Treatment of the secondary waste streams can add significantly to the cost.
- Safety concerns arise with the use of hazardous materials such as strong acids and oxidizers and with the production of hazardous byproducts such as hydrogen.
- Chemical decontamination is not usually effective on porous surfaces.
- By mobilizing the contaminant, there is increased risk of downstream recontamination and cross contamination of equipment, and increased risk of environmental consequences in the event of accidental releases.
- Sometimes higher temperatures are needed to increase the kinetics of the decontamination.
- Due to the complexity of the systems used, chemical decontamination often requires the availability of in-depth chemical expertise. This is true both for the decontamination itself and for ancillary concerns, such as waste stream management.

This last point, that of complexity and the need for scientific expertise, is essential in understanding the effective use of chemical decontamination. In the case of a simple, small-scale situation such as a minor liquid spill, a dried spill, or limited particulate contamination, simple chemical decontamination is usually sufficient. A typical response might be a wash using a detergent solution (for example, half a kilogram of commercial detergent with half a kilogram of sodium triphosphate in 100 liters of warm water) followed by a wash using a simple chelator (for example, three kilograms of citric acid or EDTA (ethylenediamine tetra-acetic acid) in 100 liters of warm water). Though such an approach is excellent for simple problems, as the complexity of the contamination increases, such as in the decontamination of nuclear power systems where radiological contaminants are deeply and tenaciously embedded in corrosion products, so the complexity of the chemical response must increase. Two examples are the decontamination of: 1) the Reactor Water Clean Up System at Unit 1 of the Browns Ferry Nuclear Station; and 2) the Indian Point Nuclear Power Plant. At Browns Ferry, decontamination was achieved using a four-step combination of the Low Oxidation State Transition Metal Ion (LOMI) and alkaline-permanganate (AP) processes in the order LOMI-LOMI-AP-LOMI (NPJ 2003). At the Indian Point Nuclear Power Plant, the primary reactor coolant system, the residual heat removal system, and the chemical and volume control system of Unit 2 were decontaminated using a five-step combination of the Canadian Decontamination and Remediation Process (CANDEREM) and AP processes in the order CANDEREM-AP-CANDEREM-AP-CANDEREM (ISOE 1996).

Therefore, although chemical decontamination can be effective, it is affected greatly by the level of characterization of the problems and level of expertise available to analyze the options for response. Much of this expertise resides in engineering and service companies that work in the nuclear area, and the responses they use are the result of in-depth study of the problem.

It should also be realized that a poorly performed chemical decontamination can increase risks. For example, when contaminants are removed from a surface by chelation, the chelate-contaminant complex is usually of higher toxicity than the contaminant alone since it usually has a higher bioavailability. Further, since the contaminant is more mobile when complexed, it is potentially a greater environmental threat and also poses a risk of cross-contamination of decontamination equipment and other down-stream recontamination. The decontamination is thus a two-edged sword. The risks can be managed to allow the technology to perform well, but the appropriate level of thought must be put into it.

The technologies presented in the following profiles provide general information on the principal types of chemical decontamination and should only be considered for further exploration if detailed characterization and expert assistance is available.

2.2 CHELATION AND ORGANIC ACIDS

2.2.1 Description of Technology

Chelation is the binding of an organic chemical to a metal ion in such a way that the metal ion can be "enveloped" and removed from its insoluble state (e.g., as an oxide deposit), brought into solution, and hence removed. The organic chemicals, often known as ligands (from a Latin word meaning "to bind") and usually referred to as the chelating agents or chelators, tend to have flexible chain structures with more than one site that can strongly interact with the metal ion. The sites on the chelator have an excess of negative charge that bind with the positive charge on the metal ion. The technical term for such ligands is "polydentate" from a Latin root meaning "many teeth" or "many bites." Thus the chelator has the ability to grab hold of the metal and pull it away from the surface like a claw taking hold of an object. In fact, the word "chelation" is derived from a Greek word meaning "crab's claw." The term "chelate" refers to the chemical species where the chelator and the metal ion are bound together. Chelation is also commonly known as complexation or sequestration.

In the decontamination of nuclear power systems, chelation has the advantage over other chemical decontamination approaches in that, since the metal ion contaminant is strongly bound up in the chelate complex, the chance of redeposition or surface binding elsewhere in the system is extremely small. It should be noted that this advantage also brings some risks: since the contaminant is mobilized by the formation of the chelate complex, the waste management of the spent decontamination solutions must include the greatest care so that there are no environmental releases. Mobilized radionuclides can pose serious health, safety and environmental risks.

There are many potential chelators, each possessing different abilities to bind to different metals. The most common chelators used in decontamination are:

- Oxalic acid,
- Citric acid,
- Gluconic acid,
- Ethylenediaminetetraacetic acid (EDTA),
- Hydroxyethylenediaminetriacetic acid (HEDTA),
- Ethylenediaminedisuccinic acid (EDDS),
- Oxyethylidenediphosphonic acid (OEDPA), and
- Diethylenetriaminepentaacetic acid (DTPA).

Exhibit 2-1 depicts the chelator EDTA.

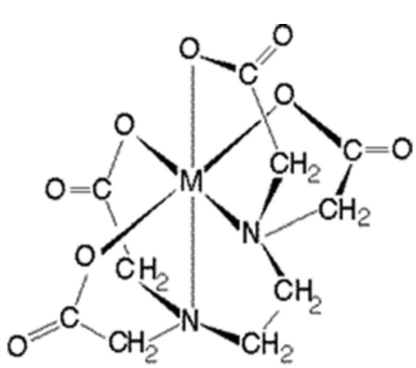


Exhibit 2-1

All of the chelators listed above are organic acids. From a chemical perspective, chelators do not have to be organic acids as there are indeed many excellent neutral organic chelators; but, for radiological decontamination, having the chelator be an organic acid provides certain advantages. The acid functionality allows the chelator to also effect a decontamination similar to that of strong mineral acids. Since many of the organic acids can be readily oxidized, they can act as reducing agents and bring about decontamination by an oxidation-reduction mechanism as well. In addition, since many chelators are composed of carbon, hydrogen and oxygen, they can be destroyed by oxidation to produce carbon dioxide and water. This feature can enable waste treatment options unavailable with other materials.

Chelators can be used on a stand-alone basis:

- Minor spills in radiological facilities are frequently cleaned up with a simple wash of solutions of EDTA or oxalic acid and using in-house chemical expertise.
- Oxalic acid has been found to be effective for removing rust from iron in nuclear facilities and is an excellent complexer for niobium and fission products (DOE 1994). During cleaning, however, secondary deposits of ferric oxalate containing radionuclides may be formed on the decontaminated surfaces (Ampelogova 1982). Oxalic acid is a basic component of circuit decontamination technology used for Reactor Bolshoy Moshchnosty Kanalny (RBMK) reactors (Ampelogova 1982; Nechaev 1998; Sedov 1988).
- Oxalic peroxide is used for the simultaneous dissolution of Uranium Dioxide (UO_2) and for the defilming and decontamination of metals (DOE 1994; Ampelogova 1982).
- Citric acid has been used at Capenhurst in the United Kingdom (Boing 1995), and solutions containing citric acid and Na 2-chromotropic acid have been used in the Kola Nuclear Power Plant in the Russian Federation (Ampelogova 1982).

However, particularly in the nuclear industry, chelators are usually employed as part of a more complex or multistage process that combines the chelation phenomena with other approaches, such as strong acid dissolution or oxidation-reduction. Some examples include:

- The Low Oxidation State Transition Metal Ion (LOMI) decontamination solvent developed by the Central Electricity Generating Board (UK) and the Electric Power Research Institute (EPRI) is effective on a wide variety of metal oxides and uses a vanadium (II) reductant with a picolinic acid chelating agent.
- The CITROX process, a proprietary process of PN Services Inc., uses both citric acid and oxalic acid as chelating agents.
- The NITROX process, another proprietary process of PN Services Inc., uses cyclic application of a nitric acid/permanganate (NP) solution followed by oxalic acid as a chelating agent.
- The DfD (Decontamination for Decommissioning) process developed by EPRI uses cyclic applications of permanganate (an oxidant) and oxalic acid (chelating agent) each in a fluoroboric acid base solvent.
- The OPG (Oxalic acid-Peroxide-Gluconic acid process) process uses an oxalic acid (chelating agent), peroxide (oxidizing agent), gluconic acid (chelating agent) solvent, often cycled with another solvent such as NP, to remove uranium and plutonium oxides.
- The Atomic Energy of Canada Limited (AECL) developed CANDEREM process uses EDTA as both a chelating agent and reductant together with citric acid as a chelating agent.
- Ammonium citrate has been used successfully after alkaline-permanganate pretreatment and water rinsing to decontaminate stainless steel and carbon steel (DOE 1994). EDTA can also be added to this process to keep the iron oxide in solution and inhibit its redeposition (DOE 1994). One example of its application is at the nuclear submarine prototype reactor in the United Kingdom (Jones 1995).
- A mixture of oxalic acid, citric acid, and an inhibitor is an effective decontaminant of stainless steel as the second step after alkaline-permanganate pretreatment (DOE 1994).
- Citric acid is used as a reducing agent, and it is very effective for decontaminating stainless steel in a two-step process following alkaline-permanganate treatment (DOE 1994).
- Alkaline-permanganate followed by sulfamic acid is effective in removing the contaminated film from stainless steel piping without causing redeposition of a precipitate (DOE 1994).

- Alkaline-permanganate followed by oxalic acid has been successful in removing aged films on high temperature stainless steel water piping, but it has the disadvantage of causing redeposition in the form of a tenacious oxalate film on the metal (DOE 1994). This redeposition can be avoided by using an acidic permanganate solution. Alkaline-permanganate-oxalic acid solutions have been used in the Russian Federation for circuit decontamination (Ampelogova 1982; Nechaev 1998).

Chelation can be a very effective process, but it is highly dependent on the availability of expert chemical knowledge together with in-depth characterization and knowledge of the system to be decontaminated.

2.2.2 Target Contaminants

Chelators can be general (e.g., EDTA which chelates most metals) or specific (cuprizone for copper) in nature. The state-of-the-art in ligand chemistry is such that chelators can now be designed with extremely high selectivity, though the cost of the more highly selective chelators is frequently prohibitive for applications such as decontamination. Chelation is generally used against fixed contamination rather than smearable contamination, since the latter can usually be removed by simpler means.

2.2.3 Applicable Media and Surface Characteristics

Chelation has been used to decontaminate metal, concrete, wood, and other surfaces, though it is best used on non-porous surfaces. It is effective on floors, walls, ceilings, piping, and duct work. Since the technology can be used in spray form, by immersion, or by flushing, it is effective on complex surface geometries and may be applicable to surfaces or equipment that may have areas accessible only to liquid chemical reagents.

2.2.4 Waste Streams and Waste Management Issues

The primary waste-stream from use of chelators is the spent chelating solution. The major issue is the increased mobility of the contaminant in the chelated form and the risks that this poses in the event of release to the environment. This must be clearly appreciated; in a sense, the chelation process can be viewed as the very opposite of what a "treatment" is supposed to do - a formerly fixed and immobilized hazardous material has now been mobilized in a form that has increased toxicity. The situation is unavoidable, and it can of course be safely managed, but a proper understanding of the phenomena coupled with relevant engineering knowledge is necessary to safely handle the materials. Solutions of chelated contaminants can be treated with ion exchange, providing the binding of the metal to the ion exchange resins is far stronger than it is to the chelator. In such situations the chelator solution is regenerated and can be reused. More often, the approach is to destroy the chelator, usually by oxidation with hydrogen peroxide, permanganate, or ultraviolet light, which has the advantage of requiring no additional chemicals. Since oxidation will produce carbon dioxide, precautions about pressurization should be taken. When the chelator is destroyed, the previously chelated metals fall out of solution as precipitates and can be treated by filtration or controlled evaporation to produce a sludge requiring final treatment prior to disposal.

Principal waste management issues include:

- Primary and secondary waste forms (e.g., liquid, solid, gaseous, contaminated surface debris, ion exchange resin, metal grit),
- Quantities of waste,
- Waste containment requirements, and
- Any non-typical waste treatment, disposal, or other management issues.

2.2.5 Operating Characteristics

Operationally, chelation can be as simple as mixing a chelator such as oxalic acid, citric acid or EDTA in the proper proportions with water, spraying the solution on the contaminated surface, and collecting the resulting waste liquid. In such cases the issue of enhanced mobility of contaminants (and the associated enhanced risks) must be considered, so great care must be taken over barriers and containment.

Choice of chelator is very important, especially now that chelators can be designed to be highly selective in the metals that they target. For example, a corroded iron surface will have a bottom layer of uncorroded iron on which layers of ferrous oxide (FeO), magnetite (Fe_3O_4), and hematite (Fe_2O_3) corrosion are built. These oxide layers are repositories for radiological contaminants. Decontamination with an acid, for example, occurs through acid attack on all materials including the underlying metal structure. However, with specially designed chelators that preferentially bind with metals in the plus-two oxidation state (refer to Section 2.5, Oxidizing and Reducing [REDOX] Agents), only the ferrous iron in the ferrous oxide and magnetite layers need be attacked to disrupt the oxide lattice, thus protecting the iron base. Further, such plus-two-oxidation-state preferentially binding chelators will also remove scale-forming plus-two-oxidation-state metals such as magnesium and calcium leading to further improved decontamination. The NOXOL series of chelating solutions from Corpex is a good example of the sort of selectivity available:

- NOXOL®-100 is designed for iron oxides (difficult magnetites and hematites), secondary scales of calcium carbonate and magnesium hydroxide,
- NOXOL®-550 is designed for calcium carbonate and magnesium hydroxide,
- NOXOL®-678 is designed for oxides of iron, aluminum, and copper, zinc phosphates, calcium carbonate, magnesium hydroxide, and calcium sulfates, and
- NOXOL®-771 is designed for strontium, barium and radium sulfates.

Surface pretreatments may be needed with some chelating agents. For example, a room temperature mixture of citric acid (0.2 molar) and oxalic acid (0.3 molar) with a corrosion inhibitor is very effective in decontaminating stainless steel when used in a two-stage process with hot alkaline-permanganate as the first stage. However, without the alkaline-permanganate, its performance is greatly reduced (DOE 1994; Ayers 1970).

Appropriate operating temperatures may need to be investigated for both the chosen chelator in general and under the specific conditions of the planned decontamination. In common with many other organic compounds, some chelators can start to decompose as temperature increases. Not only does this reduce the effectiveness of the decontamination, but, since carbon dioxide is usually evolved, over-pressurization of closed systems may occur. Further, reactions between the chelator and other non-contaminant material should be investigated. For example, oxalic acid is good at removing rust and complexing niobium and fission products. At the DOE Savannah River Site, recirculating a 2% solution at 70ºC was effective for decontaminating stainless steel heat exchangers. However, at 90ºC, the oxalic acid started to react with the iron in the steel and formed a highly insoluble ferrous oxalate film which subsequently required very aggressive treatment for removal.

Contact times for the chelator should also be considered. Some chelators, such as sulfamic acid with an inhibitor for decontaminating carbon steel, may be chosen because they have a low reactivity with the base metal. For them to be at their most effective against the contamination, the lowered reactivity must be compensated by increased contact time.

There are few special safety considerations for chelators *per se*, but, since chelators are often part of a more complex system, appropriate safety and worker training considerations need to be taken at the system level.

2.2.6 Performance

Since the range of application of chelators is so wide, from simple first response solutions such as a citric acid wash following a detergent wash to the complex decontamination processes used in the nuclear industry, generalizations about performance are extremely difficult to make.

Chelators are widely used for decontamination. A recent survey (Pettit 2004) showed that, between 1990 and 1998, 124 nuclear reactors underwent decontamination operations using either the LOMI, CITROX or CANDEREM processes, all of which use chelators as part of their process.

2.2.7 Capital and Operating Costs

Costs will depend upon the specific application, task conditions and agent used, but are typically in the order of $1.00 per square foot (DOE 1997).

2.2.8 Commercial Availability

Chelators and related materials are readily available from a large number of industrial chemical and specialized decontamination suppliers.

2.3 STRONG MINERAL ACIDS AND RELATED MATERIALS

2.3.1 Description of Technology

The strong mineral acids used in chemical decontamination are hydrochloric acid (HCl), nitric acid (HNO_3), sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4). A strong acid is an acid that ionizes completely or nearly completely in aqueous solution; the concept of strength here does not refer to concentration in aqueous solution. From a strict chemical perspective, phosphoric acid is not really a strong acid since its first ionization constant is 7.5×10^{-3}. However, since this still makes it stronger than most other acids used in decontamination, such as organic acids or acid salts, it is usually considered along with hydrochloric, nitric and sulfuric acids.

The general basis for the decontamination reaction with simple acids is that the hydrogen ions provided by the acid attack the oxides in the contaminant and destabilize the oxide lattice,

$$8H^+ + Fe_3O_4 \rightarrow 2Fe^{3+} + Fe^{2+} + 4H_2O$$

or the hydrogen ions attack the metal surface directly thus releasing bound contaminants,

$$3H^+ + Fe \rightarrow Fe^{3+} + 1.5\ H_2$$

The strong mineral acids can be used either by themselves as dilute solutions, in chemical formulations with other materials, or in combination with each other, such as HCl/HNO_3 (aqua regia). They are flexible, being used as sprays, in dipping processes, or in flushing processes. Their main mode of action is to react with and dissolve metal oxide films that contain contamination, though, if used in higher concentrations or at higher temperatures for extended time periods, they can work by dissolving the metal base that underlies a contaminant film. With appropriate care and precautions, they can be used on all metal surfaces except the more reactive metals such as zinc. The advantages of these acids is that they are relatively cheap, they are quick and effective, their properties are well understood, and they are readily available from chemical suppliers. Their disadvantages include safety and handling problems; the need to neutralize the waste products; the risk of overly aggressive reaction and the difficulty of controlling the reaction so that only the contamination is removed; and the potential for the creation of explosive (hydrogen) or poisonous (NOx) gases.

Hydrochloric acid has been widely used as a cleaning agent in the chemical processing industry and in utility boilers. For radiological decontamination operations, it is typically used to remove radiological contaminants and metal oxide films from metal surfaces to depths of up to 90 micrometers. The depth to which the technology is effective in reducing contaminant levels is a function of the base material, the acid strength, and contact time of the decontaminating agent. It is generally used for inorganic deposits such as metal oxides but is not effective on organic deposits. A reagent grade solution at 70ºC was used in decontamination of components of the Bonus Reactor (Boiling Nuclear Superheater), an Atomic Energy Commission (AEC)-owned demonstration reactor in Puerto Rico, in preparation for entombment (DOE 1994).

Nitric acid is widely used for dissolving metallic oxide films and layers in stainless steel and Inconel systems and has also found use in decontaminating molybdenum steels and EP-630 alloy (IAEA 1999; Nechaev 1998). A typical solution is 10 percent by volume at 75ºC (DOE 1994). Nitric acid is a strong oxidizing agent. There are several advantages and disadvantages to using nitric acid. It is adaptable for remote locations, and, when used in a bath, it suppresses hydrogen production. Nitric acid cannot be used on carbon steel and may cause fires and explosions when combined with incompatible materials.

Nitric acid is the critical component in a number of multi-chemical decontamination techniques. Work at Idaho National Laboratory has shown that dilute nitric acid- hydrofluoric acid mixtures are extremely effective decontamination solutions. Another example is the Nitric Acid Permanganate (NP) process, which uses an oxidizing solvent for chromium removal where the active species are nitric acid (used for pH adjustment) and permanganate (used as an oxidant):

$$Cr_2O_3 + 2MnO_4^- + H_2O \rightarrow 2HCrO_4^- + 2MnO_2(s)$$

The process is non-regenerative, has rapid dissolution kinetics, and is applied at 90 - 95°C. The solid MnO_2 is removed with a dilute oxalic acid rinse:

$$MnO_2 + H_2C_2O_4 + 2H^+ \rightarrow Mn^{2+} + 2CO_2 + 2H_2O$$

The NP process is itself the basis for the proprietary NITROX process developed by PN Services Inc. This is a cyclic application of the NP solvent and oxalic acid, is effective on most oxides encountered in nuclear facilities, has a regenerative oxalate phase, and gives extremely low waste generation.

Sulfuric acid is an oxidizing acid. Dilute solutions have been used for removal of deposits that do not contain calcium compounds (due to the insolubility of calcium sulfate), and concentrated solutions have been used for the removal of organics (Boing 1995). Sulfonitric acid (50:50 mixture of sulfuric and nitric acid) has also been used in nuclear power plant decontamination. It is not as widely used as other strong mineral acids since it is highly corrosive without giving particularly high decontamination factors.

Phosphoric acid is commonly used in removing films from carbon steel surfaces: at 60 -70°C. A 10 percent phosphoric acid solution will remove up to 99 percent of contamination and all visible film in approximately 20 minutes.

Related Materials**:** A number of other chemicals and chemical formulations work in a similar manner to strong mineral acids, even though technically they do not fall into this class. This category includes some discrete acids and acid salt mixtures.

Fluoroboric acid (HBF_4) is used industrially as a metal surface cleaner in galvanotechnology (electroplating). This acid's ability to attack metal surfaces directly led to its use in development of chemical decontamination technologies where it has been described as an excellent decontamination reagent with extremely high decontamination factors. The main disadvantage of fluoroboric acid is the large amount of waste its use generates, but a process for regenerating and recycling the acid, the DECOHA process, has been developed by a Swiss company Recytec (Demmer 1994). The Electric Power Research Institute (EPRI) has also developed a chemical decontamination process based on fluoroboric acid, the DfD process (Decontamination for Decommissioning), in which the hydrofluoric acid is applied under conditions of controlled pH and oxidation potential to remove contamination from surfaces by dissolution of the underlying metal (Pettit 2004).

Fluoronitric acid (a 50:50 mixture of hydrofluoric and nitric acids) has been used for decontamination and has given excellent results (Demmer 1994; Massault, et al., 1995; Massault, et al., 1996). Its earlier lack of investigation has been ascribed to concerns over the safety issues associated with the use of hydrofluoric acid.

Salts of various weak and strong acids can sometimes be used in place of the acids themselves or as a more effective combination with the acids. The most commonly used salts include sodium phosphates and polyphosphates, sodium bisulfate ($NaHSO_4$), sodium sulfate ($Na_2 SO_4$), ferric sulfate [$Fe_2(SO_4)_3$], ammonium oxalate ($NH_4C_2O_4$), ammonium citrate [$(NH_4)_2HC_6H_5O_7$], ammonium bifluoride (NH_4HF_2), and sodium fluoride (NaF). They work in a manner similar to their parent acids but can also provide counterions to replace contaminants at ion exchange sites. They are often chosen because they increase the versatility of the acid decontamination, can give better decontamination factors than the acid alone, are safer to work with, and their lower reactivity makes for less materials compatibility problems.

2.3.2 Target Contaminants

Strong mineral acids and related materials are typically used against oxide deposits where the straightforward reaction to give a salt and water allows for a facile removal of contaminant. Since the acids can also attack the underlying metal substrate to which contaminants of all types can adhere, acid treatment can be effective against a wide variety of contaminants.

The specific chemistry of the acid-contaminant interaction is very important. For example, acids containing fluoride, such as fluoroboric acid or fluoronitric acid, are effective against silica containing deposits due to the ability of the hydrofluoric acid that is present to react with silicates:

$$SiO_2 + 6HF \rightarrow 2H_2O + H_2SiF_6$$

2.3.3 Applicable Media and Surface Characteristics

Strong mineral acids and related materials are typically used on metal and other non-porous surfaces. Material compatibility is a critical issue in using acid decontamination since the acid will react to some extent with the metal surface. Acid-based decontamination processes developed for the nuclear power industry frequently employ inhibitors to lessen the reaction between metal and acid. In general, nitric acid can be used on stainless steel, aluminum alloys and Inconel; sulfuric acid can be used on stainless steel and carbon steel; hydrochloric acid can be used on stainless steel, chromium/molybdenum steel, and copper alloys; phosphoric acid can be used on carbon steel; and fluoroboric acid, fluoronitric acid and acid salt preparations can be used on most metal surfaces.

2.3.4 Waste Streams and Waste Management Issues

For simple acid washing, as opposed to the more complex processes used in the nuclear power industry, the two primary issues are neutralization of the acid characteristic of the aqueous waste stream and safe management of the radionuclides and any other hazardous constituents that have been solubilized and mobilized by the decontamination process. Neutralization of wastes is performed using standard reagents, procedures and precautions. Management of mobilized radionuclides requires care. A common practice is to transfer the radionuclides to a solid, immobilized form by passage of the aqueous effluent over an appropriate ion exchange resin which can then be treated as a radioactive solid waste.

The characteristics of the acid should also be considered in regard to the final waste form. For example, the presence of phosphorus from phosphoric acid can be detrimental to glass if vitrification is an option.

2.3.5 Operating Characteristics

Decontamination by use of strong mineral acids and related materials is a flexible approach and can take a number of operational forms including spray application, immersion of components in reaction vessels containing the acids, or flushing of piping and systems. In general, no surface pretreatments are required, though preliminary testing to ensure the suitability is always advisable. Issues of equipment portability or mobility, equipment weight, power requirements, installation requirements, and complementary technologies will depend on the specific application. In the case of a simple spray application with guttered or wet-vacuum collection of waste and run-off, specialized worker skills are basically the same as those associated with the operation of any process involving a very hazardous material. Strong mineral acids and related materials are corrosive to human tissue, and their use requires substantial personal protective equipment and adherence to relevant safety protocols. No special regulatory issues need be anticipated with this technology.

2.3.6 Performance

Though strong mineral acids and related materials are used in the nuclear industry for decontamination, no comprehensive comparative evaluation of performance is available. On their own they are rarely used now since improved technologies specifically designed for nuclear plants have become available.

The decontamination of the Bonus Reactor in Puerto Rico used reagent grade (10 percent volume) hydrochloric acid and achieved decontamination factors of approximately 10. The N-Reactor at Hanford was decontaminated annually from 1967 to 1983 using phosphoric acid, and the decontamination resulted in decontamination factors of 3 to 6 on the carbon steel surfaces.

Studies were performed at Idaho National Engineering Laboratory (Demmer 1994) on the testing and evaluation of eight decontamination chemicals on simulated contaminated metal coupons and included alkaline-permanganate, nitric acid-permanganate, organic acids, fluoronitric acid, fluoroboric acid, thermally unstable complexing solutions (TUCS), and aluminum nitrate. The evaluation took into account decontamination factors, waste generation values, and corrosion rates. The fluoroboric acid solution was by far the best decontaminating solution though it suffered from large waste generation values. The fluoronitric acid was the second best performer as a decontaminant and produced the smallest waste generation values.

2.3.7 Capital and Operating Costs

Costs for decontamination range widely depending on task conditions, but they are typically in the order of $2.00 per square foot (DOE 1997).

2.3.8 Commercial Availability

Strong mineral acids and related materials are readily available from a large number of industrial chemical and specialized decontamination chemical suppliers.

2.4 CHEMICAL FOAMS AND GELS

2.4.1 Description of Technology

Foams and gels are used as carrier media for other chemical decontamination agents, primarily chelators and acids, and have little inherent decontamination ability on their own. This technique has been widely used in the nuclear industry for large components with complex shapes or large volumes. A foam can be produced using water, detergents (or specially formulated foaming agents), and the decontamination agent or mixture of agents in a standard industrial foam generator. The foam generating equipment is cheap, simple and reliable, and can be used for either manual or remote operation (Sanders 1994). The detergent part of the foam can have a minor decontamination effect in much the same way as a simple wash with soapy water is the baseline technique for human decontamination, but, in the absence of any significant mechanical or scrubbing action to remove particles, a detergent foam achieves only minor levels of decontamination.

Foams can be applied to surfaces in any orientation (DOE 1994) even on overhead surfaces, can be pumped through piping or other closed systems, produce quite low volumes of secondary waste, and avoid the potential for aerosol generation associated with aqueous sprays. Their effectiveness comes from the increase in dwell time they permit compared with aqueous solutions, which tend to drain rapidly. However, since the amount of decontamination agent in contact with the surface is small compared with an un-foamed solution, repeated applications may be necessary to achieve good levels of decontamination.

Foams usually employ chelators as the decontaminating agents but have also used acids such as the use of a sulfonitric mixture during the decontamination of a graphite/gas cooler made of ferritic steel and brass (EC 1994; Faury 1998). Specialized foaming equipment and automatic foam spray devices have been developed for use in high activity handling cells, piping and other situations (Boing 1995; Bregani 1998; Nechaev 1998; Gamberini 1996; Costes 1995; Costes 1996; Cali 1994; Costes 1998; Manners 1995; Ampelogova 1982).

Foams have also been used in military decontamination equipment such as the Canadian Aqueous System for Chemical-Biological Agent Decontamination (CASCAD) system as fully self contained systems, packaged in a rugged MINI Military containers and using decontamination chemicals in a sticky foam for the simultaneous destruction of chemical and biological agents and removal of radioactive particles (Allen-Vanguard 2005a; Allen-Vanguard 2005b).

Gels are also used as carriers of chemical decontamination agents. They can be sprayed or brushed onto a component or surface, again including overhead and unusually shaped surfaces, then wiped, rinsed or peeled off (DOE 1994). They provide an alternative medium to foams when the properties of the decontamination chemicals are incompatible with foam stability needs. Gelling agents such as carboxymethylcellulose are used with care being taken to ensure compatibility of the gelling agent with the decontamination agent. Like foams, gels can employ chelators, detergents or acids such as nitric/hydrofluoric/oxalic acid mixtures and sulfuric/phosphoric acid and cerium (IV) (Juan 1995). Their effectiveness comes from the increase in dwell time they permit compared with aqueous solutions. They tend to require more than one application to produce effective decontamination, and they avoid the potential for aerosol generation associated with aqueous sprays (EC 1991).

Decontamination by pastes is related to decontamination by foams and gels. In non-radioactive situations, pastes, usually consisting of a filler, a carrier, an abrasive and an acid, have been widely used for treating metal surfaces. Mechanical action allows the abrasives to break down oxide films and enhance the dissolution ability of the acids (IAEA 1993).

2.4.2 Target Contaminants

Foams and gels are used for removal of particulates and corrosion deposits that act as reservoirs for other contaminants. Since they are basically carriers for other decontamination agents, they can be formulated to address other specific radionuclides.

2.4.3 Applicable Media and Surface Characteristics

Foams and gels are used on metal and other non-porous surfaces. The only exception is that concrete surfaces have been cleaned by spraying aqueous solutions of ammonium or sodium carbonate onto the surface, allowing the aqueous layer to dry, then spraying again with an aqueous mixture of a complexing acid and detergent. The acid both reacts with the carbonate to form a foam stabilized by the detergent and complexes with the contaminant. The foam tends to move to the outside surface rather than be driven into the porous material and can be skimmed off. However, the technique is rarely used since there is some penetration into the porous matrix.

Foams and gels will work with complex geometries but their flow characteristics usually prevent them from being effective on geometries containing deep crevices.

2.4.4 Waste Streams and Waste Management Issues

Foams and gels tend to produce smaller volumes of waste than comparable aqueous spray or immersion techniques. Since they are typically removed by an aqueous wash waste, management is the same as that used for comparable aqueous systems employing acids, chelators or redox decontamination agents, i.e. neutralization, ion exchange, or coprecipitation and filtration. Typical waste generation may range from approximately 0.01 to 1 gallon of rinsate per square foot of surface treated. For small scale decontaminations using gels, swabbing may be the most effective means of removal. In these cases the swabs should be disposed of according to solid waste management guidelines. The foam can be allowed to dry and then rinsed off or removed as a foam. In the latter case, wet/dry vacuum apparatus may be employed if properly adapted for use with radioactive materials.

In the case of foams, foam destabilizers may need to be added to the final rinse water, and care should be taken that this does not adversely affect down-stream waste management operations. If chelators are the active decontamination ingredient in the foam or gel, the normal concerns over enhanced radionuclide mobility must be considered. Waste containment requirements such as liquid runoff and drainage and aqueous aerosol generation and mitigation are greatly reduced by the very nature of foams and gels.

2.4.5 Operating Characteristics

The reduced mobility of foams and gels compared with aqueous-based systems makes decontamination operations easier, though typical precautions for working with the active decontamination agent within the foam must be taken. Specialized worker training is not usually required, and surface pretreatments are not typically needed. Specialized foam generators are not required. Foam generation is common in a range of applications such as fire protection, pest control, automobile and industrial cleaning, agriculture (as marker during spraying), and oil production.

Some special safety aspects need to be considered. Foams and gels are slippery and can pose an occupational hazard; personnel movement should be restricted when foams and gels are used; and appropriate warning signs should be clearly posted. A special level of precaution should be taken when using foams in closed systems where positive pressure is used to drive the foam through the system volume. On one occasion at the US DOE Savannah River Site, when a large amount of organic detergent was used in a set up to drive a nitric acid decontamination agent through a closed system, a reaction at a constantly accelerating rate occurred between the nitric acid and the organic material producing large amounts of gaseous products. The pressure produced by this unanticipated volume of gas surpassed the pressure relief point for the system and rupture occurred with the release of nitric acid. In such circumstances, precautions, such as continuous pressure monitoring and pressure relief valves and associated release containment areas, should be incorporated into plans.

No special regulatory issues or permit requirements are associated with the use of foams or gels.

2.4.6 Performance

Chemical gels have been used to decontaminate carbon dioxide coolant pipes and steel pipes. This involved several steps in the decontamination procedure: soda gel spraying and contact time, rinsing, acid gel spraying, and extensive rinsing. Results of this application indicated that the gel spraying method is effective for beta gamma emitters on steel pipes with simple geometry. Chemical gels have also been used in decommissioning the walls of the Steam Generating Heavy Water Reactor at Winfrith Technology Center. The walls were pressure washed prior to application of the decontaminating gel. The gel was applied and allowed to soak for a predetermined period of time. Rinsing was used to remove the gel from the surfaces. Target activity readings were achieved. Chemical foams have also been used at Winfrith for decontamination of a cave with considerable loose contamination and high risk. An experienced operator entered the cave in a full pressure suit and cleaned the cell of gross activity within 30 minutes and within the exposure objectives for the task. The chemical foam was also used to successfully decontaminate the personal protective equipment used in the decontamination.

2.4.7 Capital and Operating Costs

Costs vary, depending on task conditions, but are typically in the order of $2.00 per square foot (DOE 1997). The chemical foam or gel itself is inexpensive, but the added costs of personnel, waste management, etc., will tend to bring the total cost into line with other methods. Despite the apparent cost advantage, foams and gels are usually chosen for operational rather than cost reasons.

2.4.8 Commercial Availability

Foaming agents are available from standard industrial chemical suppliers. The decontamination agents used are case specific and are available from decontamination chemical suppliers. Foam generators are available in many forms and sizes depending on their application and should be selected according to need.

2.5 OXIDIZING AND REDUCING (REDOX) AGENTS

2.5.1 Description of Technology

Redox is the term used for chemical reactions in which one material, the reducing agent, accepts an electron (the reduction process) while another material, the oxidizing agent, donates an electron (the oxidation process). Redox reactions are always a coordinated pair of oxidation and reduction reactions - an oxidation reaction cannot occur unless a reduction reaction is happening in concert with it.

The concept of oxidation state originates in the question of whether or not a metal atom is attached to an oxygen atom. Unattached atoms of any element, including metals, are said to have an oxidation state of zero. Since oxygen almost always accepts two electrons when it combines with other atoms to make an oxide, the oxygen in the oxide is said to have an oxidation state of minus two. Since electrons are neither consumed nor produced but merely transferred in a chemical reaction, the metal atom in a metal oxide such as FeO is said to have an oxidation state of plus two. If an oxidizing agent is introduced, the FeO can be oxidized to Fe_2O_3 where the iron now has an oxidation state of plus three; alternatively, if a reducing agent is introduced, the FeO can be reduced to Fe where the iron now has an oxidation state of zero.

The ability to control the oxidation state of an element is important because a metal may be more soluble in certain oxidation states than in others, a type of behavior that is obviously important to decontamination. Generally, solubility increases with increasing oxidation state, so oxidation tends to be more important in decontamination than reduction. However, reduction of the oxidation state of a metal can be useful if the metal in a lower oxidation state has a stronger binding behavior with a chelator. Sodium hypophosphate ($NaHPO_2$) and hydrazine (N_2H_2) have been used as stand-alone reducing agents, while chelating agents such as oxalic acid and EDTA are often used as reducing agents in more complex processes.

In addition to modifying solubility, the ability to control the oxidation state of an element is also important since contaminants are often present as metal oxides. If some of the metal atoms in the oxide lattice can undergo a change in oxidation state, then the lattice may be disrupted and the contaminant may become more easily removed from the surface. This conditioning of the metal oxide is important since it complements the decontamination effects brought about by acids or chelators.

Decontamination by use of an oxidizing agent alone has been performed but is now comparatively rare due to its limited effectiveness compared with the combination of oxidation with other decontamination processes such as acid dissolution or chelation. The most common stand-alone oxidizing agents are bleach (usually calcium or sodium hypochlorite based compounds), nitric acid (where both the oxidation and acid-dissolution effects occur together), and alkaline-permanganate (commonly known as AP) solutions. AP is often used to remove chromium in a corrosion film that harbors radiological contaminants; the permanganate is a powerful oxidizing agent that oxidizes chromium to Cr_2O_3 which can then dissolve in the alkaline solution as a chromate.

More frequently oxidation is one step in a more complex process. In recent years the nuclear power industry has developed a number of such processes aimed at specific, well-defined types of contamination. A number of examples are given in the section on chelation and organic acids, including the Low Oxidation State Transition Metal Ion (LOMI) process, the NITROX (nitrate - oxalic acid) process, the DfD (Decontamination for Decommissioning) process, the Ontario Power Generation (OPG) process, the CANDEREM process, the alkaline-permanganate/sulfamic acid process, and the alkaline-permanganate/oxalic acid (APOX) process. Other examples include**:**

- The Nitric Acid/Permanganate (NP) process, which uses an oxidizing solvent for chromium removal. The active species are nitric acid for pH adjustment and permanganate as an oxidant to raise chromium from the plus three to plus six oxidation state: $Cr_2O_3 + 2MnO_4^- + H_2O + 2HCrO_4^- + 2MnO_2$. The process has rapid dissolution kinetics, and the manganese dioxide produced is removed with dilute oxalic acid: $MnO_2 + H_2C_2O_4 + 2H^+ + Mn^{2+} + 2CO_2 + 2H_2O$.
- The Chemical Oxidizing Reducing Decontamination (CORD) process uses multiple cycles of a three-step process involving 1) an oxidation step where NP is used to oxidize chromium from Cr^{3+} to Cr^{6+} oxidation state; 2) a reduction step where oxalic acid is used for the dissolution and chelation of hematite and Ni^{2+}, Mn^{2+}, Co^{2+} ions are removed on cationic ion exchangers; and 3) a cleaning step where excess oxalic acid is removed by UV light, NP, or hydrogen peroxide plus catalysts, and chromium and iron oxalates are removed on anionic ion exchangers. The process was developed by Siemens and is now available as a compact, mobile decontamination appliance named DECON-BOY.
- The nitric acid/potassium permanganate/oxalic acid (NPOx) process developed at Idaho National Laboratory is based on the Siemens CORD process but uses more cost-effective reagents for site applications.
- The Strong Ozone Decontamination Process (SODP), a one-step, room temperature process, developed in the late 1980s by Studsvik RadWaste AB, and based on nitric acid, cerium (Ce^{4+} as a very strong oxidizing agent) and ozone for regeneration of Ce^{4+} (Lindberg 1997).
- The REDOX decontamination process, a Japanese technology similar to SODP, using Ce^{4+} in nitric acid but with an electrochemical regeneration of Ce^{4+}. The REDOX decontamination process is a much faster operation than SODP, and it is used as a dipping method for removing contaminants from relatively complex-shaped equipment such as valves, pumps, and small-diameter pipes.
- The Metal Decontamination by Oxidation with Cerium (MEDOC) process, a Belgian technology that also uses Ce^{4+} as a strong oxidizing agent, but employing sulfuric acid as the solvent. MEDOC is much faster in operation than SODP, and gives very high decontamination factors.

2.5.2 Target Contaminants

Oxidizing and reducing agents primarily target corrosion cruds, usually iron and chromium oxides, in metal components. These oxides act as reservoirs for radiological contaminants, and removal of the oxides (by either dissolution or by disruption of the lattice, which then leads to removal of corrosion particulates) brings about the decontamination. The target contaminants are thus broad in range.

2.5.3 Applicable Media and Surface Characteristics

Due to their underlying mode of action, oxidizing and reducing agents are almost always used for metal surfaces. They can be used in a flushing mode or as a batch immersion process for smaller components of unusual geometry.

2.5.4 Waste Streams and Waste Management Issues

The nature and quantity of waste streams varies quite widely with the particular process under consideration. In fact reduction in waste volume and facilitation of waste treatment have been among the driving forces for the development of new technologies. Since many of the processes use acids, neutralization is often required. Corrosion particulates require some form of solid/liquid separation with appropriate stabilization and disposal of residues. Dissolved radioactive and other toxic species are almost always removed on ion exchangers, so standard stabilization and disposal practices for the spent resins are required. Since many of the processes employ chelators, the special precautions necessary for chelator use, owing to the enhanced mobility and enhanced risk of chelated radionuclides, must be observed. Finally, redox reactions can employ unusual metals such as vanadium and cerium to generate the redox couples. Since these metals are in a soluble form, they must be used with caution.

NPOx Equipment
Exhibit 2-2.

2.5.5 Operating Characteristics

Processes that use oxidizing and reducing agents are for the most part complex and require highly skilled workers and the availability of considerable scientific and engineering support. Though a simple bleach spray and wash, or a dilute nitric acid spray and wash, will be of a similar level of complexity to a chemical extractant spray and wash, the more complex processes require almost constant attention.

The CORD process and the related NPOx processes described above are examples of this operational complexity. Exhibit 2-2 depicts the equipment necessary for the NPOx process (Ramer 2001). During the nitric acid/permanganate first step, the process engineer has to continually monitor the permanganate concentration and maintain it in the 50-300 µg/L range. At the beginning of the step, the permanganate concentration should be at the higher end of the concentration range dropping off toward the end. High concentrations of permanganate at the end do not increase solubilization of chromium but do increase the total volume of waste. At the same time, the operating temperature has to be maintained in the 90-95ºC range, and the chromium concentration must be monitored to determine when the step ends. The chromium concentration will increase rapidly, and then the rate of increase will rapidly decline at which point the step can be terminated. The excess permanganate and the manganese dioxide product must now be destroyed prior to proceeding to the second step: the reduction step. The permanganate and the manganese dioxide are destroyed by reducing both species to the corresponding manganous ion through addition of stoichiometric amounts of oxalic acid. Excess oxalic acid is then added to bring about the decontamination by dissolving hematite; the final oxalic acid concentration has to be about 1.5 g/L. In the dissolution step, pH, temperature, oxalic acid concentration, and metal ion concentration must all be monitored. Variations in these parameters as the solutions are passed through the ion exchangers must be accounted for. In the final cleanup step where excess oxalic acid is destroyed and carbon dioxide produced, pressure must also be monitored.

2.5.6 Performance

Since many of the processes have been developed for specific applications, cross comparison is rather difficult. In general the state of development of redox processes is such that very high levels of decontamination can be achieved when the process is properly targeted.

An examination of the MEDOC process illustrates the point. An industrial plant has been developed in Belgium to treat 20 square meters of contaminated material and has successfully decontaminated the material using a batchwise technique. Contaminated materials are attacked with an average corrosion rate of about 2.5 µm h^{-1}, and it has been found that the removal of about 10 µm of metal surface is generally sufficient to completely remove the contaminated layer and to reach the European free release level, even with highly contaminated samples up to 20,000 $Bq.cm^{-2}$ beta/gamma, such as samples of hot cells strongly contaminated in Cs-137 or metal samples covered with Pressurized Water Reactor (PWR) crud. After using the MEDOC process, 77 percent of the treated materials have very low residual contamination (lower than 0.1 $Bq.g^{-1}$). This material may be disposed of in Europe as free release decontaminated material. The remaining 23 percent has a residual activity lower than 1 $Bq.g^{-1}$ and may be disposed of in Europe as free release route after melting. Overall treated materials have a very low residual contamination, lower than 0.4 $Bq.cm^{-2}$, giving decontamination factors higher than 10,000.

2.5.7 Capital and Operating Costs

Meaningful cost data are not readily available. For the simplest redox washes on a metal surface (e.g., bleach or sodium hypophosphate), costs range depending on task conditions but have been estimated to be on the order of $2.00 per square foot (DOE 1997). For the more complex processes, costs will be highly dependent on task conditions and would have to be estimated in consultation with vendors.

2.5.8 Commercial Availability

Redox reagents and related materials are readily available from a large number of industrial chemical and specialized decontamination chemical suppliers**.**

2.6 TECHXTRACT

2.6.1 Description of Technology

The TechXtract® technology is a decontamination system using proprietary chemical formulations to remove fixed and removable contaminants such as radionuclides, PCBs, and other hazardous organic and inorganic substances from materials such as concrete, construction bricks, wood, lead, iron, and steel.

The overall system employing the proprietary chemical formulations is flexible. In the radionuclide demonstration on which this profile heavily draws (DOE 1998a), the process was entirely housed in a portable trailer that moved small objects to be decontaminated along a hoist and rail system. The objects can then be dipped in several chemical solutions in sequence. In such a situation, the chemicals that bring about contamination can be driven into the contaminated matrix with the aid of ultrasound. In other situations where immersion is not practical, the TechXtract™ formulations are sprayed onto the treatment surface as a fine mist, after which the chemicals are worked into the surface using an abrasive pad. They are finally removed with a wet vacuum. The solutions are claimed to contain no hazardous constituents, though spent solutions will contain extracted contaminants.

The TechXtract® chemistry targets contaminant migration into the pores and microscopic voids of a material surface, even for seemingly non-porous media. Over time, physicochemical forces drive these contaminants deeper in the substrate where they can become chemically or electrostatically bonded to the substrate. The pore openings may become blocked with grime and other materials. To address this, the TechXtract® chemical extraction is designed to:

- Reopen the pores and capillaries,
- Penetrate into the pores as deeply as possible
- Break the physical and chemical bonds holding the contaminants in place, and
- Capture the contaminants in the chemical solutions to prevent recontamination.

To achieve this, the TechXtract® formulations contain macro- and micro- emulsifiers, electrolyte, flotation, wetting agents, buffered organic and inorganic acids, and sequestering agents. The proprietary chemical mixtures are prepared onsite on a material and contaminant-specific basis and can be tailored to remove specific contaminants including PCBs and other organics, heavy metals and other inorganics, and radionuclides. The mode of use of the technology can also be tailored to the site-specifics, but use is essentially a cycle of sequential immersions in the chemical formulations to optimize penetration and extraction of the contaminant from the surfaces. The sequence is a series of stages involving an application step (spraying, immersion), a scrubbing step (manual, ultrasonic, air sparging), a period of setting, a rinsing step, and a removal step (vacuum). Each stage involves a different TechXtract® solution, and the sequence of these stages constitutes a cycle. If necessary, the cycle may be repeated to achieve the desired level of decontamination (NETL 2002).

As an example, we can consider the decontamination of lead bricks performed by the Hanford Site C Reactor Technology Demonstration Group (DOE 1998a). The first two stages contain surface preparation formulations designated “Pro” and “Clean” that are blends of acids and other agents that clean dirt, oil, grease, and other interfering substances from the surface. The third stage is an extraction blend designated “XT” containing organic compounds, including chelating agents, and other compounds designed to interact with contaminants at the molecular level.

2.6.2 Target Contaminants

The technology is applicable to radionuclides, PCBs, tritium, and other hazardous organic and inorganic substances. The extraction chemistry can be modified to some extent and tailored to the specific decontamination circumstances (NEFSC 2001; Blauvelt 2001).

2.6.3 Applicable Media and Surface Characteristics

The technology is applicable to concrete, brick, asphalt, wood, iron, steel, and other metals. The flexibility that comes with application of solutions to a surface means that the technology can be applied to open surfaces or smaller objects that are amenable to batch dipping.

2.6.4 Waste Streams and Waste Management Issues

The spent chemical solutions do not contain any hazardous constituents, except for the extracted contaminants, and can be disposed of by incineration, solidification and land disposal, and discharge to liquid effluent treatment systems. Waste contaminated liquids are removed in operation using vacuum systems with HEPA filters on the exhaust side. Wastes are captured in the vacuum drum body and later transferred to a disposal drum. Solutions that remain in the ultrasonic baths at the conclusion of the decontamination operation constitute another waste stream that can be handled in a similar fashion to vacuumed streams. The process produces approximately 2.7 kilograms (6 pounds) of liquid waste per ton of lead decontaminated.

It should be noted that extra care must be taken when using materials that can mobilize previously fixed contaminants. If inadvertently released to the environment, the mobilized contaminants can cause risks. Appropriate waste disposal measures should be taken.

2.6.5 Operating Characteristics

Since the technology is flexible, the operating characteristics described here refer to the decontamination of lead bricks performed by the Hanford Site C Reactor Technology Demonstration Group, for which a detailed Innovative Technology Summary Report is available (DOE 1998a).

All material handling, decontamination, and waste handling systems were housed in a 16-foot x 8-foot) trailer, the interior of which was covered with welded, seamless, 4-mil high-density polyethylene for easy decontamination. The trailer's power requirement is 120v, 60 Hz, 45 amps, which can be provided externally or with an onboard generator.

The bricks are decontaminated in batches of four. The individual bricks are placed into baskets constructed from non-reactive materials. Batches are staged at the open end of the trailer where the baskets are loaded and then lifted by means of a light-rail hoist. The hoist's I-beam and manual hoist construction has a lift capacity of 91 kilograms (200 pounds). The I-beam rail runs in a circuit along the ceiling of the trailer and outside for loading and unloading baskets.

The decontamination stations inside the trailer consist of three heated ultrasonic baths, two rinse stations with vacuum drying, and a final vacuum drying station. The ultrasonic baths are electronically heated and thermostatically controlled to approximately 60ºC and measure 51 centimeters x 29 centimeters x 28 centimeters (20 inches x 11.5 inches x 11 inches). A total of 57 liters (15 gallons) of TechXtract® solutions were used in the ultrasonic baths. The batch dwell time is a maximum of 15 minutes per station, with the capability to run simultaneous batches.

The normal work crew for the unit is two people, a technician and a supervisor. Minimal skills are required to operate the decontamination equipment. However, a chemist experienced in liquid extraction of radioisotopes must be available to advise on proportioning the chemical solutions. For a decontamination such as this, D&D Workers and radiation control technicians should be trained in Lead Hazards and Awareness, Rad Worker, 40-Hour OSHA, and Bioassay Lead Blood Level Baseline. They should also be in a respiratory protection program.

Other operational points of note are:

- The selection of chemicals, operating temperatures, and bath dwell times should be optimized, depending on the substrate being cleaned, what isotopes are being extracted, their concentrations, and their depth below the surface.
- The technology is applicable to lead that has become contaminated from the outside and not to activated lead or lead that has been remelted after becoming contaminated.
- Cleaned bricks that fail to meet release criteria should be rerun through the process, disposed of as mixed waste, or decontaminated by a different process.
- To ensure that the decontamination was totally effective, smear samples should be taken from cleaned bricks at least several days after cleaning when a lead oxide film has formed because, after some time, the oxide can cause removable contamination to form from beneath the surface.

No special regulatory permits are required for operation of the TechXtract® system. At the Hanford Site, the system met air quality permit conditions by incorporating HEPA filtration for exhausts from the vacuum stations. The system can be used in daily operation under the requirements of 10 CFR Parts 20 and 835, and proposed Part 834 for protection of workers and the environment from radiological contaminants. Although the demonstration took place at a CERCLA site, no CERCLA requirements apply to the technology demonstrated.

2.6.6 Performance

The TechXtract® lead decontamination technology demonstrated at the C Reactor had the following objectives for desired capabilities and design features:

- Have a production rate of at least 100 bricks per day or up to 9.1 square meters (100 square feet) of lead sheets per day,
- Result in a very high percentage of bricks or sheets that meet surface release criteria,
- Stabilize any liquid chemical waste to meet waste disposal regulations for landfills,
- Be easy and economical to operate
- Be able to operate in ambient temperatures from 3°C to 40°C (37°F to 104°F),
- Use conventional equipment in a portable enclosure, and
- Be safe for workers**.**

The demonstration successfully achieved all objectives except for the treatment of lead sheet which was not attempted for non-technical reasons. Specific achievements include:

- Production rates were more than 200 bricks per day,
- Decontamination factors exceeded 182,
- Decontamination took place in a safe work place environment employing “as low as reasonably achievable”(ALARA) practice, and
- Secondary waste production was only 0.038 liters (0.01 gallons) per brick or 2.7 kilograms (6 pounds) per ton of lead processed**.**

Six bricks (7.5 percent of the 80 bricks processed) did not meet release criteria after one time through the process. Of these, four bricks met release criteria after a second time through, and two bricks increased in surface contamination levels. It is believed that for these two bricks, the process was bringing contaminants to the surface from deeper in the substrate and that decontamination would succeed if enough passes through the process were made.

Comparison of the TechXtract® system with the baseline approach of encapsulation and disposal gives the results in Exhibit 2.-3.

Exhibit 2-3. Comparison of TechXtract® System with Encapsulation and Disposal

Activity or Feature	TechXtract	Encapsulation and Landfill
Setup	2 h to connect power to trailer and fill warm baths	Much more time
Production Rate	220 bricks per 5-h day	Approx. 1,000 bricks per day
Safety	Need precautions against radioactivity, lead, and organic vapors	Same, except no organic vapor concerns
Ease of operation	Same	Same
Waste generation	Minimal waste (0.2 m^3, or one 55-gal drum)	Maximum waste - approximately 100 times as much
Utility requirements	Minimal--heating and ventilation	None
Source: DOE 1998a.		

2.6.7 Capital and Operating Costs

The DOE demonstration of the decontamination of lead bricks performed by the Hanford Site C Reactor Technology Demonstration Group produced a detailed Innovative Technology Summary Report which contains an in-depth cost analysis (DOE 1998a). The data presented in the Innovative Technology Summary Report is summarized below, but it should be noted that the costs described were calculated in May 1998 at the time of the demonstration.

The cost analysis assumes rental of the main equipment for the improved technology (one vendor personnel oversight only) and site labor. The cost estimate is based on decontaminating 1,956 bricks (an extrapolation, based on the actual demonstrated) under two different scenarios compared to the baseline costs for simple disposal of the same quantity of lead bricks. Scenario A incorporates a 100 percent radiological pre-survey and sort with a 100 percent post-decon survey while Scenario B uses no pre-survey and sort with a 20 percent post-decon survey. Scenario A has a lower unit cost than Scenario B because the demonstration indicated that approximately half the used bricks stored at C Reactor can be released without cleaning if the bricks are pre-surveyed. The improved and baseline costs use a site-specific production time available of five hours per eight-hour shift. When using this information for another site, the basis of production and non-production time must be adjusted. The cost effectiveness analysis includes the improved technology equipment, site mobilization, decontamination, demobilization, and secondary waste disposal activities. Each brick weighs 11.8 kilograms (26.0 pounds) and is 5 centimeters x 10 centimeters x 20 centimeters (2 inches x 4 inches x 8 inches) in size. The baseline disposition of lead bricks at the Hanford Site is to encapsulate the bricks with grout in a cask at $.22/kilograms ($0.10/pounds) followed by disposal as low-level mixed waste at the site's Environment Restoration Disposal Facility (ERDF) at $60 per ton of material including lead, grout and the cask.

The Lead Brick Decontamination technology uses commercially fabricated equipment that is transported to the site in a single mobile trailer. The vendor Active Environmental charges $3,500 to deliver one person and the trailer to the Hanford Site in Washington State and return it to New Jersey. This equipment is outfitted with government-owned HEPA vacuum/filtration systems after arrival. The vendor charges $2,700 per eight-hour day including chemicals plus vendor technician living expenses. The costs for equipment rental and purchase and rates for vendor personnel are summarized in Exhibit 2-4 below.

Exhibit 2-4. Costs for Equipment and Rates for Vendor Personnel

Description	Hourly Rate	Purchase Price	Maintenance Cost	Technician Living Expense
Decon Trailer	$192	$52,000	$3,000 for 3-year life	-
Vendor Technician	$59	-	-	$80 per diem
Source: DOE 1998a.				

Observed unit costs and production rates for principal components of the demonstrations for both the improved and baseline technologies are presented in Exhibit 2-5 below.

Exhibit 2-5. Summary of Production Rates and Unit Costs

Scenario	Scenario Production Rate	Scenario Unit Cost	Baseline Production Rate	Baseline Unit Cost
Scenario A	17.9 bricks/h (including 2 min bricks for pre-survey)	$2.12/kg ($0.96/lb) less salvage value	194 bricks/h	$0.36/kg ($0.165/lb)
Scenario B	44 bricks/h	$2.18/kg ($0.99/lb)	194 bricks/h	$0.36/kg ($0.165/lb)
Source: DOE 1998a.				

2.6.8 Commercial Availability

Active Environmental Technologies, Inc.
40 High St., Suite 100
Mount Holly, NJ 08060
U.S.
Phone: (800) 328-2613
Fax: (609) 702-1521
http://www.active-env.com

Chapter 3. Physical Decontamination

3.1 INTRODUCTION TO PHYSICAL DECONTAMINATION

Physical decontamination, also referred to in the literature as mechanical decontamination, is the removal of surface radiological contamination by physical processes such as flushing, wiping, brushing, vacuuming, grinding, blasting, scabbling, shaving, spalling, peening, scaling, other forms of scarifying, or the application of strippable coatings. Physical decontamination techniques can be divided into surface cleaning techniques and surface removal techniques. Surface cleaning techniques include brushing, wiping, flushing, vacuuming, and strippable coatings, where the surface remains intact but contamination on the surface is mechanically dislodged. Surface removal techniques include grinding, blasting, scabbling, shaving, spalling, peening, and scaling, where the contamination is removed by virtue of the removal of an entire layer of the surface.

Physical decontamination can be either an alternative or a complement to chemical decontamination. Compared to chemical decontamination, physical decontamination has certain advantages and disadvantages. Among the advantages are:

- Physical decontamination can work on almost all surfaces. In practice the more difficult it is to remove the surface, the less advantageous physical decontamination becomes. For example, though it is fairly easy to remove a plaster or grout surface, it becomes more much difficult and expensive to remove a steel surface.
- For some surfaces, physical decontamination is the only choice. The most common example is a porous surface such as concrete on which no barrier layer was placed and where contamination has reached deep within the matrix. In such situations, a chemical approach is rarely successful and may worsen the situation by driving the contamination even deeper below the surface.
- Physical decontamination can usually achieve higher decontamination factors than chemical decontamination simply because it is capable of removing the contaminated surface in its entirety.
- Surface preparation is usually not an issue with physical decontamination techniques since the entire surface is removed.
- Waste management tends to be simpler since removed surface material can be collected directly and routed to waste disposal rather than requiring secondary treatments such as ion exchangers, etc.

Among the disadvantages of physical decontamination are:

- Physical decontamination technologies, by their very nature, have no radionuclide or chemical specificity.
- Physical decontamination technologies, by their very nature, are destructive to the surface being cleaned, so are either inapplicable to facilities or equipment requiring reuse or will entail a subsequent surface refinishing operation.
- Since physical decontamination technologies often work by the physical abrasion of the surface, airborne emission of abraded particulates is an operational problem that must be addressed either directly by the technique or by ancillary measures.
- Access to and the complex geometry of surfaces can be a significant issue in the application of physical decontamination technologies. Even if surface contamination would be amenable to a

physical decontamination approach, when the surface is remote (e.g., the inside of a long, thin pipe) or of complex geometry (e.g., equipment parts with crevices and joints), then the application of the technology can be adversely impacted.

- Physical decontamination technologies tend to be more "hands-on," requiring workers to operate tools in the immediate vicinity of the contaminated surface and hence requiring greater general attention to safety and health concerns due to the higher dosages.
- Waste volumes can be larger than with chemical decontamination especially when deep surface removal is required or when large amounts of additives, such as abrasion media, are involved.
- Though surface preparation *per se* is easier with physical decontamination technologies, the immediate environment in which the decontamination is taking place must be properly prepared, including the removal of obstacles or encumbrances such as piping or conduit if the physical decontamination technology requires a flat, unhindered surface.

As with chemical decontamination, generalizations about the applicability of a given technology are very difficult and, possibly, counterproductive. The performance of a given technology is highly dependent on a variety of factors concerning the circumstances of the contamination, including contaminant type, contaminant chemical and physical properties, contaminant origin and history, depth of penetration, surface material properties, etc. Treatability and feasibility studies are critically important. If any generalization can be made, it is that operator experience indicates that physical decontamination technologies are best applied to large, regular, unencumbered surfaces.

Just as chemical decontamination owes much to experience in industrial cleaning, physical decontamination technologies owe much to industrial surface preparation and finishing experience. Both types of decontamination draw heavily on experience gained in their respective background areas, and both are likely to draw further from these areas for future technology developments.

3.2 STRIPPABLE COATINGS

3.2.1 Description of Technology

Strippable Coating
Exhibit 3-1.

Strippable coatings are paints, polymers and related coating materials that can be applied to a surface contaminated with loose, removable particulates or loose contaminant-harboring debris. The coatings are allowed to penetrate into microvoids on the surface and adhere to (or mechanically envelope) the contaminants, allowed to set or cure, and then removed bringing the contamination with the coating. Exhibit 3-1 depicts a strippable coating being removed. Removal of the strippable coating from the surface involves stripping or pulling the coating away from the surface. To facilitate its removal, the coating can be scored into large sections with a sharp knife. The coating can be rolled as it is removed for ease of handling and to further trap any residual contamination on the surface of the coating. The coatings are frequently water-based organic polymers thus minimizing organic vapor releases. As the polymers interlink, the effectiveness of contaminant removal increases (Ebadian 1998; DOE 2000). The coatings can be applied by spray, brush, roller or squeegee, and to enhance strippability, fiber reinforcement can be added to the polymer mix.

Strippable or temporary coatings were used to assist in the cleanup of the Three Mile Island incident. A wide variety of these materials are available. In one survey (Ebadian 1998), DOE requested information on 30 products, received replies from 19 suppliers, and determined that six were appropriate for use in radiological decontamination.

Strippable coatings can be used in three ways:

- As a decontaminating coating outlined above,
- As a protective coating applied to uncontaminated surfaces in areas that are liable to contamination, and
- As a means of fixing loose contamination on surfaces while other operations proceed to prevent the further spread of contamination.

Strippable coatings have the advantages of producing a single solid waste. In situations where airborne contamination has to be avoided and the treatment and management of liquid secondary wastes is problematic, strippable coatings can be an effective solution. In addition to radiological decontamination, they can be used to mitigate other hazardous wastes including PCBs, asbestos and hazardous metals.

3.2.2 Target Contaminants

Strippable coatings target loose particulates or other loose debris that may harbor contaminants. As with other physical decontamination technologies, there is no radionuclide specificity.

3.2.3 Applicable Media and Surface Characteristics

Strippable coatings can be used on bare and painted concrete, wood, carbon and stainless steel, plastic, and insulation. They can be used on fairly complex geometric shapes, but, the more complex the shape, the more involved the stripping process.

3.2.4 Waste Streams and Waste Management Issues

The only waste produced by a strippable coating is the cured, stripped coating removed from the decontaminated surfaces. Minor amounts of waste water will be produced in cleaning up equipment.

3.2.5 Operating Characteristics

The U.S. Department of Energy (DOE) has conducted a demonstration of a strippable coating for use in radiological surface decontamination. The coating demonstrated was Carboline 1146 ALARA™ strippable coating sold by Williams Power Corporation. The demonstration was performed in May 1999 at the 321-M Fuel Fabrication Facility at Savannah River Site (SRS). This facility was built in the 1950s to manufacture fuel tubes for the SRS production reactors. The facility covers approximately 62,000 square feet and contains casting, forging, extruding, and machining equipment that was used to produce uranium-aluminum fuel tubes. The demonstration involved decontamination of 2,845 square feet of painted carbon steel walls, unpainted carbon steel walls and ceiling, and epoxy coated concrete. The information provided in this section and the following sections on performance and cost draw heavily on this demonstration and the associated Innovative Technology Summary Report (DOE 2000).

The work required a three-person full time crew with a one-quarter time health physicist. No special skills are needed when working with the strippable coating although training was necessary on the operation of the airless spray system. The ALARA™ vendor recommended a Graco electric airless spray system with the following specifications: a minimum pump ratio of 30:1, a minimum output of 3 gallons per minute at 1,800-2,300 psi, minimum tip size of 0.021 inch, and an electrical utility supply of 110 volts.

The technique requires no surface preparation. Application instructions are to hold the spray gun at 45° and 10-12 inches from the surface, moving the spray gun slowly (10-15 seconds) across the surface with a 50 percent overlap on each pass. Application conditions range from 4°C to 32°C. Theoretical coverage at the recommended wet film thickness of 45-50 mil was 26 square feet per gallon. Drying times were 9 hours to touch, 18 hours to foot traffic, and 24 hours until removal.

Operating concerns included the potential for the spray gun tip to clog and delays for it to be taken apart and cleaned. The use of a reversible tip minimizes this concern. The vendor recommends airline respirators to prevent inhalation of over-spray, although SRS required full-face respirators due to possible airborne contamination while spraying and the potential for clogging of ventilation filters by sprayed material. No regulatory permits are required to use the ALARA™ 1146 strippable coating.

3.2.6 Performance

In the DOE project, the ALARA™ 1146 successfully demonstrated its ability to remove surface contamination from metal and concrete surfaces safely and effectively. For transferable alpha contamination, the overall decontamination factor (defined as initial contamination divided by final contamination then averaged over all surfaces) was 6.68 indicating that 85 percent of initial alpha was removed. For transferable beta/gamma contamination, the overall decontamination factor was 5.55 indicating that 82 percent of initial alpha was removed.

Contamination decreased from an average transferable alpha contamination level of 2,044 disintegrations per minute (dpm)/100 cm^2 with a maximum level of 60,000 dpm/100 cm^2 to an average of 417 dpm/100 cm^2 with a maximum contamination level of 10,000 dpm/100 cm^2. In over one-third of all survey locations, the alpha transferable contamination levels were reduced to less than the survey instrument's Minimum Detectable Activity (MDA). Beta transferable contamination was decreased from an average level of 5,162 dpm/100 cm^2 with a maximum level of 40,000 dpm/100 cm^2 to an average of 1,384 dpm/100 cm^2 with a maximum contamination level of 12,000 dpm/100 cm^2 beta. In over two-thirds of all survey locations, the beta transferable contamination levels were reduced to less than the survey instrument's MDA.

The productivity was calculated to be 133 square feet per person-hour, and the waste generated was 70 gallons of stripped coating (14 5-gallon buckets).

3.2.7 Capital and Operating Costs

A detailed cost analysis is included in the DOE Innovative Technology Summary Report where the 1146-ALARA™ strippable coating was compared directly with steam vacuum cleaning as a baseline technology (DOE 2000).

Data were collected during the demonstration for each of the cost elements. Time to complete a task associated with the alternative technology was recorded. Labor hours were multiplied by a work group's collective charge rate. As applicable, equipment and material cost were added to labor cost. Unit costs were determined based on the square footage of decontaminated surface area. Labor rates were those in effect for the SRS site labor agreement. Crew size for the ALARA™ 1146 technology varied between two and three mechanics and a health protection technician. Mobilization and demobilization costs for the strippable coating were based on field data recorded during the demonstration. Indirect costs were omitted from the analysis, since overhead rates can vary greatly between contractors. Engineering, quality assurance, administrative costs, and taxes were also omitted from the analysis. Capital equipment costs were based on the cost of ownership. The cost of the strippable coating equipment package is $4,950. The cost of shipping the equipment was included in this capital equipment cost. Since no information was available to definitively determine the projected time of use per year, plausible assumptions given in the analysis were made to calculate an equipment unit rate. Based on these assumptions, the extended equipment cost per hour of operation would be approximately $0.95/hour.

Approximately 2,845 square feet of ALARA™ 1146 strippable coating was applied during the demonstration, but not all of this was removed. Some was left on as a fixative. Since only 1,555 square feet were stripped (removed) during the demonstration, the unit production rate used for the cost analysis was based on a job size of 1,555 square feet. For fixed cost elements, which are independent of the quantity of decontamination work, costs were calculated as lump sum costs instead of unit costs. Unit cost elements, which are dependent on the quantity of decontamination work, were based on the amount of decontamination performed. Decontamination, personal protective equipment, and waste disposal costs are combined and expressed on a unit cost basis ($\$/ft^2$).

The cost of performing the decontamination work was found to be lower, on average, for the strippable coatings technology, independent of mobilization and demobilization cost. The equipment cost varies greatly between the two technologies with an approximate cost difference of $189,000.00. The life spans are comparable, five to 10 years for the innovative equipment and 15 years for the baseline equipment. There is no break-even point for this comparison. The innovative technology is less expensive, independent of the quantity/job size. The innovative equipment is easier to mobilize. It does not require a water source to operate, and it is not internally contaminated as it is operated. The baseline steam cleaning/vacuum equipment recycles the cleaning liquid and is labor intensive to decontaminate/cIear from the controlled area. On the other hand, the innovative equipment required only flushing with clean water and is easily cleared from the controlled area.

For this demonstration, the total costs of the comparative demonstrations are $7,539 (strippable coatings) and $11,582 (baseline technology). The unit cost per square foot including mobilization and demobilization is $4.85 versus $7.46. The strippable coatings offer a 35 percent cost savings over the baseline technology.

3.2.8 Commercial Availability

Stripcoat TLC Free, sold by

Bartlett Services
Phone: (800) 225-0385 (outside Massachusetts only)
Phone: (508) 746-6464 (within Massachusetts)
Fax: (508) 830-0997
http://www.numanco.com/

ALARA™ 1146, sold by

Williams Power Company
One Williams Center
Tulsa, OK 74172
U.S.
Phone: (800) 945-5426
http://www.williams.com

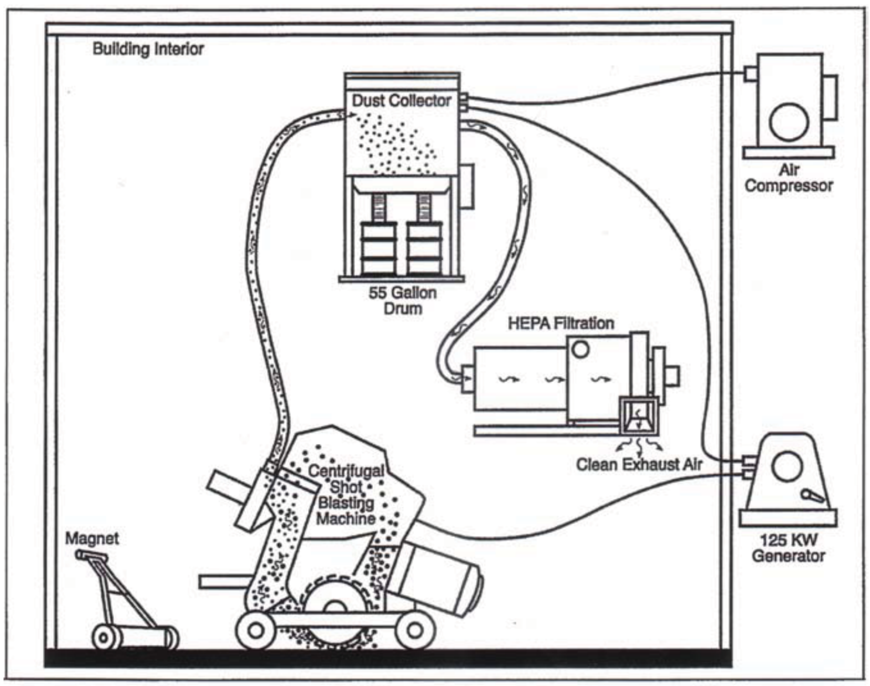
NLB Corporation
29830-T Beck Rd.
Wixom, MI 48393-2824
U.S.
Phone: (800) 441-5059
http://www/nlbcorp.com

Nilfisk-Advance America
300 Technology Dr.
Malvern, PA 19355
U.S.
Phone: (877) 215-8663
http://www.n-aa.com

3.3 CENTRIFUGAL SHOT BLASTING

3.3.1 Description of Technology

Centrifugal shot blasting is a decontamination technology used to remove paint and light coatings from concrete surfaces or to abrade concrete surfaces directly. Hardened steel shot is rapidly propelled at contaminated surfaces to fracture the surface, resulting in small dust sized particles which can be vacuumed and removed for proper disposal. Used shot is recycled by the system; lighter weight pieces that become small through repeated use are removed from the system by the vacuum suction while those still large enough to be reused are cycled back through. The diagram in Exhibit 3-2 shows a typical centrifugal shot blast system.Unlike many decontamination technologies, shot blasting results in a relatively smooth surface which can be recoated and reused (DOE 1998b; DOE 1999a).



Centrifugal shot blast system.

Exhibit 3-2.

Marketed by a variety of vendors, centrifugal shot blasting is electrically powered, and can remove light coatings or concrete surfaces up to 0.5 to 1 inch deep, though it is ideal for removing surfaces between 1/16 and 1/8 inch in depth. A motorized blast wheel inside the system is supported by a booster motor and fan. Once these components are running, shot is released into the system through a gate from a storage hopper. The speed of the system, the size of the shot, and the amount released into the system can be varied based on the degree of removal necessary. Gauges on the control panel of the unit tell an operator when more shot needs to be added to the system and how fast the unit is moving. The amount of shot released can be controlled by a panel switch, and toggle switches on the control panel are used to steer the unit.

The shot blast unit relies on a dust collection system to remove abraded dust and particles and to reduce airborne contaminants during the decontamination process. An air wash baffle system separates the reusable shot from the contaminants to cycle back into the system. Contaminant debris and recycled shot too small to use is gathered in a collection drum attached to the dust collection system. In addition, a HEPA filtration system, an air compressor, and a generator (125 kW) or power source are required to operate the system. A magnetic roller is supplied to retrieve escaped shot from the system.

The system in operation requires three workers: one to operate the centrifugal shot blast unit, another to use the magnetic roller to recapture escaped shot, and a third to assist in drum exchange in the contamination system.

3.3.2 Target Contaminants

Centrifugal shot blasting is used in the general radiological decontamination of concrete surfaces, including the removal of hazardous paint and light coatings due to contamination. As with other blasting decontamination technologies, there is no inherent radiological/non-radiological specificity.

3.3.3 Applicable Media and Surface Characteristics

Centrifugal shot blasting can be used to decontaminate concrete surfaces by removing contaminants and substrate and is particularly effective at removing paint and light coatings. This technology can be used on uniform concrete surfaces that contain wire mesh, rebar, and floor drains, but it does not respond well to concrete that contains riverine pebbles. It can grind down these surfaces by 1/16 to 1 inch and functions well when removing thin layers, as it leaves a surface in reusable condition.

3.3.4 Waste Streams and Waste Management Issues

The presence of the vacuum filtration system significantly reduces the issue of dust contamination, and, because the system operates without a liquid stream, the waste stream is minimal. The primary waste stream usually includes a dusty mixture of paint chips and concrete, depending on the condition of the surface prior to treatment, as well as spent shot. Secondary contributors to the waste stream include personal protective equipment, HEPA filters, used shot (still of usable size, but contaminated), and any other materials that might have been used during the decontamination process (damp rags, brushes, plastic matting, etc.).

3.3.5 Operating Characteristics

Centrifugal shot blast systems may consist of as many as six separate units (DOE 1998b; DOE 1999a). The main centrifugal shot blast unit can range in size from 50 inches x 16.5 inches x 43 inches to 72 inches x 80 inches x 34 inches. It can weigh from 650 pounds to 2,700 pounds, and it may have a cutting width as large as 13 inches. Even in large systems, the main unit can be operated by one person and is driven using a toggle switch to move it right, left, forward, or backward. Typically, the system requires five additional units, including a dust collection system, a HEPA filtration system, an air compressor (for larger units), a forklift, and a generator. The significant physical characteristics of these units are summarized in Exhibit 3-3 below.

Exhibit 3-3. Physical Characteristics of Centrifugal Shot Blast Systems

System	Size (Inches)	Weight (Pounds)	Other
Main Unit	50x16.5x43 to 72x80x34	650 – 2700	Cutting Width: Up to 13 in
Dust Collection	60x27x113.25 to 127x76x57	700 – 1800	-------------
HEPA Filtration	44x79x45	1000	HEPA filters can be simply attached to smaller dust collection systems.
Air Compressor	-------------	-------------	Required capacity varies.
Forklift	-------------	-------------	5000 lbs – 8600 lbs lifting capacity
125 kW Generator	-------------	-------------	60 – 100 amps 480 volts Three phase
Source: DOE 1998b; DOE 1999a.			

A magnetic roller is supplied to collect shot escaped from the system, and collection drums, ranging from 23 to 55 gallons in size, are required to gather dust and debris from the dust collection system. A dust hose with a six-inch diameter and length ranging from 50 to 75 feet connects the dust collection system to the main unit. Smaller units have a hopper that can accommodate about 100 pounds of steel shot, while larger units can hold 800 pounds.

While only one person is required to operate the shot blast unit, at least two additional workers should be on hand to change out dust collection drums as they become filled, to operate the forklift for set up, and to use the magnetic roller to collect escaped shot. Personal protective equipment required to operate the system may include coveralls, shoe covers, hoods, glove liners, gloves, ear plugs, hard hats, powered air purifying respirators, breathing zone monitors, and a Personal Ice Cooling System (PICS). Minimal training is required for operation. Certain OSHA and CFR requirements govern the operation of this equipment and the disposal of its waste.

Centrifugal shot blasting units can be limited by their large size, as they can only get within two to six inches of a floor and wall interface and within five inches of a corner. A decontamination device designed to cover smaller surface areas, such as concrete grinder, might be used along with a shot blasting unit for smaller decontamination areas.

3.3.6 Performance

Centrifugal shot blasting has been the subject of two in-depth demonstrations and analyses by the DOE (DOE 1998b; DOE 1999a). The first demonstration compared a large shot blasting system as an innovative technology against a rotary drum planer (baseline technology) at DOE’s Fernald Environmental Management Project (FEMP) site in Fernald, Ohio. The second compared a much smaller shot blast system against mechanical scabbling (the baseline technology) at the Argonne National Laboratory-East (ANL) CP-5 Research Reactor.

Centrifugal shot blasting was compared to the baseline technologies with respect to its ability to:

- Remove coatings from concrete floors,
- Reduce the quantity of concrete that must be disposed of off site,
- Reduce the amount of secondary waste generated during the concrete removal process,
- Provide a cost-effective concrete decontamination process, and
- Provide a direct comparison to baseline concrete removal technologies.

The most important factor in evaluating the smaller centrifugal shot blast system was its effectiveness in the removal of radiologically contaminated coatings (paint) from the surface of a concrete floor, leaving the floor in reusable condition. This was accomplished successfully, in addition to significantly reducing worker fatigue, exposure, and bringing the contamination to background levels. Some modifications to the unit were required to improve overall stability and drum removal processes.

The larger shot blast system was used to determine the effectiveness of the system to remove concrete surfaces at 1-inch depth. When compared to the baseline, the larger shot blast unit was able to work over obstructions in the concrete, to maneuver in smaller areas, and to remove thin surface layers leaving the floor in reuseable condition. Where this system fell short, however, was that it had trouble removing concrete down to the required 1-inch depth, where the rotary drum planer easily accomplished this task. It is important to note here that the concrete below the surface contained large numbers of riverine pebbles which hindered the shot-blasting significantly.

In both cases, escaped shot from the system posed a significant hazard to workers. Even in contained areas and despite precautions, escaped shot would often ricochet off walls and plastic used to contain the demonstration and hit workers. Additionally, before it was collected by the magnetic roller, escaped shot was dangerous to walk on and around, and presented a slipping hazard to those working with it.

The DOE studies provided a significant amount of the performance and cost data used in this profile. Accordingly, the data should be used only as a guide, and the manufacturer should be contacted for specific information on the technology's performance.

Exhibit 3-4, below, provides the overall performance results of the Centrifugal Shot Blast Unit.

Exhibit 3-4. Performance Results of the Centrifugal Shot Blast Unit

Performance Factor	Assessment
Productivity	310 ft^2/h for the smaller unit; 17.7 ft^2/h for the larger unit
Water Usage	None
Ease of Use	Vendor training required.
PPE Usage	Required one set of PPE, and the larger unit required less hearing protection than the baseline.
Primary Waste	Significantly lower than baseline, particularly when comparing the larger unit to the drum planer.
Secondary Waste	Lower than baseline.
Airborne Contamination	Lower than baseline due to presence of vacuum filtration system.
End Condition	When concrete is of uniform consistency, leaves a smooth reusable surface.
Source: DOE 1998b; DOE 1999a.	

3.3.7 Capital and Operating Costs

DOE studies provide extensive cost analyses of centrifugal shot blasting for decontamination of debris in the FEMP and ANL CP-5 Research Reactor demonstrations. Furthermore, additional cost information and demonstration data are contained in the CP-5 Large Scale Demonstration Project, Technical Data for the Concrete Cleaning, Inc. Centrifugal Shot Blast Technology 1997, which is available upon request from the Strategic Alliance for Environmental Restoration. The studies caution that the analysis is only a limited representation because it uses only data that were observed during the demonstration, and some of the observed costs have been eliminated or adjusted to make the estimates more realistic.

The following cost elements were identified in advance of the demonstrations, and data were collected to support a cost analysis based on these drivers:

- Mobilization (including cost of transporting equipment to the demonstration site and necessary training),
- D&D work (including items such as the cost of labor, utilities consumed, supplies and the use of equipment for washing debris),
- Waste disposal,
- Demobilization (including removal of temporary work areas and utilities, decontamination of technology equipment, and removal from the site), and
- Personal protective equipment.

The study provides full details of the methodology and assumptions. Salient points are that equipment costs were based on the cost of ownership. Hourly equipment rates were calculated using a standard U.S. Army Corps of Engineers method. The fixed cost elements (i.e., those independent of the quantity of D&D work, such as equipment mobilization) were calculated as lump sums. The variable cost elements (i.e., those dependent on the quantity of D&D work, such as labor costs) were calculated as costs per unit of D&D work performed.

The conclusions of the cost analysis for the large shot blasting unit vs. the rotary drum planer are given in Exhibit 3-5, with unit costs provided where applicable. According to the study, equipment decontamination caused demobilization costs to rise significantly for centrifugal shot blasting.

Exhibit 3-5: Conclusions of the Department of Energy Cost Analysis

Cost driver	Rotary Drum Planer (Baseline)	Centrifugal Shot Blasting (Innovative)
Mobilization	$3,386	$9,500
D&D work	$4.30/ft^2	$30.21/ft^2
Waste disposal	$3.35/ft^2	$2.23/ft^2
Demobilization	$5,895	$6,195
PPE	$1.79/ft^2	$1.82/ft^2
Source: DOE 1998b; DOE 1999a.		

The conclusions of the cost analysis for the smaller shot blasting unit versus mechanical scabbler are given in Exhibit 3-6. The conclusions drawn from the demonstration indicate that the total cost for centrifugal shot blasting is equal to that of the baseline technology at 1,900 square feet, and for areas beyond that square footage, centrifugal shot blasting is less expensive than the baseline. Additionally, the maintenance cost for machinery that might wear during the demonstration are significantly lower for the shot blasting (0.03/square feet) as compared to the baseline (0.22/square feet).

Exhibit 3-6. Summary Cost Comparison Process-Enriched Uranium Material

Cost driver	Mechanical Scabbler (Baseline)	Centrifugal Shot Blasting (Innovative)
Mobilization	$4,308	$6,330
D&D work	$3,240	$6,480
Waste disposal	$1,655	$1,399
Demobilization	$3,702	$8,432
PPE	$46.33/day$1.79/ft^2	$46.33/day
Source: DOE 1998b; DOE 1999a.		

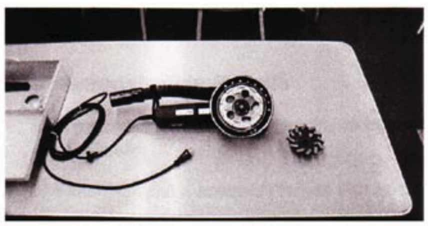
3.3.8 Commercial Availability

Mike Connacher, Owner
Concrete Cleaning, Inc.
5110 N. Ormond
Ohs Orchards, WA 99027
U.S.
Phone: (509) 226-0315
E-mail: conclsrs@aol.com

3.4 CONCRETE GRINDER

3.4.1 Description of Technology

The concrete grinder uses a diamond grinding wheel to decontaminate and strip concrete surfaces. The light-weight hand-held device creates a smooth surface when applied to flat or slightly curved surfaces, produces little vibration, and with a vacuum attachment, effectively removes dust created by the grinding process (DOE 1998c). A picture of a concrete grinder appears in Exhibit 3-7. Exhibit 3-8 portrays a worker using one.



Grinder and Spare Wheel.

Exhibit 3-7.

Concrete Grinder in Use
Exhibit 3-8.

Sold by C.S. Unitec, Inc., the Lightweight Concrete Grinder is electrically powered. When used in a circular motion, it rapidly grinds concrete surfaces 1.5 to 3 millimeters deep. A dust collection shroud can is designed to attach to the vacuum hose of an on-site HEPA filtration system, and the vacuum filtration system is required for grinder use. The diamond grinding wheel has external shroud holes which allow air intake to cool the working blades. Air taken in by the external shrouds passes into the internal discharge holes which feed to the vacuum filtration system.

The technology requires one person for operation and is considered effective for the decontamination and stripping of concrete. It is quick and easy to use compared to similar technologies.

3.4.2 Target Contaminants

Concrete grinding is used for more general radiological decontamination of concrete surfaces or for hot spot decontaminations of concrete surfaces. Non-radiological decontamination uses include deep-cleaning and concrete resurfacing due to the smooth finish the device produces.

3.4.3 Applicable Media and Surface Characteristics

Concrete grinding can be used to decontaminate interior and exterior flat or slightly curved concrete surfaces, particularly floors and walls. It can grind down these surfaces 1.5 to 3 millimeters in ambient temperatures ranging from 3 to 40°C.

3.4.4 Waste Streams and Waste Management Issues

The presence of the vacuum filtration system significantly reduces the issue of dust contamination, and, because the system operates without a liquid stream, waste streams created are minimal. Additional contributors to the waste stream include personal protective equipment, plastic wrapping and sleeving for vacuum hoses, and the concrete dust collected by the vacuum. The fee for waste disposal is minimal.

3.4.5 Operating Characteristics

The system consists of one unit. Because it is hand-held, it is totally portable, limited only by the hose and power cord length. Typical concrete grinders weigh 6 pounds. The diamond grinding wheel is 5 inches (12.7 centimeters) in diameter. When in motion, it spins at 10,000 rpm and needs to be replaced after approximately ten hours of grinding (though this estimate is heavily based on wear on the wheel and the removal rate of the grinding). The vacuum port is 1.25 inches (3.2 centimeters) in diameter. There are internal and external air intakes which cool the system and reduce dust feed into an attached vacuum hose. The motor operates at 110 VAC, is rated at 11 amps, and can be plugged into any standard electrical outlet. The depth of grinding is affected by the number of passes and the amount of time spent on any given area.

The system takes about five minutes to set up, assuming a vacuum filtration system is in place. As part of set up, users should check the freewheel spin of the grinding wheel, ensure that the power cords and connectors are free of cuts or signs of wear, connect the vacuum hose and power cord, and proceed with any required safety checks.

Although the grinder can be operated by one person, it is helpful to have a second on hand to monitor the vacuum filtration system and to make sure hoses stay attached and in place. Personal protective equipment required to operate the system includes an air purifying respirator, face shield, booties, coveralls, double coveralls (5 percent of the time), hood, pairs of inner and outer gloves and glove liners, and rubber overshoes. Minimal to no training is required for operation. While normal safety procedures should apply when workers operate this equipment, no special regulatory or permit requirements exist in order for it to be used.

The effectiveness of concrete grinders can be limited by their size, and it may be advantageous to use them with other decontamination technologies. A decontamination device designed to cover large surface areas such as pneumatic scabbler might be used along with a grinder, whereas floor and wall interfaces might require a device designed for difficult crevices, such as an air-driven needle gun.

3.4.6 Performance

Concrete grinding has been subject of an in-depth demonstration and analysis by the Department of Energy (DOE 1998c) where it was compared with a pneumatic scaler and single-piston scabbler, the latter two being regarded as the baseline technology. The technologies were demonstrated at the DOE's C Reactor Interim Safe Storage (ISS) Project as part of the Large Scale Demonstration and Deployment Project (LSDDP) at the Hanford Site in Richland, Washington.

The objectives of the LSDDP were that, compared to the baseline scabbler and scaler, the grinder should demonstrate:

- Capability at grinding floors and walls 1.5 to 3 millimeters deep,
- Operations at ambient temperatures from 3 to 40°C,
- Decontaminations using conventional equipment, and
- Safety to those operating the device.

The DOE study provided a significant amount of performance and cost data used in this profile. However, the data should be used only as a guide, and the manufacturer should be contacted for specific information on the technology's cost.

The overall performance results of the concrete grinder are given in Exhibit 3-9 below.

Exhibit 3-9. Performance Results for the Concrete Grinder

Performance Factor	Comparison to Baseline
Productivity and Work Hours	Concrete Grinder: an average of 4.5m^2/h @ 1.5 mm removal depth Scabbler: 1.13 m^2/h @ 1.5 to 3 mm removal depth Scaler: 1.1 m^2/h @ 1.5 mm removal depth
Decontamination Effectiveness	Effective in decontaminating the surface to below release levels
PPE Usage	Same as baseline
Secondary Waste	Less dust than baseline as the depth of surface removal is easier to control
Temperature Considerations	Same as baseline; performs at ambient temperatures between 3 and 40°C
Worker Safety	Because it is more efficient than the baseline technologies, the Concrete Grinder reduced worker exposure to contaminants, and vibration. It also weighs less.
Source: DOE 1998c.	

3.4.7 Capital and Operating Costs

The Department of Energy study provides an extensive cost analysis of concrete grinding for decontamination of concrete surfaces in the LSDDP demonstration. The study cautions that the analysis is only a limited representation because it uses only data that were observed during the demonstration, and some of the observed costs have been eliminated or adjusted to make the estimates more realistic.

The following cost elements were identified in advance of the demonstrations, and data were collected to support a cost analysis based on these drivers:

- Mobilization (including cost of transporting equipment to the demonstration site and necessary training),
- D&D work (including items such as the cost of labor, utilities consumed, replacement parts),
- Waste disposal,

- Demobilization (including removal of temporary work areas and utilities, decontamination of technology equipment, and removal from the site), and
- Personal protective equipment (including replacement costs of disposable items).

The study provides full details of the methodology and assumptions. Salient points are that equipment costs were based on the cost of ownership. Hourly equipment rates were calculated using a standard U.S. Army Corps of Engineers method. The variable cost elements (i.e., those dependent on the quantity of D&D work, such as labor costs) were calculated as costs per hour of D&D work performed.

The conclusions of the cost analysis are given in Exhibit 3-10 and Exhibit 3-11.

Exhibit 3-10. Department of Energy Cost Comparisons

Cost driver	Concrete Grinder (Innovative)	Pneumatic Scaler (Baseline)	Pneumatic Scabbler (Baseline)
Mobilization	$1,293	$1,339	$1,391
D&D work	$1,592	$4,198	$4,101
Waste disposal	$404	$404	$404
Demobilization	$749	$750	$761
PPE	$94.36	$94.36	$94.36
Source: DOE 1998c.			

Exhibit 3-10 is based on removing surfaces of concrete walls to a depth 1.5 millimeters for the concrete grinder and the scaler, and 1.5 to 3 millimeters for the scabbler.

Exhibit 3-11. Summary of Unit Costs

Cost Estimates	Concrete Grinder (Innovative)	Pneumatic Scaler (Baseline)	Pneumatic Scabbler (Baseline)
Production Rate	4.5 m^2/h (48 ft^2/h)	1.11 m^2/h (11.8 ft^2/h)	1.13 m^2/h (12 ft^2/h)
Unit Cost	\$31.43/m^2 (\$2.92/ft^2)	\$112.70/m^2 (\$10.47/ft^2)	\$111.62/m^2 (\$10.37/ft^2)
Source: DOE 1998c.			

3.4.8 Commercial Availability

CS Unitec
22 Harbor Ave.
Norwalk, CT 06850
U.S.
Phone: (203) 853-9522
Phone: (800) 700-5919
Fax: (203) 853-9921
E-mail: info@csunitec.com
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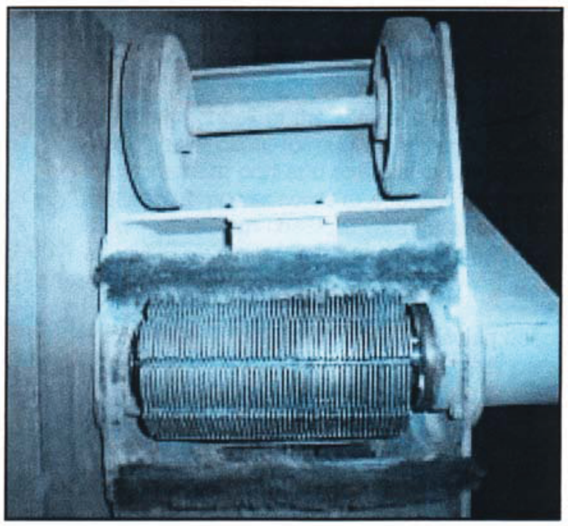
Andrews Machinery Construction
1757 First Ave. South
Seattle, WA 98134
U.S.
Phone: (206) 622-1121

3.5 CONCRETE SHAVER

3.5.1 Description of Technology

The concrete shaver is an electrically driven, self-propelled system capable of removing contaminants from concrete floors. It is considered an attractive alternative to the traditional hand-pushed, multi-piston pneumatic scabbler on wheels (DOE 1998d). A picture of one appears in Exhibit 3-12.

The cutting head of a concrete shaver is a drum that contains embedded diamonds. It is controlled by the operator from the handles. In the Marcrist-patented model, the machine is fitted with a 25-centimeters (10-inches) wide by 12.7 centimeters (5- inches) diameter shaving drum, onto which diamond-impregnated blades are fitted. The number of blades chosen is dependent upon the surface finish required. One set of shaver blades is rated for 156 hours of operation. The design for mounting the blades on the drum results in low vibration levels.



Shaver and the shaving drum.

Exhibit 3-12.

The concrete shaver can achieve variable shaving depths from 0.01 centimeters (0.004 inches) to 1.3 centimeters (0.5 inch). The depth of shaving is set by the use of a manual rotary wheel that is linked to a digital display. The unit weighs 150 kilograms (330 pounds), consumes 16 amps of 380-volt to 480-volt, 3-phase power, and has forward and reverse action. The system can operate in ambient temperatures from 3^0 C to 40^0 C (37^0 F to 104^0 F). Commercially available concrete shavers are well suited for large, wide-open concrete floors and slabs.

3.5.2 Target Contamination

Concrete shavers are used in the general decontamination of concrete surfaces and for large areas or “hot spots” on floors. They are effective against radiological contaminants and paints. However, as with other physical decontamination technologies, there is no inherent radiological/non-radiological specificity.

3.5.3 Application Media and Surface Characterization

The technology can be used to decontaminate concrete floors and slabs that are generally planar or slightly curved. It can be used on both interior and exterior surfaces. The self-propelled, electric-powered concrete shaver is particularly useful on large, flat, wide-open areas. Due to the physical size and geometry of the concrete shaver, it is not appropriate for use on very small concrete floors and slabs or those with a significant number of obstructions.

3.5.4 Waste Stream and Waste Management Issues

The presence of the vacuum filtration system significantly reduces the issue of large amounts of dust contamination. Nevertheless, the amount of concrete dust generated by the concrete shaver is slightly less than multi-piston pneumatic scabbler. Also, because the system operates without a liquid stream, the waste stream is minimal. The primary waste stream usually includes a dusty mixture of paint chips and shaved concrete, depending on the conditions of the surface prior to treatment. Personal protective equipment is a secondary contributor to the waste stream. The use of HEPA filters, personal protective equipment, and vacuum systems significantly reduces worker exposure to dust.

3.5.5 Operating Characteristics

The descriptions of the operating characteristics, performance, and costs of the concrete shaver in this and the next two sections are based on an in-depth demonstration and analysis by the U.S. Department of Energy to measure performance and costs against a baseline technology, the multi-piston pneumatic scabbler. The test was conducted at Sample Rooms X and Y at the Hanford C Reactor building during 1997 using a Marcrist Industries shaver. For dust-free operation, a vacuum extraction system was also used. Demonstration of the baseline technology, the scabbler, was conducted at Sample Room A and B at the C Reactor building. Onsite decontamination and decommissioning (D&D) workers instructed by the vendor Marcrist Industries conducted the demonstration (DOE 1998d).

The Marcrist Industries concrete shaver uses a diamond cutting head roller that rotates towards the front of the device. The cutting head is enclosed in a metal pan to prevent thrown blades from hitting the operator. Also, the cutting blades can be configured in several ways allowing different modes of removal. It is important that the cutting head be kept above the floor surface while starting the unit. The cut can be set up for a depth of from 0.1 to 15 millimeters for each pass, and the depth of the cut can easily be set at the handle by turning a control knob. The greater the depth on each pass, the rougher the finished surface. The width of the cut can also be adjusted. For this test, the widest available cut was performed, approximately 250 millimeters.

The concrete shaver can operate from a slow crawl up to the speed of a moderate walk, giving a high production rate. Once engaged, it can continue shaving while moving forward without the operator. A knob on the side of the device controls the speed of the unit, which remains constant until readjusted.

3.5.6 Performance

The DOE demonstration (DOE 1998d) compared the concrete shaver as an innovative technology against the baseline technology air-powered scabbler. The scabbler is a walk-behind, push-type device with five piston heads. It is designed to remove concrete surfaces between 0.3 cm^2 (1/8 inch) and 0.6 centimeters (1/4 inch) from large areas. A single pass with this tool on an area of 3.0 cm^2 (11.5 in^2) delivers 1,200 piston strikes per minute to the concrete surface.

The DOE conducted the analysis in order to determine if the concrete shaver was:

- Capable of removing radiologically contaminated concrete using the diamond shaving technology,
- Compatible with a dust collection shroud that may be attached to an existing onsite high-efficiency particulate HEPA filtration system,
- Useful with commonly available electric power,

- Able to remove 3 millimeters (1/8-inch) depth of potentially contaminated concrete,
- Able to handle steel-reinforcing bar and piping that may be imbedded in the concrete being decontaminated,
- Able to operate in ambient temperatures from 3^0 C to 40^0 C (37^0 F to 104^0 F), and
- Able to address the lead-based paint contamination in the sample rooms which required from 1.5 to 3 millimeters (1/16 inch to 1/8 inch) of concrete removal from floors in wide areas and up to 6 millimeters (1/4 inch) removal in small areas.

The results of the project concluded that the concrete shaver was more effective then the scabbler in removing radiologically contaminated material from the concrete floors than the scabbler. The shaver decontaminated approximately 76 square meters (816 square feet) of floors in Sample Rooms X and Y at the Hanford C Reactor Building southeast work area, removing 3 millimeters (1/8 inch) depth from the concrete surfaces. The major difference in productivity between the shaver and the scabbler is related to the removal methodology each employ. With the floor shaver, the diamond-bit drum enables single-pass cutting at precise depths while minimizing and containing the waste generated. The scabbler is neither as precise nor as fast as the floor shaver since it essentially works on a carbide-tipped bit hammer-blow principle. After making a pass with the scabbler, the resulting floor surface is left rough and irregular and not always cut to the proper depth. This forces the operator to decrease the speed of the device and rework areas. The reworking also means more concrete waste is generated, thus, increasing disposal costs.

In summary, the shaver provided the following advantages:

- It left a smoother surface than the scabbler, so final release surveying was more reliable.
- It removed the concrete surfaces much faster than the scabbler by a factor of almost five (11.9 m^2/h [128 ft^2/h] vs. 2.5 m^2/h [27 ft^2/h] at 3 millimeters [1/8 inch] depth).
- It operated with less vibration.
- It abraded embedded steel in addition to concrete.
- It showed no visible wear after removing 0.3 centimeters (1/8 inch) depth of concrete from the two sample rooms.

The diamond blades of the shaver are estimated by the manufacturer to be good for removing 0.3 centimeters (1/8 inch) depth from 1,800 square meters (20,000 square feet) of concrete surface areas. This would be equivalent to over three times the hours of usage between blade changes versus bit changes for the baseline scabbler.

3.5.7 Capital and Operating Costs

The Department of Energy study (DOE 1998d) provides a cost analysis of concrete shaver technology. The operating costs for the concrete shaver technology are $14.21/square meters ($1.32/square feet) versus $43.60 square meters ($4.05 square feet) for the baseline scabbler. Exhibit 3-13 provides a comparative view of the costs of the two technologies. The exhibit shows only elemental costs; other costs, such as those associated with mobilization, waste disposal etc. are not included.

Exhibit 3-13. Production Rates and Unit Costs (1997)

Concrete Shaver			Pneumatic Scabbler		
Cost Element	**Production Rate**	**Unit Cost ($)**	**Cost Element**	**Production Rate**	**Unit Cost ($)**
Removing 0.3 cm (1/8 in) of concrete	11.9 m^2/h (128 ft^2/h)	14.21/m^2 (1.32/ft^2)*	Removing 0.3 cm (1/8 in) of concrete	2.52 m^2/h (27 ft^2/h)	43.60/m^2 (4.05 ft^2)
Replacement blades for the (Marcrist) concrete floor shaver	1 set/1800 m^2 (20,000 ft^2) of concrete shaved or 1 set/156 hs	7172.00/set (for normal concrete)	Replacement bits for the floor scabbler	1 set/113 m^2 (1215 ft^2) of concrete scabbled or 1 set/45 hs	480.00/set (for normal concrete)
*Unit cost includes blade wear cost; blade life is estimated at 1860 m^2 for removing 0.3 cm (1/8 in) depth of concrete or 156 hours of use.					

This technology demonstration indicated that the shaver saved approximately 50 percent in cost over the baseline scabbling technology. The cost savings resulted from three factors:

- Labor savings from increased productivity realized with the concrete shaver
- The longevity of concrete shaver blades as compared to the scabbling tools, and
- The generation of less waste.

The significance of each of these factors may vary from site to site.

3.5.8 Commercial Availability

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United Kingdom
Phone: +44 (0) 1302 890 888

3.6 CONCRETE SPALLER

3.6.1 Description of Technology

The concrete spaller is used to decontaminate and strip both slightly curved and flat concrete surfaces (DOE 1998e). It is effective in large areas, and it is a good tool for hot-spots and in-depth decontamination of cracks in concrete. It can also be used to gather samples of concrete to be tested. Although the result is an uneven surface, the advantage of the spaller is that it can decontaminate more rapidly than other technologies at 3 millimeters or greater surface depth.

With a patented bit designed by Pacific Northwest National Laboratory, the spaller is powered by a 9-ton hydraulic cylinder. Holes are drilled in the concrete surface to be decontaminated in a honeycomb pattern, and the spaller bit is inserted into a drilled hole. The four-way hydraulic valve on the hydraulic pump is then turned on, and the bit expands in the hole causing the spalling. Chunks of concrete resulting from the spalling are up to 5 millimeters thick and 18 to 41 centimeters in diameter and are captured by a metal shroud which is attached around the spaller. A detachable shroud includes a vacuum port which will allow a hose to connect to an on-site HEPA filtration system if dust control is necessary.

The technology requires two people for operation. The process of predrilling the holes in the surface to be spalled is most time consuming. Each hole takes 10 to 40 seconds to drill on 20 centimeters (8 inches) centers.

3.6.2 Target Contaminants

Concrete spalling is used for deeper radiological decontamination of large areas of concrete surface, the decontamination of concrete cracks, or for hot spot decontaminations of concrete surfaces. Non-radiological decontaminant uses include concrete sampling.

3.6.3 Applicable Media and Surface Characteristics

Concrete spalling can be used to decontaminate interior and exterior flat or slightly curved concrete surfaces, particularly floors and walls, and can work around piping or reinforcements embedded in the concrete. It can spall these surfaces 3 millimeters deep or greater, in ambient temperatures ranging from 3 to 40°C. It leaves behind a rough, uneven surface sufficiently decontaminated for demolition.

3.6.4 Waste Streams and Waste Management Issues

Since it is designed to remove large chunks of concrete from surfaces at depth, the concrete spaller leaves a larger volume of waste than other decontamination technologies. The presence of a vacuum filtration system reduces the amounts of airborne contamination generated, and a water spray may be used on surfaces prior to drilling if the concrete is alpha/beta contaminated. Additional contributors to the waste stream include personal protective equipment, plastic wrapping and sleeving for vacuum hoses, and the concrete dust collected by the vacuum.

3.6.5 Operating Characteristics

The concrete spaller system consists of one unit. It is hand-held and portable and weighs 13.6 kilograms (30 pounds). A sling is recommended to help support the unit and ease operator strain. The steel spalling bit contains an internal-tapered sliding push rod; removable sheet metal shroud for dust and fragment control with a viewing window and vacuum port; a hydraulic cylinder (9 tons); a handle extension for the hydraulic cylinder; hoses to connect the pump and cylinder; and an electric/hydraulic pump (19.5 amp, 110 volt, 50 kilograms or 108 pounds, rated at 10,000 psi). The push rod connects to the hydraulic piston rod with a screwed coupling. It expands the bit as it moves through an opening in the end of the bit. The rod then pushes against the bottom of the pre-drilled hole, enabling the bit to back out of the hole slightly while it expands. The expansion breaks the concrete apart. The depth of spalling is related to pilot hole spacing, and 5 centimeters deep holes (to limit bit breakage) are recommended. Holes 2.54 centimeters (1 inch) in diameter are typically drilled in a triangular or honeycomb pattern on 20-centimeter (8 inches) centers. The spaller performs best when removing surfaces of 3 millimeters (1/8 inch) depth or greater.

The system takes about five minutes to set up and requires a user to connect hoses to the hydraulic cylinder, check the power cords and connectors for cuts or signs of wear, connect the vacuum hose and power cord, and ready a water sprayer if one is required for the predrilling of the holes. Additional safety checks may be required depending on site conditions. A longer preparation time is required to predrill the holes (estimated at 10-40 seconds/hole), and the number of holes necessary depends on the size of the area to be spalled.

The system requires two people for operation, unless an electrically operated valve can control the hydraulic pump from the spaller handle. Vibration and noise from the system is minimal, and no hearing protection is required. Personal protective equipment required to operate the system includes an air purifying respirator, face shield, booties, coveralls, double coveralls, hood, pairs of inner and outer gloves and glove liners, and rubber overshoes. Minimal training is required for operation. While normal safety procedures should apply when workers operate this equipment, there exist no special regulatory or permit requirements in order for it to be used.

Concrete spallers can be limited by their size, and it may be more effective at times to use them with other decontamination technologies. A decontamination device designed to cover large surface areas might be used along with a spaller for more efficient decontamination. Floor and wall interfaces might require a device designed for difficult crevices, such as an air-driven needle gun.

3.6.6 Performance

Concrete spalling has been subject of an in-depth demonstration and analysis by the Department of Energy (DOE 1998e) in which it was compared with a pneumatic scaler and single-piston scabbler, the latter two being regarded as the baseline technologies. The technologies were demonstrated at the Department of Energy's C Reactor Interim Safe Storage (ISS) Project as part of the Large Scale Demonstration and Deployment Project (LSDDP) at DOE's Handford Site in Richland, Washington. The demonstration objectives were that compared to the baseline scabbler and scaler, the spaller should demonstrate:

- Capability at grinding floors and walls, up to 3 millimeters deep,
- Operations at ambient temperatures from 3 to 40°C,
- Decontaminations using conventional equipment, and
- Safety to those operating the device.

The DOE study provided a significant amount of performance and cost data used in this profile. Accordingly, the data should be used only as a guide, and the manufacturer should be contacted for specific information on the technology's cost.

The overall performance results of the concrete spaller are given in Exhibit 3-14 below.

Exhibit 3-14. Performance Results of the Concrete Spaller

Performance Factor	Assessment Compared with Baseline
Productivity and Work Hours	Concrete Spaller: an average of 1.3 m^2/h Scabbler: 1.11 m^2/h Scaler: 1.10 m^2/h @ 1.5 mm removal depth
Decontamination Effectiveness	Effective in decontaminating the surface to below release levels.
PPE Usage	Approximately the same as baseline
Secondary Waste	Very little dust generation with the exception of drilling, for which dust should be controlled. Large chunks of concrete generated
Temperature Considerations	Same as baseline; performs at ambient temperatures between 3 and 40°C
Worker Safety	Comparable exposure time to baseline, but less airborne contamination is less
Source: DOE 1998e.	

3.6.7 Capital and Operating Costs

The Department of Energy study (DOE 1998e) provides an extensive cost analysis of concrete spalling for decontamination of concrete surfaces in the LSDDP demonstration. The study cautions that the analysis is only a limited representation because it uses only data that were observed during the demonstration, and some of the observed costs have been eliminated or adjusted to make the estimates more realistic.

The following cost elements were identified in advance of the demonstrations, and data were collected to support a cost analysis based on these drivers:

- Mobilization (including cost of transporting equipment to the demonstration site and necessary training),
- D&D work (including items such as the cost of labor, utilities consumed, replacement parts)
- Waste disposal,
- Demobilization (including removal of temporary work areas and utilities, decontamination of technology equipment, and removal from the site), and
- Personal protective equipment (including replacement costs of disposable items).

The study provides full details of the methodology and assumptions. Salient points are that equipment costs were based on the cost of ownership. Hourly equipment rates were calculated using a standard U.S.

Army Corps of Engineers method. The variable cost elements, those dependent on the quantity of D&D work, such as labor costs, were calculated as costs per hour of D&D work performed.

The conclusions of the cost analysis are given in Exhibit 3-15 and Exhibit 3-16.

Exhibit 3-15. Department of Energy Cost Comparisons

Cost driver	Concrete Spaller (Innovative)	Pneumatic Scaler (Baseline)	Pneumatic Scabbler (Baseline)
Mobilization	\$837.21	\$1,293.99	\$1,348.37
D&D Work	\$4,386.28	\$4,263.48	\$4,289.84
Waste Disposal	\$403.60	\$403.60	\$403.60
Demobilization	\$121.91	\$754.32	\$767.34
PPE	\$94.36/day	\$94.36/day	\$94.36/day
Source: DOE 1998e.			

The following exhibit is based on removing surfaces of concrete walls to a minimum depth of 3 millimeters as demonstrated.

Exhibit 3-16. Summary of Unit Costs

Cost Estimates (Unit Cost)	Concrete Spaller (Innovative)	Pneumatic Scaler (Baseline)	Pneumatic Scabbler (Baseline)
Drill Holes	\$142 m^2/h (13.16 ft^2/h)	N/A	N/A
Decontaminate Wall	\$58/m^2 (\$5.41/ft^2)	\$155/m^2 (\$14.4/ft^2)	\$156/m^2 (\$14.5/ft^2)
Unit Cost	\$200/m^2 (\$18.52/ft^2)	\$155/m^2 (\$14.4/ft^2)	\$156/m^2 (\$14.50/ft^2)
Source: DOE 1998e.			

Although the data in this exhibit reflect a performance cost higher than that of the two baseline technologies, the inexperience of the crew and an ineffective drill at the time of the demonstration raised the cost significantly. The study estimates that under optimum conditions, the spaller will actually save a user 15 percent as compared to the two baseline technologies.

3.6.8 Commercial Availability

Pacific Northwest National Laboratory
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Richland, WA 99352
U.S.
Phone: (509) 372-4069 (Mark Mitchell)

3.7 DRY ICE BLASTING

3.7.1 Description of Technology

Dry ice blasting, or carbon dioxide (CO_2) blasting, is an industrial cleaning process for surfaces that uses carbon dioxide pellets as the blasting medium (Renard 1997; May 2003). Carbon dioxide pellets (Exhibit 3-17) are about 1-3 millimeters in size but may be as long as about 4.5 millimeters. The pellets are very cold (below minus 100°F).They are housed in a machine where they are typically accelerated by compressed air with pressures in the range of 100 – 150 psi, although lower and higher pressures of up to 300 psi may be used in certain circumstances. To remove the contamination, the pellets are fired at a contaminated surface.

Typical Pellets - 1'8" diameter, approximately 1/16"-3/16" long

Exhibit 3-17.

In dry ice blasting, contamination is removed by three mechanisms which occur nearly simultaneously. In the first mechanism, the accelerated carbon dioxide pellets drive the contamination off of the surface because of their impact at high velocities. This mechanism of removal is similar to that of sandblasting. In the second mechanism, the cold pellets create a thermal differential with the contaminant material and the surface. This thermal differential may cause the contaminant and the surface to contract at different rates, thereby weakening the bond between them. In the third mechanism, the carbon dioxide pellets lift the contamination off of the surface when they expand into a vapor. This expansion occurs when the pellets are exposed to room temperature and when they collide with the surface. The carbon dioxide gas rapidly expands, and, as it does, it lifts the contamination off of the surface.

Alpheus MiniBlast™ Model PLT-5x

Exhibit 3-18.

Dry ice blasting machines are commercially available, and the Department of Energy (DOE) and its contractors have also modified a system for DOE needs. A company called Cold Jet offers several different models and a full range of supplies and accessories. The vendor CryoGenesis sells some Cold Jet equipment, and it also sells blasting systems made by Alpheus and robotic systems (remote operated systems) of its own design . At the Savannah River Site, contractors for DOE tested an Alpheus MiniBlast Model PLT-5X (Exhibit 3-18) which they modified for their use (May 2003). Contractors for DOE have also tested in part a remote operated dry ice pellet decontamination system built by CryoGenesis, which DOE had planned to use for decontamination work at Oak Ridge National Laboratory and at the Hanford site (Renard 1998).

In general, the dry ice blasting machines work by delivering compressed air and the pellets to a nozzle which may be directed at the surface of interest. The machines are either electric or pneumatic, and they store the pellets for use. The rate of pellet delivery may be adjustable. Some machines use one hose, delivering the pellets and high-pressure air down the same path. Other machines use two hoses with the first using transport air of about 40 psi to carry the pellets and a second hose to delivering the high-pressure air to the nozzle gun where the pellets and high-pressure air are combined.

All of these machines operate on the principle that the CO_2 gas returns to the atmosphere and leaves only the contaminant and particles removed from the surface as waste. Therefore, they are usually used with other systems that filter the CO_2 gas and collect the waste material. For blasting in radioactive environments, DOE reports that it would use support systems such as an air compressor, air dryer, and containment hut with a HEPA filtered ventilation system. In designing the remote operated blasting system, DOE and its contractors developed a separate vacuum system to collect the dislodged contaminant particles. In general, dry ice blasting requires superior off-gas treatment systems and has been described as slow.

3.7.2 Target Contaminants

Dry ice blasting targets surface contaminants and particulates. According to the vendor Cold Jet, its dry ice blasting systems are designed to remove excess grease, sludge, sealant and weld slag. Their systems have also been used to remove smoke, soot, vaporized synthetic resins, and char. The vendor further claims that its dry ice blasting process can remove 100 percent of mold spores from wood. CryoGenesis advertises the removal of resins, glues, food wastes, and fire and smoke residue from damaged materials. When DOE tested the Alpheus MiniBlast Model PLT-5X, the target contaminant was cesium-137 applied from a cesium nitrate solution. However, as with other physical decontamination technologies, there is no inherent radiological/non-radiological specificity to dry ice blasting.

3.7.3 Applicable Media and Surface Characteristics

Vendors of dry ice blasting services and equipment claim that the technology is effective on a variety of materials, including cement, concrete, plastic, wood, stainless steel, and other metals. DOE experience with the technology yielded reasonable success on stainless steel, although methods of contaminant deposition and the way the blasting equipment was operated did affect the efficiency of contaminant removal. Preliminary DOE testing of the remotely operated blasting system suggests that the system should be successful on concrete. However, no specific information was found on how irregularities in the surface or the composition of the media might affect the efficiency of contaminant removal.

3.7.4 Waste Streams and Waste Management Issues

No significant waste stream or waste management issues were noted in the DOE tests, and the vendors do not report any specific waste concerns. It is important to note, however, that, in both DOE tests, systems and procedures were in place for the efficient collection of particulates and gas. As mentioned previously, all of these machines operate with the idea that the CO_2 gas returns to the atmosphere through a HEPA filter and leaves only the contaminant and particles removed from the surface as waste streams. Nevertheless, separate systems must be in place to filter the carbon dioxide gas and to contain and collect waste materials, especially when dealing with radioactive substances.

3.7.5 Operating Characteristics

The basic principles of operation have been described previously. Characteristics of importance are noted below:

- Air pressures of 100 – 150 psi are typical, although 300 psi pressure is available in some machines.
- Low pressure machines (20 – 40 psi) are available.
- Blast pressure is typically adjustable.
- Rate of pellet delivery is variable on some machines.
- Nozzle type may vary from machine to machine, but no reports of nozzles with variable settings were found.
- Dry ice blasting equipment may be stationary, mounted on carts, or available as a remote operated unit.
- The machines can be operated by one person.
- Separate systems and equipment (containment hoods or enclosures; HEPA filters; vacuums; etc.) are necessary to contain and collect CO_2 gas and wastes.

3.7.6 Performance

Preliminary DOE testing of the CryoGenesis (Renard 1997) remote operated system yielded reasonable results, but data on actual removal capabilities of radioactive materials seems limited to the results of the DOE test with the Alpheus MiniBlast Model PLT-5X (May 2003). In that test, cesium-137 was applied two ways to stainless steel: directly (cesium nitrate solution applied to the stainless steel and dried) and indirectly (cesium-137 volatilized and condensed onto the stainless steel). In the case of the indirectly applied contamination, dry ice blasting removed the cesium below the design requirements of the test in all cases. However, the dry ice blasting did not meet the design requirements in five of 11 cases when the cesium-137 was applied directly to stainless steel.

In addition, a statistical analysis of the results indicated that the following factors could influence the efficiency of the dry ice blasting contaminant removal process:

- As blast pressure increases, the amount of removed contamination increases.
- Increases in nozzle standoff, the distance of the nozzle from the surface, decrease contamination removal.
- Increases in travel speed, the rate at which the nozzle passes over the surface, decrease contamination removal.

Changes in pellet rate delivery did not produce statistically significant changes in contamination removal. Other factors such as the orientation of the nozzle with regard to the surface and the configuration of the pellet delivery system were not evaluated.

3.7.7 Capital and Operating Costs

No reliable information on costs was available for this technology.

3.7.8 Commercial Availability

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3.8 DRY VACUUM CLEANING

3.8.1 Description of Technology

Dry vacuuming has been used effectively in radiological surface decontamination of building surfaces, floors, beams, stairs, and other solid media. The decontaminated areas are then wet-wiped. Generally, no wastewater is generated. The goal is to render concrete and steel as non-hazardous, so that the structures can either be used for normal occupancy or demolished without creating vast amounts of hazardous wastes (DOE 1994; DOE 1997).

Dry vacuum cleaning uses a commercial or industrial grade vacuum with a High Efficiency Particulate Air (HEPA) filter to remove dust and particles from building and equipment surfaces. The vacuum uses suction to draw air and loose surface particles into the storage body of the vacuum unit. Exhaust air passes through a HEPA filter before being vented back to the atmosphere. The HEPA filters trap dust and debris to protect against airborne contamination and to prevent recontamination of the air and surfaces just vacuumed. Depending on the nature of the contamination, the dry vacuuming process often occurs in a containment structure, which may consist of two layers of reinforced nylon tied to a self-supported, reusable framework. The floors, walls, and ceiling are often one piece or are sealed to prevent the escape of contaminants. Tents may have zippered doors.

HEPA vacuuming is ideal for the decontamination of surfaces with loose contamination. The filters remove a minimum of 99.97 percent of particulates larger than 0.3 microns. In some commercial models, the HEPA filter is integrated into a "bag-in/bag-out glove-box" assembly that permits removal of spent filters directly into sealable, disposal bags without exposure to the atmosphere.

Dry vacuuming removes only loose particles, and no fixed surface or subsurface contamination is removed. Thus, dry vacuuming may be used as an initial treatment method, possibly followed by another technology for further treatment to reach desired protection levels.

3.8.2 Target Contamination

Dry vacuuming is typically used for the physical removal of contaminated particles from bare and coated concrete surfaces. It can be used to remove lead-based paint chips, PCB-contaminated particles, asbestos, and other fine hazardous and radioactive material, but it is applicable only to contamination in the form of small, loose particles.

3.8.3 Application Media and Surface Characterization

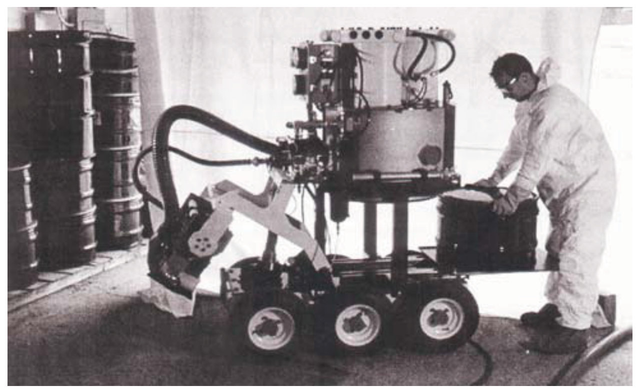
Dry vacuuming is particularly effective at removing loose contaminants from surfaces. It should not be used on porous surfaces, as loosely deposited materials may be pushed deeper into the surface.

3.8.4 Waste Stream and Waste Management Issues

Dry vacuuming operates without any liquids, and the waste stream is minimal. Depending upon the condition of the surface before treatment, the primary waste stream usually consists of a dusty mixture of concrete and other components. In the Pentek VAC-PAC system, waste remains contained at all times, as the system is safely and conveniently positioned above palletized or drawer-supported waste drums. Full, sealed drums are immediately ready for safe disposal. The particles removed must be disposed of in a landfill appropriate for the specific characteristics of the contaminants.

3.8.5 Operating Characteristics

Dry vacuuming is typically used in conjunction with other decontamination technologies. Tools such as grinders and scabblers may be used to loosen contaminated material and concrete, and vacuums with HEPA filters are used to collect the loose particles. A commercially available system, the Pentek Dustless Decontamination System (Exhibit 3-19; DOE 1997), integrates a suite of remotely and manually operated equipment to remove radioactive material, lead-based paints, PCBs, and other contaminated coatings from concrete and steel in an environmentally safe manner. The system includes pneumatically operated scabblers and needle scalers to safely loosen contaminated material and a vacuum to collect the debris. Airborne particulates are completely contained within a shroud and collected by vacuum to prevent the spread of contamination and dust. The mechanical system is completely dry, reducing waste volumes to just the removed contaminated material. The dust and debris are captured at the cutting tool surface, thereby preventing cross contamination and eliminating the need for local tenting and operator respiratory protection.



Pentek Vacuum System
Exhibit 3-19

3.8.6 Performance

A key measure of vacuum system performance is the ability to provide the desired vacuum flow at the actual operating vacuum point. Since vacuum flow is the characteristic that controls the effective entrainment and transport of material, the vacuum produced by the system under actual flow conditions must be sufficient to overcome the total system pressure loss or flow resistance. If the system cannot maintain a sufficient vacuum to sustain flow, material will not be transported through the hose and collected in the vacuum body. The better the system, the higher the vacuum maintained over the full length of the hose, from nozzle or collection point to the vacuum body itself.

Pentek's high performance HEPA Vacuum/Drumming Systems offer two-stage filtration of hazardous particulates, including radioactive materials and lead-based paint (vendor information). First stage efficiency is claimed to be 95 percent at 1 micron; second stage HEPA efficiency is 99.97 percent at 0.3 microns. First stage design offers automatic self-cleaning by reverse-flow pulses of high-pressure air, reducing the need for work stoppages and prolonged maintenance. Other features of the system, according to Pentek, include**:**

- Automatic, full-drum level alarm,
- Multiple nozzles for simultaneous operation of several hoses,
- High flow capacities to operate with hoses up to 200 feet long, and
- Compact design to facilitate mobility.

During a recent demonstration of a Pentek dry vacuum system, the VAC-PA Model 24 High Efficiency Particulate Air (HEPA) filter and waste recovery system, production averaged 125 ft^2/h (10 m^2/h), well within the DOE's acceptable range (DOE 1997).

As noted above, in the Pentek dry vacuum systems, the removed contaminants are collected in the vacuum body and the exhaust air is discharged through a HEPA filter and into the atmosphere. During operation, waste is contained in vacuum cleaner bags which may require containerization or other treatment before disposal. No other waste is generated in the decontamination process. Where a HEPA filter is required, the filter may require disposal at a LLRW facility along with the contaminated debris. Also, typical personal protective equipment, at a level commensurate with the contaminants involved, is typically required. The personal protective equipment may consist of safety glasses, respiratory protection, gloves, and coveralls.

3.8.7 Capital and Operating Costs

The DOE 1997 estimates the cost of dry vacuuming at $2.00 per square foot. This estimate is dependent on actual site conditions.

3.8.8 Commercial Availability

EQ Northeast Inc.
(Previously Franklin Environmental Services)
185 Industrial Rd.
Wrentham, MA 02093
U.S.
Phone: (508) 384-6151
http://www.eqonline.com

Pentek, Inc.
1026 Fourth Ave.
Coraopolis, PA 15108
U.S.
Phone: (412) 262-0731
Fax: (412) 262-0731
E-mail: pentekusa@aol.com
http:/www.pentekusa.com

Ion Technology
640 Maple Ave.
Saratoga Springs, NY 12866
U.S.
Phone: (501) 584-0166

3.9 ELECTRO HYDRAULIC SCABBLING

3.9.1 Description of Technology

Electro-hydraulic scabbling (EHS) uses a short (microsecond), high current (tens of thousands of amps), high voltage (tens of thousands of volts) discharge between two electrodes in water to create a plasma bubble and a shockwave capable of scabbling concrete surfaces. A series of discharges repeated at a rate of a few pulses per second are created between electrodes placed close to the concrete surface and under a thin layer of water. The water acts as a medium for transferring the shock and cavitation waves that crack and peel away layers of concrete. The water prevents air breakdown of the wave above the concrete surface, and it eliminates airborne contamination (Goldfarb 1997).

The EHS process is a rapid and controllable concrete scabbling technique that generates very little secondary waste. The consumption of water in EHS is much lower than in conventional high-pressure, water-jet decontamination techniques. By varying the energy of the pulse, the profile of the pulse, and the total number of pulses at a given location, the depth of scabbling can be controlled (Pettit 2004).

EHS can be used to decontaminate deeply contaminated concrete floors, walls, or ceilings (NETL 1997). Its advantages include the following:

- The ability to perform single pass deep scabbling,
- The reduction of waste volumes,
- The reduction of health and environmental hazards from airborne particulates,
- The reduction of cost due to lower energy consumption,
- Higher processing rates,
- Lower labor requirements, and
- Lower waste disposal costs.

3.9.2 Target Contaminants

EHS targets contaminants that have migrated deeply into concrete. As with other physical decontamination technologies, there is no radionuclide specificity to this technology; it works by bulk removal of the concrete matrix in which the contaminants can reside.

3.9.3 Applicable Media and Surface Characteristics

This technology is specifically designed for flat concrete surfaces; it will not work on metals, plastics, wood etc., and cannot accommodate complex geometries.

3.9.4 Waste Streams and Waste Management Issues

The major waste streams from EHS are scabbling debris and process water. If the water does not contain soluble contaminants it can be filtered and recycled for further use, thus greatly reducing the waste volume. The volume of scabbling debris will depend on the depth to which the concrete is scabbled. There are no specific waste containment requirements, and no non-typical waste treatment, disposal, or other management issues.

3.9.5 Operating Characteristics

The technology has been demonstrated at the Metal Fabrication Plant (Bldg. 6) of the Fernald Environmental Management Project and at Florida International University (NETL 1997). Equipment used in these demonstrations includes a high voltage power supply cabinet; a process control cabinet; a scabbling chamber/enclosure containing a scabbling module with 26 inches wide electrodes and module positioner; a water/fine debris flow system including a pump, valves, and drum/collector; and HEPA vacuums to reduce enclosure air pressure and to remove wet, coarse rubble remaining after the enclosure is transferred to the next position. The scabbling chamber and flow system were mounted on a conventional forklift truck.

The main operating parameters are:

Unit size	8' x 5' x 4'
Unit weight	1700 lbs
Power	30kW
Operating voltage	28-32 kV
Pulse energy	3-5 kJ
Pulse frequency	4-7 Hz
Scabbled track width	30 inches
Area scabbled at each position	6 ft^2
Scabbling depth	up to 1 inch
Scabbling rate (at 3/8" depth)	30 ft^2/hour

The technology requires skilled operation.

3.9.6 Performance

Data from the Fernald Environmental Management Project indicate decontamination factors in excess of 10 for uranium removal. Part of the residual activity remaining on the concrete is attributed to concrete fines left over after wet rubble removal. If residual activity needs to be further reduced, improved wet or dry post-scabbling processing should be implemented.

3.9.7 Capital and Operating Costs

The estimated cost of a unit is $120,000. Total operating costs are estimated to be in the $5-10/square foot range and are allocated as consumables (5 percent), maintenance (12 percent), capital at 5 years (8 percent), and labor (75 percent). Waste management costs will be specific to each site and will depend on the composition of the waste.

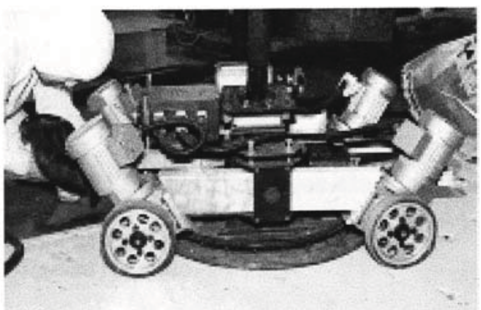
3.9.8 Commercial Availability

Textron Defense Systems, Inc.
2385 Revere Beach Parkway
Everett, MA 02149
U.S.
Phone: (617) 381-4325
Fax: (617) 381-4160

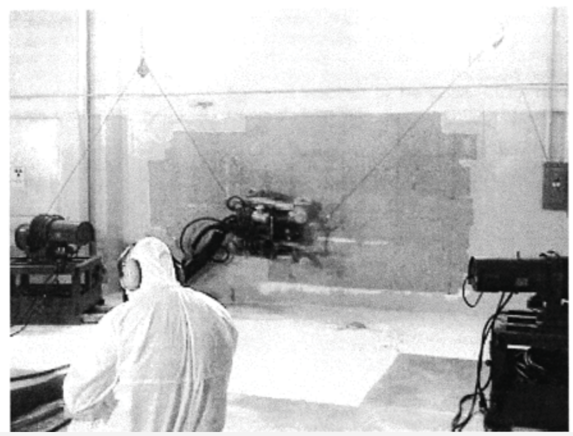
3.10 EN-VAC ROBOTIC WALL SCABBLER

3.10.1 Description of Technology

The En-vac Robotic Wall Scabbler (ERWS) is really a remote-controlled grit blasting unit specifically designed to work on flat-surfaced walls (Exhibit 3-20; Exhibit 3-21). It also is capable of working on floors. The ERWS adheres to walls by high vacuum suction created in a sealed blasting chamber at the unit's base. The vacuum system also serves to prevent any fugitive dust or grit emissions from the working surface of the blasting operation. The unit is supported by a safety harness system and moves horizontally and vertically along floors, walls, and ceilings by individually motor-controlled wheels. The complete En-vac Blasting System consists of the En-vac robot (the unit that performs the scabbling), a recycling unit, a filter, and a vacuum unit (DOE 2001).



En-vac Robotic Wall Scabbler
Exhibit 3-20.



En-vac removing paint from wall in the Decon Shop
Exhibit 3-21.

The ERWS is able to decontaminate much deeper than comparable baseline technologies.

The main components of the En-vac robot are the blast housing, lip seal, four motor and wheel drive-steer assemblies, blast nozzle with oscillator motor, and vacuum control device. The ERWS scabbles by abrasive blasting using abrasive steel grit or steel shot as the surface removal medium. The vacuum unit creates the vacuum that holds the robotic unit to the wall and contains and transports the waste. Recyclable and spent blast grit and blast residue are returned from the robot to the recycling unit through the vacuum hose. Debris from the scabbling operation is processed by a recycling unit, a filter, and a vacuum unit, all of which are separate from the robotic unit. The recycling unit continuously provides abrasive grit to the robot through the blast hose.

3.10.2 Target Contaminants

The ERWS targets contaminants on painted wall surfaces, on floors, and in the near surface of concrete. As with other physical decontamination technologies, there is no radionuclide specificity to this technology; it works by bulk removal of the paint and concrete surface where contaminants reside.

3.10.3 Applicable Media and Surface Characteristics

This technology is specifically designed for flat, painted concrete and carbon steel surfaces. It is not suitable for bare metals, plastics, wood etc., and cannot accommodate complex geometries.

3.10.4 Waste Streams and Waste Management Issues

The primary waste generated by ERWS is a stream of scabbled concrete and paint debris containing small amounts of grit. The grit is recycled on average 10 times so it constitutes only a small proportion of the waste. Waste is collected automatically by the vacuum system. The recyclable grit is separated in the recycling system, and the waste portion is stored in drums for disposal. The particulars of waste disposal are case specific depending on radionuclides present and also on whether or not lead or other hazardous materials were present in the paint. In a demonstration of the technology at a DOE facility (DOE 2001), 1.84 cubic feet of concrete, paint and grit waste were generated in the scabbling of 60 square feet of wall surface, with estimated disposal costs in this situation of $159/ft^2. Secondary wastes consist of disposable personal protective equipment. There are no non-typical waste treatment, disposal, or other management issues associated with the ERWS.

3.10.5 Operating Characteristics

The En-vac system, consisting of three large units in addition to the robotic scabbling unit, is heavy with a total weight of 10,000 pounds. The heaviest piece is 6,800 pounds. All units are designed to be lifted and transported by industrial forklift or mobile carry crane.

The system requires a three-person work crew – two laborers and one equipment operator. The robot scabbler is movable, but, once set up with the safety harness system, it is not portable until demobilized and relocated. The safety harness arrangement must be prepared and properly rigged to suit the circumstances. The weight of the robot and supporting hoses must be calculated along with the resulting loads imposed by the rigging angles, forces and vectors. Harness attachment points must be selected for maximum safety.

The En-vac system requires a maximum of 640-scfm compressed air with an air dryer, and 440VAC, 3-phase, 60-Hz, 120-kW-peak demand electrical power. Surface pretreatments are not required, though. Since the unit is designed for flat surfaces, piping and conduit must be removed as necessary.

In operation the En-vac robot is placed on a wall and attached to the auto tension winch, a safety device consisting of a winch and cable system tethered to the wall and connected to the robot to prevent accidental damage to the robot, equipment, and nearby personnel in case of a loss of power or vacuum. The auto tension winch also assists in repositioning the robot on the wall after moving around piping and conduit, as the robot is not capable of scabbling on small piping. The robot can scabble to a depth of 1/8 inch on the walls, removing multiple layers of paint and surface concrete, and within eight inches of piping and other obstructions. An optional Accessory Corner Robot can be quickly installed on the same working umbilical, using the same support equipment as the En-vac robot. The corner robot is designed to remove a 20-inch path by using the winch system to move along wall corners.

No other complementary technologies are needed in conjunction with the ERWS and there are no special regulatory issues or permit requirements.

3.10.6 Performance

Data on performance and cost are based on a demonstration of the ERWS in March 2000 at the DOE's Idaho National Laboratory (INL) Test Area North (TAN) Facility to decontaminate and remove paint and/or concrete from the TAN-607 Decontamination (Decon) Shop walls. In the demonstration, the

ERWS robot's scabbling performance was compared against a commercially available hand-held scabbling unit using a grinding technology (DOE 2001).

Test Area North was established in the 1950s by the U.S. Air Force and Atomic Energy Commission Aircraft Nuclear Propulsion Program to support nuclear-powered aircraft research. Upon termination of this research, the area's facilities were converted to support a variety of other DOE research projects. The Decon shop operations began in 1957 and continued for 30 years, providing radiological decontamination of tools and small equipment from INL and non-INL facilities. Nevertheless, because of a decline in business activity and cost of maintenance, decon shop operations terminated in 1987.

The demonstration area on the wall was a grid 60 square feet in size. The ERWS took three hours to set up and then scabbled the 60 square feet grid in 36 minutes. This is approximately five times faster than the baseline technology, and the ERWS scabbling was to a greater depth. No debris was found on the floor, and the air samplers detected no airborne contamination because all operation is contained in the closed loop system that concurrently separates the paint and concrete residue and spent blast media. A final filter on the vacuum unit inlet removes 99.999 percent of all particulate larger than 1 micron from the system exhaust. After the demonstration, the entire ERWS system including the robot was decontaminated and released free of radioactive contamination.

Safety issues associated with the ERWS are related primarily to electrical and falling hazards of the robot. These hazards can be easily mitigated by a safety engineer. The risks associated with the use of ERWS are routinely acceptable to the public.

The En-vac Robotic Wall Scabbler is a mature technology that performed well during the INL demonstration. Operating the robot unit required no special skills; however, the En-vac system required the user to be trained to operate the equipment. According to the operators, this technology completed a large surface area much more easily and faster than the baseline technology. The system was user-friendly and able to remove paint at a faster rate than the baseline technology. It was noted that ao nchor points are needed to support the robot in case of emergency power shutdown.

3.10.7 Capital and Operating Costs

DOE performed an in-depth cost analysis of the ERWS during the INL demonstration (DOE 2001). The cost analysis was based on government ownership of the ERWS and rental of an air compressor and generator. The observed activities for both the ERWS and baseline technology against which it was compared included mobilization, set-up, donning/doffing personal protective equipment, operating the equipment to decontaminate the wall, moving to the next wall when the previous wall was completed, radiological surveying of the wall, demobilizing, and disposing of waste. Use of the ERWS involved additional activities that were not required for the baseline, such as performing engineering calculations for the anchor bolt installations, installing anchor bolts, making operational adjustments to the equipment, and removing and replacing the equipment on the wall when moving to the next wall. In the demonstration, the ERWS vendor's crew operated the innovative equipment, but the cost analysis assumed that the equipment was operated by site labor, and that it required a crew consisting of two laborers, one Radiological Control Technician (RCT), one industrial hygienist, and one job supervisor. Some of the observed activity durations were adjusted before using them in the cost analysis to eliminate some of the artificial effects on the work imposed by the need to collect data and the first time use of the equipment at the INL, as well as other effects associated with the demonstration. For example, the equipment setup required nine hours for the demonstration. But, two hours were used in the cost analysis as being representative of typical real work situations. The labor rates for the crew members and equipment are based on standard rates for the INL site.

The cost of the entire system is approximately $390,000. Mobilization and demobilization costs were $1,313 and $1,142 respectively. Productivity was 23 ft^2/hour for obstructed areas of wall and 146 ft^2/hour for unobstructed areas of wall.

The ERWS has higher costs for mobilization and demobilization and higher costs for the equipment rates. The DOE cost analysis assumed purchase of the equipment, which increased the costs considerably. These higher costs make the innovative technology less cost effective for small and intermediate-sized jobs if the average size of the walls is relatively small (average of 60 square feet of area for individual walls). But the ERWS becomes cost effective for large jobs with large walls because of its much higher production rate (approximately fives times). For large jobs with large walls, the innovative technology's higher production rate compensates for the equipment cost and may provide savings over the baseline technology.

DOE calculated an hourly rate of $52.74/hour for the ERWS based on amortizing the purchase price over a 15-year service life. Comparing this rate with a rate of $11.99/hour for the baseline technology, the ERWS becomes a cost effective alternative for wall areas in excess of 1,500 square feet.

3.10.8 Commercial Availability

MAR-COM, Inc.
8970 N. Bradford St.
Portland, OR 97203
U.S.
Phone: (503) 285-5871
Fax: (503) 285-5974

3.11 GRIT BLASTING

3.11.1 Description of Technology

Grit blasting is a process where abrasive particles are pneumatically accelerated and forcefully directed against a surface. These high speed particles can be used to remove contaminants from a surface and to condition the surface for subsequent finishing (DOE 1994). Typical grit blasting applications include:

- Roughening surfaces in preparation for thermal spraying, painting, bonding or other coating operations,
- Removing rust, scale, sand, or paint,
- Removing burrs.
- Providing a matte surface finish,
- Removing flash from molded components, and
- Cosmetic surface enhancement or etching.

Shooting abrasive particles at a surface is an effective means of cleaning, descaling, deburring, and removing oxides and other surface contaminants from metal, synthetic, and masonry surfaces. Grit blasting can be used on open surfaces like floors and walls and for awkwardly shaped surfaces like machine parts. The efficiency of the blasting process will depend in part on the abrasive used, on the force with which it is delivered, on the material targeted, and on the characteristics of the surface (NEA 1999).

A number of different abrasive materials are commercially available (bestofblasting). Sand blasting is now seldom used due to silicosis concerns. Traditionally, the metal grit used in grit blasting had consisted of iron or aluminum oxide, but many crushed or irregular abrasives are now used. Exhibit 3-22 details the chemical composition of some of the most common abrasive materials.

Exhibit 3-22. Chemical Composition of Abrasive Materials

Chemical	Sand *	Staurolite	Garnet	Olivine	Specular Hematite	Coal Slag	Copper slag	Nickel slag	Crushed Glass	Steel Grit	Aluminum Oxide
Silicon Dioxide **	90-100%	29%	36-38%	39-46%	<1%	45-51%	45%	37-51%	72.5%	0.3-1.3%	0.5-1.7%
Crystalline Silica	49-96%	<5.0 %	<0.8%	<0.3%	<1.0%	<1.0%	0.1%	<0.1%			
Aluminum Oxide		45%	20-26%	0.2-2.3%	0.34%	14-26%	7.2%	1.5-6.6%	0.16%		92-97%
Specular Hematite		14%	30-33%	6-11%	98.18%	18-21%	23.3%	12-20%	0.2%		0.1-1.5%
Calcium Oxide		0.07 %	1.0-2.0%	0.2-1.2%	0.06%	4.3-8.2%	19.6%	0.5-2.5%	9.18%		0.14-0.18%
Magnesium Oxide		0.75 %	1.0-6.0%	39-49%	0.05%	1.0-2.0%	3.7%	4.7-33%	3.65%		0.23-0.30%
Titanium Oxide		4.2%	<=2.0 %		0.18%	<1.3%					1.6-4.0%
Potassium Oxide		0.1%				<1.9%		<1.3%	0.12%		0.05-0.08%
Sodium Oxide		0.18 %				<1.1%			13.2%		0.07-0.12%
Manganese Oxide		0.1%	1.0%			<0.06%					
Iron										>95.0%	
Carbon						<0.4%				0.7-1.3%	
Manganese					0.026%					0.5-1.3%	
Sulfur					0.026%					<0.05%	
Sulfur Trioxide						<0.6%			0.39%		
Zirconium		3.3%	<0.2%								
Zircon Oxide			<=1%								
Phosphorous					0.011%					<0.05%	
Chromium				0.1-0.4%	0.002%					<0.2%	
Nickel				0.1-0.3%	0.009%					<0.2%	
Radioactivity Picocuries/gram						15-19.8%					

*The remaining portion of the silica sand abrasive composition consists of water or moisture content and loss on ignition

** The silicon dioxide chemical includes both non-crystalline and crystalline silica.

Source: bestofblasting

There are some restrictions on the type and chemical characteristics of abrasive materials that may be used. Restricted substances include any substance that consists of or contains 2 percent or more dry weight of crystalline silicon dioxide. Common substances that fall in this category are river sand, beach sand, white sand, pool filter material, and dust from quartz rock. Also restricted are substances that contain more than 0.1 percent antimony, 0.1 percent arsenic, 0.1 percent beryllium, 0.1 percent cadmium, 0.5 percent chromium, 0.5 percent cobalt, 0.1 percent lead, 0.5 percent nickel, or 1.0 percent tin. Radioactive substances, recycled materials that have not been treated to remove respirable dust, and any substance capable of causing harm to the upper respiratory tract of a person are also generally prohibited.

Exhibit 3-23 details the shape, hardness, density, and reported durability of many of the common abrasives.

Exhibit 3-23. Abrasive Characteristics

Abrasive	Shape	Hardness (Mohs)	Bulk Density (lbs/ft^3)	Number of Uses
Sand	Rounded Irregular	5.0-7.0	100	1
Staurolite	Rounded Irregular	6.5-7.0	128-148	1* 5**
Garnet	Subangular	7.0-8.0	130-147	3-5* 4-10**
Olivine	Angular	6.5-7.0	90-109	1
Specular Hematite	Semi-rounded	6.5-7.0	183.5	6-7**
Coal Slag	Angular	6.0-7.0	75-100	1
Copper Slag	Angular	7.0-8.0	110	1* many**
Nickel Slag	Angular	7.0-8.0	110	1
Crushed Glass	Angular Irregular	5.5-6.5	75	1
Steel Grit	Angular	40-70 HRc	260	50-100* 200-1500**
Aluminum Oxide	Irregular	9.0	120-131	3-5* 15-20**

*Some of the more conservative number of uses that have been listed for steel grit, aluminum oxide, and garnet are 50-100, 3-5, and 4-10 [Austin 1991 and Williams, 1986]
** Abrasive blasting suppliers estimates for the number of times that steel grit, aluminum oxide, and garnet may be reused are: 1500, 20, and 10 times; depending on the grade of material that is used. However the maximum number of uses listed by suppliers often rely on ideal field conditions in abrasive blasting such as low moisture, etc. that do not always exist.

Source: bestofblasting

Other abrasive materials are also available. Glass grit, which is recycled glass particles, comes in a variety of grades. It is reported to be non-toxic and inert, thereby reducing the likelihood of respiratory and environmental problems. It is chloride and salt-free, which leads to less corrosion on prepared surfaces; it is reported to have the ability to cut and/or clean many different surfaces efficiently; and it has lower disposal costs than some other abrasive materials. Synthetic grits are available, with PlasTek, available through Bartlett, Inc. and Plasti-Grit from Composition Materials Co., Inc., being two varieties. Composition Materials Co., Inc., claims that Plasti-Grit is safe for substrates, primers, gel coats, and circuit boards; that it is non-toxic, and environmentally safe; that it uses no chemical solvents; that it has a consistent specific gravity; and that it is long lasting and recyclable (up to 95 percent recoverable). Plasti-Grit is manufactured in five hardness types, from 3 – 4 Mohs, and five standard mesh sizes. The vendor reports that Plasti-Grit meets the requirements of MIL-P-85891 and is approved for use by the U.S. Army, Navy, Air Force and several armed services outside the U.S.

A number of grit blasting systems are available commercially for a wide variety of purposes. Some of the systems are designed to blast small components and parts, 4 inches by 4 inches by 10 inches, for example, and others are designed for very large objects. The Rome Metals facility in Rochester, NY, can clean metal products up to 18 feet wide, 48 feet long, and weighing up to 25 tons. The PlasTek system, for example, is available in mobile or fixed installation formats and may be used to decontaminate floors and walls. Robotic systems are also available, some for use on large parts and others for cleaning room surfaces, including ceilings.

The Department of Energy (DOE) tested such a robotic system, the En-vac Robotic Wall Scabbler (DOE 2001). The system includes the En-vac robot, a recycling unit, a filter, and a vacuum unit. This robot uses suction to attach itself to the floor, wall, or ceiling and motorized wheels to propel itself along the surface. The blasting chamber uses steel grit and is sealed to ensure that the robot remains in place and so that the dislodged particles do not escape into the surrounding environment. Spent blast grit and blast residue are collected by the vacuum unit. The recycling system processes the spent abrasives and separates the blast residue. Blast residues are collected and stored for later disposal. The En-vac system weighs 6,800 pounds and can be moved by forklift or mobile crane. It costs approximately $390,000.

3.11.2 Target Contaminants

Grit blasting targets surface contaminants and materials. Grit blasting systems are designed to remove unwanted or contaminant materials such as rust, paint, sand, scale, concrete, and burrs. However, as with other physical decontamination technologies, there is no inherent radiological/non-radiological specificity to grit blasting.

3.11.3 Applicable Media and Surface Characteristics

Vendors of grit blasting services and equipment claim that the technology is effective on a variety of materials, including cement, concrete, steel, and other metals and masonry. The technology is well-established commercially for removing paint and for preparing surfaces, and DOE experience with the technology yielded success on concrete.

3.11.4 Waste Streams and Waste Management Issues

No significant waste stream or waste management issues were noted, and the vendors do not report any specific waste concerns. However, portable units and blasting equipment in general generate a large amount of dust and particulates. The significance of this waste will vary depending on whether the specific piece of equipment is designed to control fugitive emissions itself or whether additional systems are necessary. DOE tests of the En-vac system reported no significant debris outside of the blasting chamber, and the air samplers detected no airborne contamination because all operation is contained in a closed loop system that concurrently separates waste materials and spent blast media from clean blast media. Nevertheless, it is important to note that systems and procedures should be in place for the efficient collection of particulates and dust. Grit blasting equipment should be operated with equipment such as a containment hut with a HEPA filtered ventilation system to contain and collect waste materials, especially when dealing with radioactive substances.

3.11.5 Operating Characteristics

As reported above, grit blasting is a process where abrasive particles are pneumatically accelerated and forcefully directed against a surface. These high speed abrasive particles can be used to remove contaminants and unwanted materials or irregularities from a surface and to condition the surface for subsequent finishing. The equipment varies in size from portable blasters to fixed systems which fill large rooms. The robotic system En-vac is relatively large, and it should not be considered portable once it is set up for operation.

DOE tests for En-vac indicated the following operational characteristics:

- Two vendor operators for the En-vac,
- Two laborers; one equipment operator; one electrician,
- 24 hours to transport to the site,
- 3 hours to set up,
- Maximum 640-scfm compressed air with an air dryer,
- 440VAC, 3 phase, 60 Hz, 120-kW-peak demand electrical power,
- Personal protective equipment as appropriate for the materials being blasted,
- Grit may be recyclable, reducing secondary waste, and
- Limited maneuverability around objects such as pipes on walls or floors or ceilings.

3.11.6 Performance

The En-vac was compared against a Pentek hand-held scabbler, which was considered a baseline technology (DOE 2001). Performance is summarized in Exhibit 3-24.

Exhibit 3-24. Performance of the En-vac and Pentek Systems

	Pentek Hand-Held (Baseline Technology)	**En-vac Robotic**
Time/Area Covered	195 minutes/45 ft^2	36 minutes/60 ft^2
Preparation Time	2 hours to transport 2 hours to set up	24 hours to transport 3 hours to set up
Performance (Not including Prep Time)	4.33 min/ft^2	0.60 min/ft^2
Advantages	Gets closer to objects Weighs less More mobile Generates less waste	Faster Blasts deeper on concrete Controls waste better
Source: DOE 2001.		

3.11.7 Capital and Operating Costs

Costs may vary depending on the type of equipment used. Capital costs for the En-vac system run about $390,000. Capital costs for the Pentek were $32,780.

Regarding operating costs, the Pentek baseline technology costs are approximately one-half of the cost of the En-vac technology for a job where 180 square feet of wall is decontaminated. For jobs with more than 10,000 square feet of work and having large walls (15 feet x 40 feet in size), En-vac can save approximately 17 percent over the baseline technology method.

Exhibit 3-25, below, shows the unit costs, fixed costs, and production rates for the En-vac and Pentek technologies (DOE 2001). These costs are based on a job size of 180 square feet of wall decontamination and are based on the averaged costs for donning/doffing personal protective equipment; setting up a radiation control zone; installing anchors; making operational adjustments; decontaminating the wall surface; removing, moving, and setting up at the next wall; wiping down the wall; and surveying of the wall. The cost for the baseline technology includes disposal of 3.68 cubic feet of steel grit, concrete, and paint chip waste plus the personal protective equipment used. The cost for the En-vac technology includes disposal of 1.84 cubic feet of concrete and paint chip waste plus the personal protective equipment used.

Exhibit 3-25. Summary of Costs and Production Rates

	En-vac Cost	Production Rate	Pentek Cost	Production Rate
Mobilization	$1313 each	N/A	$361	N/A
D&D Work	$37.41/ft^2	23 ft^2/h obstructed area 146 ft^2/h unobstructed area	$20.52/ ft^2	15 ft^2/h obstructed area 45 ft^2/h unobstructed area
Demobilization	$1142 each	N/A	$133	N/A
Waste Disposal	$150/ft^3	N/A	$150/ft^3	N/A
Source: DOE 2001.				

According to DOE's analysis, the En-vac technology has higher costs for mobilization and demobilization (associated with picking up and dropping off the rental equipment) and higher costs for the equipment rates. These higher costs make it less cost effective for small and intermediate size jobs if the average size of the walls is relatively small (the average of 60 square feet of area for individual walls). But the En-vac technology becomes cost effective for large jobs with large walls because of its much higher production rate. The En-vac and Pentek technologies are approximately equal for job sizes of 1,500 square feet, where the individual wall sizes are larger than 60 square feet but smaller than 600 square feet. Assuming large jobs of 10,000 square feet and consisting of individual walls having average sizes of 600 square feet, the En-vac technology would save approximately $51,207 over the baseline, or $5.12/ft^2 of wall decontaminated. At this rate of savings, it would require approximately 69,770 square feet of wall decontamination to make up for the differences in purchase price of the En-vac and Pentek technology equipment (innovative $390,000 - baseline $32,780 = $357,220; $357,220/$5.12 = 69,770 ft^2).

Costs may also vary depending on the type of grit used. Exhibit 3-26 details the costs associated with two types of grit: non-recycled slag versus steel grit.

Exhibit 3-26. Materials Performance and Cost: Nonrecycled Slag vs. Steel Grit

	Slag	Steel Grit
Consumption rate	1500 lb/h	3500 lb/h
Blasting time (6hs/day x 250 days/yr)	1500 PH*/yr/operator	1500 PH*/yr/operator
Abrasive use/yr (No recovery)	1500 lb/h x 1500 PH/yr + (2000 tons/lb)= 1125 tons/yr	3500 lb/h x 1500 PH/yr + (2000 tons/lb)= 2625 tons/yr
Abrasive use/yr using SABAR recovery system	1125 tons/yr (No recovery)	17.5 tons/yr (No recovery)
Abrasive cost/ton (Average price)	$50/ton	$450/ton
Abrasive materials cost per operator/yr	1125 tons x $50/ton=$56,250	17.5 tons x $450/ton=$7,875
Total annual abrasive materials cost savings using steel grit: $56,250 - $7,875= $48,375		
Add $50/ton for reduced handling & disposal costs: $48,375 + (1125 tons - 17.5 tons) x $50/ton=$103,750 Total annual savings.		
*PH = Person Hours		
Source: bestofblasting (http://www.bestofblasting.com)		

This exhibit shows the cost justification for the use of steel grit and a Steel Abrasive Blasting and Recovery system (SABAR). The SABAR is a portable blast and recovery system that can be used in normal outdoor blasting situations. This comparison is based on blasting operations that use one-half inch nozzles at 100 psi and 330 CFM.

3.11.8 Commercial Availability

MAR-COM, Inc.
8970 N. Bradford St.
Portland, OR 97203
U.S.
Phone: (503) 285-5871
Fax: (503) 285-5974

Progressive Technologies
4201 Patterson Southeast
Grand Rapids, MI 49512-4018
U.S.
Phone: (800) 968-0871
Phone: (616) 957-0871
Fax: (616) 957-3484
E-mail: ptisales@ptihome.com
http://www.ptihome.com

Composition Materials Co., Inc.
125 Old Gate Lane
Milford, CT 06460
U.S.
Phone: (203) 874-6500
Phone: (800) 262-7763
Fax: (203) 874-6505
E-mail: info@compomat.com

Burwell Technologies
Sydney – Head Office
291 Milperra Road
Revesby, NSW 2212
Australia
(02) 9792 2733
(02) 9792 2866
E-mail: mail@burwell.com.au

Bartlett Services, Inc.
60 Industrial Park Rd.
Plymouth, MA 02360
U.S.
Phone: (800) 225-0385
Phone: (508) 746-6464
http://www.bartlettinc.com

3.12 HIGH PRESSURE WATER

3.12.1 Description of Technology

Simple flushing with water is the most basic approach to radiological surface decontamination. Soluble contaminants are dissolved and unbound particulates are dislodged and carried away. Increased pressures and flow-rates enhance the mechanical effects of the water stream, allowing more strongly bonded particulates or those trapped in surface occlusions to be removed and also allowing other surface material such as paint layers and other debris to be stripped. As the pressure increases, the ability to remove surface material increases until, at pressures of around 50,000 psi, substances such as concrete and, if abrasives are added, even metal can be cut.

The technique is known by a variety of names depending on the pressure range being used. Common terms include water flushing (low pressures), hydroblasting, hydraulic blasting, hydrolasing (up to about 15,000 psi), high-pressure water jetting, ultra- high-pressure water jetting, and water jet cutting (up to about 50,000 psi). The pressure range and flow rates chosen are usually optimized for the specific situation. For example, a corrosion deposit on a metal surface may require a higher pressure but lower flow rate than removal of paint from a concrete surface. In all cases the waste water is collected and filtered with the filtered water either being further treated for soluble material or recycled prior to final treatment to reduce both water consumption and the total waste volumes (DOE 1994).

Recent developments owe much to the advances made in the manufacturing industry, as the technology has been used in a wide range of industries since the early 1970s. Now, water jet cutting with abrasives is the fastest growing segment of the machine tool industry with many manufacturers producing a wide range of systems, pumps, nozzles, fittings, and ancillary equipment.

In the hands of a skilled user, the technique is very effective. Coatings and deposits, even galvanized layers, can be removed without damaging the underlying base metal. Typical decontamination applications include the cleaning of inaccessible surfaces such as the interiors of pipes (Ramachandran 1996), structural steel work, cell interiors (EC 1994; Carlsen 1995)) and surfaces too large for regular scrubbing. This technique has been used successfully at the United Kingdom’s Berkeley power station, where it proved an effective and efficient process (McIntyre 1998). Variations of this technique include the use of glycerine as the pressurized medium (Meservey 1994) or the entrainment of grit in the water jet. When grit is entrained, then this is the same process as grit blasting. (Section 3.11.) Further information is contained in Boing 1995. Recent Research and Development work in the European Union and Commonwealth of Independent States is described in Ampelogova 1982 and Nechaev 1998. Experience with this technology at Paks Nuclear Power Plant in Hungary is described in Bond 1996.

3.12.2 Target Contaminants

As with all physical decontamination techniques, high pressure water jetting is non-specific with regard to contaminant removal. It will remove material on the surface and will remove the surface itself to permit very effective decontamination.

3.12.3 Applicable Media and Surface Characteristics

High-pressure water technologies can be used on concrete, brick, tile, metal and similar material, working well on both porous and non-porous surfaces. It is not recommended for wood, fiber or similar substances. The technique is frequently used on difficult-to-access surfaces through use of lances or extensions to the nozzles or end applicators, or through integration into robotic and remotely operated systems. As long as access is available, it can be used to decontaminate complex geometric structures.

3.12.4 Waste Streams and Waste Management Issues

The primary waste stream from high pressure water jetting is a waste water containing particulates and debris removed from the surface, any soluble material present on the surface, and any additives such as abrasive grit or chemicals that were added to the cleaning water. Volumes of waste water can be large, and attempts are usually made to clean and recycle the water to reduce waste volumes. There are no special issues with the wastes arising from the technique itself.

3.12.5 Operating Characteristics

Many factors are critical to application success such as correct adjustment of pressure and flow-rate, use of the correct lance tip, addition of abrasives or other chemicals, cleaning head configuration, distance from head to surface, and speed of movement of head across surface. The importance of these factors can vary significantly with the pressure range being used and contaminant under consideration. For example, when using detergents, an alkaline detergent at low pressure may be best for oily contamination while an acid detergent at high pressure may be best for scale-based contaminant deposits.

Surface pretreatments are not necessary with high-pressure water cleaning. Equipment portability or mobility, equipment weight, power requirements, installation requirements, etc., can vary greatly with the particular piece of equipment and any specialized accessories chosen. For example hand-held lances are employed for general use, surface cleaning machines for floors and other wide, open horizontal spaces where great increases in productivity can be gained, while specialized tube cleaning machines are used for pipes.

Regular worker considerations apply. Personal protective equipment is needed and awareness of the potential dangers of high-pressure systems should be ensures. In general operational practice shows that assessment of each workplace for hazards prior to the start of operations can eliminate almost all problems. There are no special regulatory issues or permit requirements associated with high-pressure water cleaning, and other than containment for water run-off, there are no special complementary technologies usually applied in conjunction with it.

3.12.6 Performance

In general the technique is extremely effective and able to strip away all types of surface corrosion and scale that harbors contaminants. It is able to completely remove contamination by completely removing the layers of base material in which it is contained. Concrete hydroblasting can remove between 3/16 inch and 3/8 inch of surface at a rate of about 40 square yards per hour (DOE 1994). Water lances have been successfully used to decontaminate pump internals, valves, cavity walls, spent fuel pool racks, reactor vessel walls and heads, fuel handling equipment, feedwater spargers, floor drains, sumps, interior surfaces of pipes, and storage tanks. It has also been applied to bridges, buildings, ships, railroad cars, and to all types of machinery and process equipment.

Documented performance and treatability studies are not readily available for this technology, especially as related to the removal of radiological contamination. Needed information includes:

- Performance measures from actual projects,
- Information on removal efficiency,
- Starting and ending radioactivity levels or dose rates,
- Comparative rates for radioactivity removal or rate of surface area covered, especially as compared to other technologies,
- Depth of contamination removal,
- Amount of surface destruction,
- The number of operating personnel required,
- The setup time,
- The ability to clean around corners, pipes, and other obstructions, and
- The ease of technology equipment decontamination after use.

Also needed is any:

- Documented applications of NCP criteria, if readily available,
- Information on how performance is affected by radioactivity levels or the presence of specific radionuclide or hazardous constituents,
- Evaluations on the impacts on performance or cost of applying the technology to small vs. large surface areas, and
- Descriptions of any technology limitations or needs for future development.

Some information is available for high pressure water systems because the systems have been used as a baseline technology for comparison against other more innovative approaches for decontamination. The Hotsy® Model 550B High Pressure Water Cleaning system was the baseline technology against the Kelly Decontamination System (steam vacuum cleaning) and has been included in an in-depth demonstration and analysis by the Department of Energy (DOE 1999c). Both technologies were demonstrated side-by-side at the Department of Energy's Fernald Environmental Management Project (FEMP) site located at Fernald, Ohio. There, high pressure water system productivity was measured at 6.05 ft^2/minute compared to steam vacuuming productivity of 2.42 ft^2/minute.

3.12.7 Capital and Operating Costs

Based on DOE's study of high pressure water cleaning systems as a baseline technology, the following cost information is available (Exhibit 3-27; DOE 1999c).

Exhibit 3-27. Conclusions of the DOE Cost Analysis

Cost driver	Hotsy® Model 550B (Baseline)
Project Area	1150 ft^2
Mobilization	$2,317
D&D work	$0.17/$ft^2$ (363 ft^2/h)
Waste disposal	$1.18/$ft^2$
Demobilization	$100
PPE	$0.18/$ft^2$
Total Unit Cost	3.63/ft^2
Source: DOE 1999c.	

3.12.8 Commercial Availability

AccuStream, Inc.
4757 Mustang Circle
Mounds View, MN 55112
U.S.
Phone: (763) 717-7099
Fax: (763) 717-7097
E-mail: info@accustream.com
http://www.accustream.com

All Jetting Technologies, Inc.
2740 Martin Downs Blvd., #318
Palm City, FL 34990
U.S.
Phone: (772) 286-1218
Fax: (772) 286-8988
E-mail: Waterjet@bellsouth.net
http://www.alljetting.com

Canyon Creek Industries, Inc.
P.O. Box 169
Greenbank, WA 98253
U.S.
Phone: (800) 870-1859
Fax: (360) 678-0299
E-Mail: pat@canyon-creek.com (Pat Groce, Tech. Sales)
E-Mail: macshearer@hotmail.com (Mac Shearer, Pres)
E-Mail: nicole@canyon-creek.com (Nicole Shearer, Marketing)
http://www.canyon-creek.com

High Pressure Equipment Company
1222 Linden Ave.
Erie, PA 16505
U.S.
Phone: (800) 289-7447
Fax: (814) 838-6075

International Waterjet Parts
1299 A St. Southeast
Ephrata, WA 98823
U.S.
Phone: (509) 754-3284
Fax: (509) 754-3292
E-mail: iwp@iwpwaterjet.com
http://www.iwpwaterjet.com

NLB Corporation
29830 Beck Rd.
Wixom, MI 48393-2824
U.S.
Phone (810) 624-5555
Fax: (810) 624-0908

Ormond, LLC
1505 Central Ave. South
Kent, WA 98032
U.S.
Phone: (253) 854-0796
Phone: (253) 852-1298
E-Mail: contact@ormondinc.net
http://www.ormondllc.com

Pressure Plus
P.O. Box 130124
The Woodlands, TX 77393-0124
U.S.
Phone: (281) 296-2569
Fax: (281)367-8129
E-mail: herriford1@aol.com

QualJet LLC
12819 SE 38 St., #240
Bellevue, WA 98006
U.S.
Phone: (866) QUALJET (782-5538)
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Richel, Inc.
4485 Crystal Pkwy, Ste. 100
Kent, OH 44240-8016
U.S.
Phone: (330) 677-9100
Fax: (330) 677-9121
E-mail: richel@richel.com (Richard Ward)
http://www.richel.com
http://www.usedwaterjets.com

3.13 SOFT MEDIA BLAST CLEANING (SPONGE BLASTING)

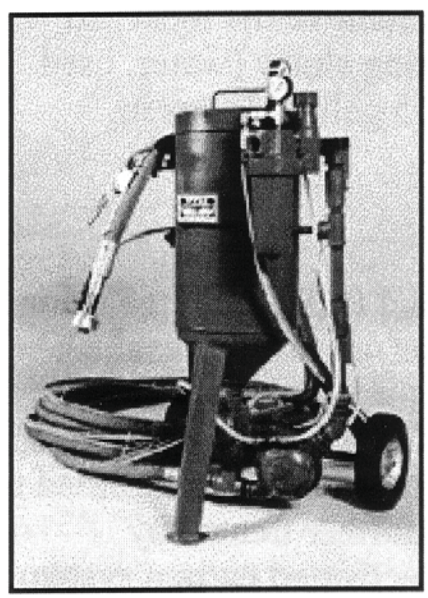
3.13.1 Description of Technology

Soft Media Blasting
Exhibit 3-28.

Soft media blast cleaning uses the kinetic energy of a soft media to abrade a surface and absorb contaminants. Soft media are propelled by compressed air against the surface to loosen, remove, and absorb contaminants in a recyclable media matrix which disintegrates over time. Due to the soft nature of the media, there is little to no bounce back from the surface (DOE 1999b; Exhibit 3-28).

Sponge-Jet's Sponge Blasting System, marketed by Sponge-Jet, Inc., relies on a pneumatic system to propel media from a feed unit through a hose and nozzle (Exhibit 3-29). The air compressor is the only component not provided as a part of the technology, but it is required to provide the system with clean, dry air, 250 ft^3/min of air, and 120 psi line pressure at the feed unit. Compressed air flows into a feed unit with two mechanisms: an actuator which stirs the media to ensure an even dispersion, and an auger which limits the amount of media fed into the air stream. Feed units are portable and vary in size, according to user requirements. A standard hose 1 inch in diameter and up to 25 feet long delivers the media air stream through a venture-style tungsten carbide blast nozzle. The system comes with a "dead-man auto-shutoff switch." Nozzles can vary in diameter size to accommodate larger surface areas or smaller more difficult to clean areas.

There are six different types of media impregnated with a range of abrasives (steel, garnet, plastic, aluminum oxide, Starblast ™) to be used for different types of surface cleaning and decontamination. Additionally, two stand alone units can be added to this system to recycle or clean used media. The vibrating Classifier Unit sieves manually collected used media through a series of screens, cycling reusable media back into the system, and removing finer spent media particles and contaminants. According to the vendor, approximately 60 percent and 90 percent of soft media can be reused after a blast cycle. The Blast Media Wash Unit centrifugally cleans grease, oils, and materials from used media in a closed system. Media washed in this system must be completely dry in order to be reused.



Soft Media Blaster
Exhibit 3-29.

3.13.2 Target Contaminants

Soft media blast cleaning removes paint, dirt, and oil. It has been used to clean electrical motors and transformers and has successfully removed enriched uranium from contaminated surfaces. It is being applied by the commercial nuclear industry in the United States, particularly for pipe and tank decontamination.

3.13.3 Applicable Media and Surface Characteristics

Soft media blast cleaning has been successfully applied to decontaminate concrete and metal surfaces. As with other physical decontamination technologies, there is no inherent radiological/non-radiological specificity.

3.13.4 Waste Streams and Waste Management Issues

Used soft media produces a waste stream composed of a solid matrix, which is much easier than a liquid or gas to collect and dispose of. In a Department of Energy demonstration (DOE 1999b) as a part of the Fernald Environmental Management Project (FEMP), decontamination of materials and surfaces was complete enough that those cleaned could be disposed of at the on-site disposal facility. The used soft media was easily collected and shoveled into plastic bags. Furthermore, because it is recyclable, there is generally less waste resulting from decontamination and cleaning as compared with other technologies. Since it is absorbent, soft media has been found to create less dust and contaminated debris than other blasting technologies.

3.13.5 Operating Characteristics

Soft blast media has as many as three process components, but it can be operated just using only one essential component: the feed unit. A feed unit, or hopper, is completely portable, and can accommodate a 50-pound bag of soft media, which at a blast pressure of 45 psi empties in about 30 minutes. Feed units come in a variety of sizes and can be chosen based on user requirements. Attached to the Feed Unit is a blasting wand, with a hose that must be a minimum 1 inch in diameter. Additionally, two stand-alone, portable units, the Classifer and Blast Media Wash Units, can be added to the system to recycle the used media after blasting.

The air compressor is an additional component that must be provided by the user, and, as noted above, it must provide the system 250 ft^3/min of clean dry air and 120 psi line pressure at the feed unit.

The basic system operating without the classifier or blast media wash units requires three individuals: one to monitor the feed unit, a second to handle the material, and a third to operate the blasting wand. Personal protective equipment requirements include cotton coveralls, hoods, booties, rubber shoe covers, nitrile gloves with liners, cotton work gloves, and double hearing protection.

The Department of Energy study (DOE 1999b) noted a number of operational strengths and weaknesses of the soft media blast system as compared against other surface cleaning and decontamination technologies. Among the strengths were:

- Decreased volume of liquid waste, as no liquid waste was generated using this technology,
- Improved cleaning effectiveness, as post cleaning survey results indicated radiation levels below the minimum detectable count rate,
- Decreased personal protective equipment use, as no waterproof clothing was required in the absence of liquid waste,
- Decreased off-site burial shipments, resulting in cost savings, and
- Flexibility in use, as features such as surface geometry did not present any cleaning problems.

Among the weaknesses were:

- The system in operation is loud, requiring workers using the equipment to wear double hearing protection, and limiting the period of time a worker can use the equipment;
- Increased airborne contamination during blasting;

- Both brown and green media were used in this study, of which the brown media produced significantly more dust; and
- Limited hose length requires equipment to be decontaminated after use, as it is unlikely it can sit outside the contaminated area.

The production rate of this technology was difficult to evaluate as compared to other technologies, as those technologies cleaned surfaces visually, while soft blast media cleaned and decontaminated 100 percent of the debris surface which required more time. Other considerations include the following:

- While the blast media wash unit was not used in this demonstration, it requires that washed media be dried completely before being reused.
- Any humidity in the air/atmosphere in the area being decontaminated can cause the system to become clogged by damp media.
- Both the feed and classifier units require thorough decontamination when repeatedly recycling blast media.

It should be noted that sponge Jet media bounce like rubber balls and may spread contamination if not properly managed at blast site**,** though they generally have less airborne contamination than typical grits.

3.13.6 Performance

Soft media blast cleaning has been subject of an in-depth demonstration and analysis by the Department of Energy (DOE 1999b) where it was compared with a Hotsy® Model 550B High Pressure Water Cleaning system, the latter regarded as the baseline technology. Neither of the media recyclable components (the Blast Media Wash Unit and the Classifier Unit) were tested at this demonstration. Both technologies were demonstrated side-by-side at the Department of Energy's Fernald Environmental Management Project (FEMP) site located at Fernald, Ohio.

The demonstration objectives were that, compared to the Hotsy® Model 550B baseline, the soft media blast cleaning should demonstrate:

- Increased production rates,
- Decreased generation of liquid wastes,
- Improved cleaning effectiveness,
- Decreased personal protective equipment requirements,
- Decrease required labor hours,
- Decreased off-site burial shipments of radioactively contaminated materials to the Nevada Test Site, and
- Decreased airborne contamination.

The most important factor in evaluating the soft media blast cleaning was its effectiveness in radiological decontamination, requiring less material to be shipped off-site for disposal for an overall cost savings. While productivity was determined to be lower and labor hours increased, it is important to note that total decontamination was being performed and compared against baseline cleaning.

The DOE study (DOE 1999b) provided a significant amount of performance and cost data used in this profile. Accordingly, the data should be used only as a guide, and the manufacturer should be contacted for specific information on the technology's performance.

The overall performance results of the soft media blast system are given in Exhibit 3-30 below.

Exhibit 3-30. Performance Results of the Soft Media Blast System

Performance Factor	Assessment
Productivity	An average of $92ft^2/h$
Work-Hours	Higher than baseline due to slower productivity, however important to note that blast media decontaminated and cleaned while baseline cleaned and did not decontaminate. Required an additional crewmember.
Water Usage	None
Washing Effectiveness	Effective in both cleaning and/or decontaminating 100% of the surface.
PPE Usage	Required less to be worn than baseline, as waterproof gear was not required, however double hearing protection was required.
Secondary Waste	Lower than baseline, as blast media equipment could be fully decontaminated, no liquid waste was produced, and solid the matrix was easily contained and disposed of.
Off-site Burial Shipments	None required, decontaminated tanks could be stored in the on-site disposal facility.
Airborne Contamination	Higher than baseline: Airborne contamination was higher during decontamination operations, but similar to levels on-site where other decontamination operations were going on.
Source: DOE 1999b.	

3.13.7 Capital and Operating Costs

The Department of Energy study (DOE 1999b) provides an extensive cost analysis of soft media blast cleaning for decontamination of debris in the FEMP demonstration. In addition, cost information and demonstration data are contained in the Detailed Technology Report for the soft media blast cleaning Technology (FEMP, 1997) which is available upon request from FEMP. The study cautions that the analysis is only a limited representation because only data that were observed during the demonstration are used, and some of the observed costs have been eliminated or adjusted to make the estimates more realistic.

The following cost elements were identified in advance of the demonstrations, and data were collected to support a cost analysis based on these drivers:

- Mobilization (including cost of transporting equipment to the demonstration site and necessary training),
- D&D work (including items such as the cost of labor, utilities consumed, supplies and the use of equipment for washing debris),
- Waste disposal,

- Demobilization (including removal of temporary work areas and utilities, decontamination of technology equipment, and removal from the site), and
- Personal protective equipment (including laundering costs and replacement costs of disposable items, assumed that four changes of clothing/shift/crew member necessary).

The study provides full details of the methodology and assumptions. Salient points are that equipment costs were based on the cost of ownership. Hourly equipment rates were calculated using a standard U.S. Army Corps of Engineers method. The fixed cost elements (i.e. those independent of the quantity of D&D work, such as equipment mobilization) were calculated as lump sums. The variable cost elements (i.e. those dependent on the quantity of D&D work, such as labor costs) were calculated as costs per unit of D&D work performed.

The conclusions of the cost analysis are given in Exhibit 3-31 and Exhibit 3-32.

Exhibit 3-31. Conclusions of the Department of Energy Cost Analysis

Cost driver	Hotsy® Model 550B (Baseline)	Soft Media Blast Cleaning (Innovative)
Mobilization	$1,206	$9,034
D&D work	$0.17/ft^2 (363 ft^2/h)	$4.19/ft^2 (92 ft^2/h)
Waste disposal	$1.18/ft^2	$0.25/ft^2
Demobilization	$100	$3,300
PPE	$0.18/ft^2	$0.16/ft^2
Source: DOE 1999b.		

Exhibit 3-32. Summary Cost Comparison Process-Enriched Uranium Material

Cost Driver	Disposal at The Nevada Test Site (Baseline)	Soft Media Blast Cleaning (Innovative)
Mobilization	$9,034	$0
D&D Work	$4.19/ft^2 (92ft^2/h)	$0
Waste Disposal (OSDF)	$0.25/ft^2	$18.08/ft^2
Demobilization	$3,300	$0
PPE	$0.16/ft^2	$0
Source: DOE 1999b.		

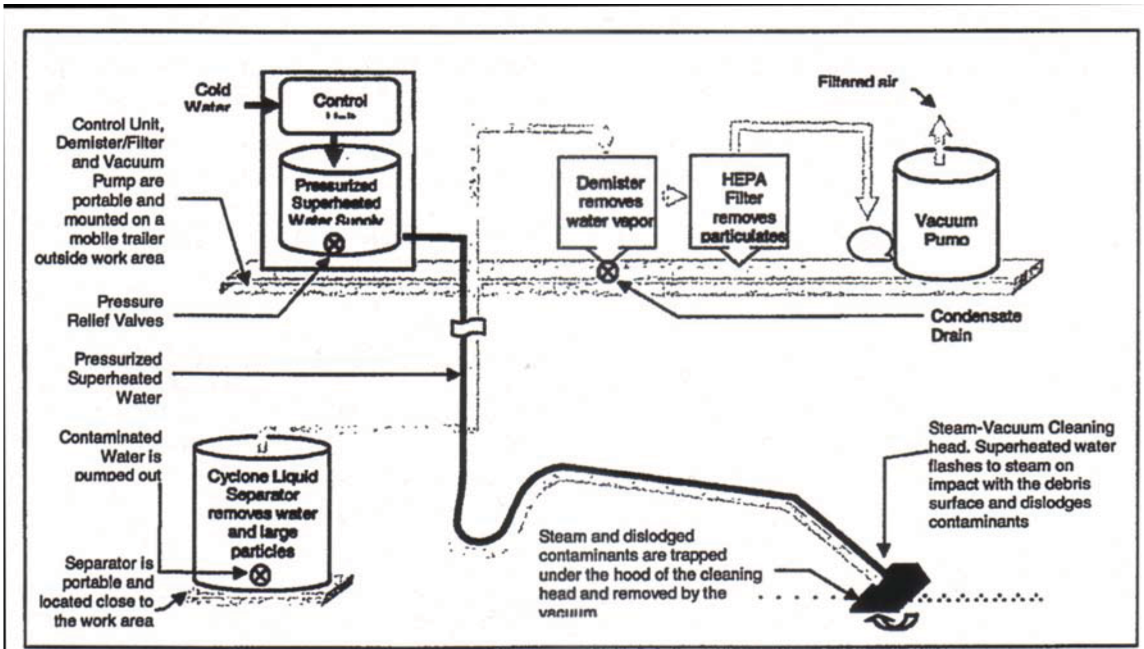
3.13.8 Commercial Availability

Sponge-Jet, Inc.
235 Heritage Ave., Suite 2
Portsmouth, NH 03801
U.S.
Phone: (800) 776-6435 (U.S. only)
Phone: (603) 431-6435
Fax: (603) 431-6042
E-mail: sjadmin@spongejet.com

3.14 STEAM VACUUM CLEANING

3.14.1 Description of Technology

Steam Vacuum Cleaning is similar to high-pressure water cleaning (HPWC) systems in that it uses the kinetic energy of a fluid to mechanically dislodge contaminants from a surface. However, in addition to the kinetic energy that arises directly from the impulse of the fluid striking the surface, there is an extra effect due to the flashing of superheated water into steam (DOE 1999c).



Schematic of the Kelly Decontamination System.

Exhibit 3-33.

The Kelly Decontamination System (Exhibit 3-33), marketed by Container Products Corporation, uses a stream of superheated (250ºF to 300ºF), pressurized (350 psi) water to dislodge contaminants from a surface, and then employs a vacuum recovery sub-system to collect the waste stream generated during the cleaning. The superheated water is delivered to the surface via a hand-held spray wand, or any of a series of steam/vacuum cleaning heads that integrate spray nozzles within a hooded vacuum recovery sub-system. These cleaning heads include a 10-inch swivel floor tool, a 9-inch handheld wall tool, a 6-inch handheld ceiling tool, and an 18-inch or 36-inch spray wand. The superheated water stream flashes to steam when it impacts the target surface and so dislodges contaminants. The hood of the steam/vacuum cleaning head traps and collects the dislodged contaminants, steam and water droplets. The waste stream passes through a vacuum recovery sub-system consisting of a liquid separator, a demister, and a high efficiency particulate air (HEPA) filter that remove contaminants and discharge clean air to the atmosphere. A detergent may be added to the pressurized water stream to improve washing effectiveness.

The main control console and superheated water supply are housed within a single unit. Process parameters such as water flow rate, pressure, and temperature are set and monitored on a digital, solid-state instrumentation panel. The superheated pressurized cleaning stream is delivered via a high-pressure hose up to 300 feet in length, directly to one of the system's cleaning tools (a spray wand or a steam/vacuum cleaning head). The superheated water flashes to steam on impact with the surface and dislodges contaminants. This unit may be operated independently as an HPWC system, or in conjunction with the other units comprising the vacuum waste recovery sub-system.

The Vacuum Unit draws the waste stream and debris removed during the washing process through a Cyclone Liquid Separator, which traps large debris in a stainless steel sieve and extracts water droplets from the air/water/debris stream. A peristaltic pump periodically pumps the extracted liquid waste from the separator to a waste sump. The effluent air stream is drawn from the Cyclone Separator to the Demister/HEPA Filter Unit. The water vapor in the effluent air stream condenses and collects in a reservoir in the demister, which is periodically drained to the waste sump. The effluent air stream from the demister passes through a high-efficiency particulate air (HEPA) filter. The HEPA filter unit is integrated into a "bag-in/bag-out glove-box" assembly that permits removal of spent filters directly into sealable disposal bags without exposure to the atmosphere. Cleaned, dry air is then drawn through the liquid-ring vacuum pump and exhausted to the atmosphere.

3.14.2 Target Contaminants

The technology targets surface contaminants and particulates. Use of a detergent allows greases to be collected. As with other physical decontamination technologies, there is no inherent radiological/non-radiological specificity.

3.14.3 Applicable Media and Surface Characteristics

The Kelly Decontamination System (DOE 1999c) is designed for the thorough cleaning and decontamination of general areas in nuclear facilities, including metals, concrete and similar surfaces. It has seen wide usage within the commercial nuclear sector primarily in the decontamination of rooms, pool walls, large components, and other large and/or smooth surfaces such as walls and floors.

The system's steam/vacuum cleaning heads were not designed for cleaning irregularly shaped objects. They are much better suited for thorough washing and decontamination of large, flat surfaces. The spray wand is much more maneuverable and effective on non-smooth surfaces, but using it eliminates the main advantage that the Kelly Decontamination System offers: its ability to simultaneously collect and contain dislodged contaminants and, thus, significantly reducing airborne contamination and risk to workers.

3.14.4 Waste Streams and Waste Management Issues

The primary waste generated by the Kelly Decontamination system is the contaminated liquid waste stream. This is automatically separated by the system into two secondary streams: the collected liquid waste and the used HEPA filters. The further treatment and disposal of these wastes will depend upon the specific circumstances of the decontamination operations taking place. When the hooded steam/vacuum cleaning head is used on smooth, flat surfaces, airborne emissions are effectively zero. In a Department of Energy demonstration (DOE 1999c) it was noted that the secondary waste produced by the Kelly Decontamination system was lower than that of the high-pressure-water-system baseline technology.

Additional waste streams will include used personal protective equipment from the operator(s) and used vacuum hoses.

3.14.5 Operating Characteristics

The system consists of four separate units (each equipped with wheels for portability):

- The control console (height x depth x width (inches) = 44 x 30 x 46; weight = 950 pounds; power requirements 480 V, 60 A, 3 phase),
- The cyclone separator (45 x 28 x 25; 175 pounds; 110 V, 6 A, single-phase),
- The demister/filter (45 x 29 x 36; 375 pounds), and
- The vacuum unit (42 x 21 x 55; 600 pounds; 480 V, 15 A, 3 phase).

A minimum water supply of 3 gallons/minutes at 40 psi is required. This gives a water flow rate in the 0.4-2.0 gallons/minute range with water at 250 psi (max) and 300 °F (max).

The basic system requires a two-person operation – one person using the steam/collection head and one operating the control console. Personal protective equipment requirements when using steam/vacuum heads include cotton coveralls, hoods and booties, rubber shoe covers (two pairs), semi-permeable Tyvek® disposable suits, and nytrile gloves (two pairs).

The Department of Energy study (DOE 1999c) noted a number of operational strengths and weaknesses of the Kelly Decontamination System. Among the strengths were:

- The system was easy to learn and use,
- Setting up the system was simple, straightforward and fast,
- Operation of the spray wand attachment was very similar to that of high-pressure water cleaning systems, and the operator was able to work in a normal upright position,
- The steam/vacuum cleaning heads were easy to change because the hose connections were designed to fit together only one way thereby simplifying setup and minimizing errors,
- The equipment is well designed from a maintenance perspective, and
- As a result of using superheated water, the washed surfaces dried quickly.

Among the weaknesses were:

- The steam/vacuum cleaning heads were not designed for cleaning crevices, corners/angles, irregular surfaces and weld seams,
- The steam recovery vacuum hose continually ran hot resulting in worker discomfort and increased risk of skin burns,
- The cleaning tools were ineffective in dislodging grease from debris surfaces,
- The vacuum hose repeatedly got in the way of the workers presenting a tripping hazard and an impediment to work,
- When using the Kelly System's steam/vacuum attachments, the workers had to bend at the waist and, over time, this resulted in fatigue, discomfort and reduced productivity, and
- Communication between the operator of the cleaning tool and the operator of the Main Control Unit was difficult due to the distance between them (typically up to 300 feet).

Other operating constraints include:

- The Kelly Decontamination System is best suited for cleaning large flat surfaces.
- The Kelly System requires two separate power supplies: 20A, single-phase, 110VAC, 60Hz and 100A, three-phase, 480VAC 60Hz; these might not be readily available in remote areas or in facilities at which the utilities have been discontinued.
- If the Kelly System is selected for debris washing, it may be best set up as a permanent "debris washing station." This would facilitate installation of overhead supports for the vacuum and high-pressure hoses, thereby eliminating the tripping hazard and work obstructions posed by these hoses.
- The worker operating the main control unit may be located up to 300 feet from the worker operating the cleaning tools. A communication link between these workers would prove useful. One possible solution is a hands-free, two-way communication device.

3.14.6 Performance

The Kelly Decontamination System has been subject of an in-depth demonstration and analysis by the Department of Energy (DOE 1999c) where it was compared with a Hotsy® Model 550B High Pressure Water Cleaning system, the latter being regarded as the baseline technology. Both technologies were demonstrated side-by-side at the Department of Energy's Fernald Environmental Management Project (FEMP) site located at Fernald, Ohio.

The demonstration objectives were that, compared to the Hotsy® Model 550B baseline, the Kelly Decontamination System should demonstrate:

- Increased productivity,
- Decreased work hours,
- Decreased volume of liquid waste generated (i.e. lower water usage),
- Increased washing effectiveness,
- Decreased personal protective equipment requirements,
- Decreased secondary waste,
- Decreased off-site burial shipments, and
- Decreased airborne contamination.

The paramount consideration in selecting the Kelly Decontamination System for the comparative demonstration was its ability to contain waste, a feature that significantly reduces airborne contamination, decreases the risk to workers, and reduces the secondary waste streams that require subsequent treatment and disposal. However, the Kelly System's steam/vacuum cleaning heads were not designed for cleaning irregularly shaped objects that comprised a large proportion of the building debris and dismantled process equipment in the DOE demonstration. Consequently, greater effort and time were required to maneuver the vacuum hose and cleaning head assembly in and around corners, seams, welds and other obstructions. As a result, longer times were required to perform the cleaning, leading in turn to lower productivity in terms of cost per unit area.

The DOE study provided a significant amount of performance and cost data used in this profile, but it must be clearly understood from the consideration above that this data comes from applying the technology to a situation for which it was not designed. Accordingly, the data should be used only as a guide and the manufacturer should be contacted for specific information on the technology's performance on smooth, flat surfaces.

It should be noted that what appear to be drawbacks to the technology under the demonstration conditions may well turn out to be advantages when used under the design conditions parallel. For example, the system was designed for thorough cleaning and decontamination. The steam/vacuum cleaning heads were operated in a manner similar to a vacuum cleaner, with back-and-forth motion and overlapping strokes and this resulted in some surfaces being cleaned more than once, and more thoroughly than required by the cleaning criteria for the demonstration. The steam used by the system also caused surfaces to dry quickly, and the operator could not always ascertain whether a particular area had been cleaned yet or not. Therefore, some areas may have been cleaned more than once.

The overall performance results of the Kelly Decontamination System (DOE 1999c) are given in Exhibit 3-34 below.

Exhibit 3-34. Overall Performance Results of the Kelly Decontamination System

Performance Factor	Assessment
Productivity	An average of 2.42 ft^2/min was achieved
Work-hours	Higher than baseline due to lower productivity. Also required an additional crewmember
Water Usage	An average of 0.37 gal/ft^2 was achieved
Washing Effectiveness	Effective except some difficulty in removing grease from surfaces
PPE Usage	Higher than baseline: the steam/vacuum heads required less PPE to be worn, but, more work hours were needed due to lower productivity, plus the need for an additional work crew member, resulted in higher overall PPE usage
Secondary Waste	Lower than baseline: only the vacuum hoses and HEPA filters
Off-site Burial Shipments	None used in demonstration
Airborne Contamination	Lower than baseline: Airborne contamination was virtually eliminated when the system was used with the steam/vacuum cleaning heads
Source: DOE 1999c.	

The experience of the demonstration allowed some needs for future technology development to be addressed, including:

- An insulating sleeve around the vacuum return hose would significantly reduce worker discomfort due to overheating of the handles of the cleaning tools. The insulated sleeve would also reduce the risk of workers being burned by the vacuum hose, and possibly lead to less restrictive hand protection gear. This enhancement would very likely lead to increased productivity.
- A more ergonomic design aimed at minimizing the need for workers to bend at the waist when using the steam/vacuum cleaning tools would reduce worker fatigue and discomfort and likely increase productivity.

- Increasing the pressure of the washing water stream would increase the effectiveness and productivity of the system in removing surface grease, without the need to use a detergent.

3.14.7 Capital and Operating Costs

The Department of Energy study (DOE 1999c) provides an extensive cost analysis of the Kelly Decontamination steam vacuum cleaning system for washing debris in the FEMP demonstration. Furthermore, additional cost information and demonstration data are contained in the Detailed Technology Report for the Steam Vacuum Cleaning Technology, FEMP, 1997, which is available upon request from FEMP. The study cautions that the analysis is only a limited representation because it uses only data that were observed during the demonstration, and some of the observed costs have been eliminated or adjusted to make the estimates more realistic.

The following cost elements were identified in advance of the demonstrations, and data were collected to support a cost analysis based on these drivers:

- Mobilization (including cost of transporting equipment to the demonstration site and necessary training),
- D&D work (including items such as the cost of labor, utilities consumed, supplies and the use of equipment for washing debris),
- Waste disposal,
- Demobilization (including removal of temporary work areas and utilities, decontamination of technology equipment, and removal from the site), and
- Personal protective equipment.

The study provides full details of the methodology and assumptions. Salient points are that equipment costs were based on the cost of ownership. Hourly equipment rates were calculated using a standard U.S. Army Corps of Engineers method. The fixed cost elements (i.e., those independent of the quantity of D&D work, such as equipment mobilization) were calculated as lump sums. The variable cost elements (i.e., those dependent on the quantity of D&D work, such as labor costs) were calculated as costs per unit of D&D work performed.

The conclusions of the cost analysis are given in Exhibit 3-35.

Exhibit 3-35. Conclusions of the Department of Energy Cost Analysis

Cost driver	Hotsy® Model 550B (baseline)	Kelly Decontamination System
Mobilization	\$2,317	\$3,688
D&D Work	\$0.17/ft^2 (363 ft^2/h)	\$0.50/ft^2 (145 ft^2/h)
Waste Disposal	\$1.18/ft^2	\$1.18/ft^2
Demobilization	\$100	\$3207
PPE	\$0.18/ft^2	\$0.21/ft^2
Source: DOE 1999c.		

3.14.8 Commercial Availability

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3.15 PISTON SCABBLER

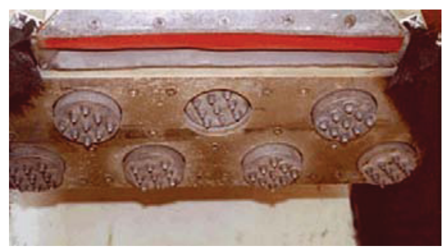
3.15.1 Description of Technology

Piston scabblers are designed to scarify concrete floors and slabs without generating large amounts of airborne contamination. In typical mechanical scabbling, the floor is fractured by a piston or series of pistons attached to the scabbling head. The pulverized concrete is vacuumed up as the head operates, and the waste material is stored in a drum assembly for later disposal.

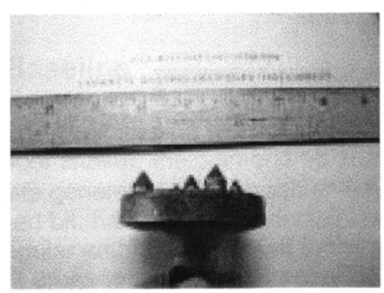
Different types of scabblers are available, and the DOE has tested the technology and reported on its performance in the Innovative Technology Summary report titled *Remotely Operated Scabbling* (DOE, 1998f). The baseline scabbler reported on is a manually driven floor/deck scabbler suitable for thick coating removal and the surface preparation of large areas of concrete floors. It has eleven 1-inch diameter pistons that impact the floor at a rate of 2,300 blows/min/piston. An aluminum shroud surrounds the pistons capturing large pieces of debris. This baseline scabbler did not come with an attached vacuum system, so a dust collection/vacuum system was not used. Instead, a containment system (i.e., a plastic tent) was erected over the area to be decontaminated to minimize the potential release of airborne dust and contamination.

DOE compared this baseline technology against a remotely operated scabbler. The remotely operated Pentek, Inc., Moose® uses a single-step floor scarification process with three integral subsystems: a scabbling head assembly, an on-board high-efficiency particulate air (HEPA) vacuum system, and a six-wheeled chassis (Exhibit 3-36). Remote operation of the Moose® is performed using a small control panel attached to the main unit by a tether up to 300-ft long. The scabbling head (Exhibit 3-37; Exhibit 3-38) uses seven, 2-inch diameter, 9-point, tungsten carbide-tipped, reciprocating scabbling bits, which pulverize the surface delivering 1,200 hammer impacts/minute. Dust and debris are captured by the two-stage positive filtration HEPA vacuum system that deposits the waste directly into an on-board 23-gallon waste drum. The six-wheeled chassis has independent skid steering which allows the Moose® to pirouette 360-degrees about its geometric center.

Pentek Remote Scabbler
Exhibit 3-36.



Remote Scabbler Head
Exhibit 3-37.



Piston head with bits for scabbler.
Exhibit 3-38.

3.15.2 Target Contaminants

Scabbling is an effective decontamination technology for surface contaminants, paints, and coatings. As with other physical decontamination technologies, it is not specific for radiological materials.

3.15.3 Applicable Media and Surface Characteristics

Concrete scabbling can be used to decontaminate concrete floors and slabs. Scabbling is also used for general demolition of concrete and other masonry materials.

3.15.4 Waste Streams and Waste Management Issues

The presence of a vacuum filtration system significantly reduces the issue of dust contamination, and, because the system operates without a liquid stream, waste streams created are minimal. Additional contributors to the waste stream include personal protective equipment, plastic wrapping and sleeving for vacuum hoses, and the concrete dust collected by a vacuum if one is used.

3.15.5 Operating Characteristics

Scabblers may be configured differently depending on design. As noted above, a typical scabbler is a manually driven floor/deck model with multiple pistons that impact the floor at a high rate. The scabbler head is designed with a shroud surrounding the pistons to capture large pieces of debris. Remotely operated systems also exist. The Moose® by Pentek, Inc has three integral subsystems: a scabbling head assembly, an on-board high-efficiency particulate air (HEPA) vacuum system, and a six-wheeled chassis. Its scabbling head uses seven, 2-inch diameter, 9-point, tungsten carbide-tipped, reciprocating scabbling bits.

Operational parameters for the Moose® are as follows:

Dimensions (L x W x H)	66 inches x 29 inches x 74 inches
Weight	1,650 pounds
Motors	Dual 90 volt DC drive motors
Cutting width	14 inches
Vendor advertised production rate	250 to 450 ft^2/h at 1/16-inch surface removal
Vendor rated vacuum flow	280 cubic feet per minute (cfm)
Primary roughing filter cartridges	Three units
Secondary HEPA filter	Three circular units (99.97 percent efficient at 0.3 microns)
Standard waste drum	23 U.S. gallons
Other equipment	375 cfm air compressor
Power requirements	110 VAC, 15 A, single phase power source

3.15.6 Performance

The baseline technology mechanical scabbler and the Pentek, Inc. remotely-operated scabbling Moose® were evaluated as part of the Large-Scale Demonstration Project (LSDP) conducted at the Argonne National Laboratory (ANL) East's Chicago Pile-5 (CP-5) Research Reactor (DOE, 1998f). The technologies were evaluated for concrete removal of 620 square feet of flooring on the service floor of the CP-5 Research Reactor. The evaluation period (August 25 to 29, 1997) included the mobilization, demonstration, and demobilization of this technology. Radiological surveys were performed both before and immediately after the demonstration. The purpose of these surveys was to determine the level of decontamination achieved through the removal of up to 1/4 inch of concrete and floor coatings by the remotely-operated scabbling system.

The baseline technology was not demonstrated concurrently with the innovative technology. The baseline data were derived from actual scabbling activities performed under similar conditions to those of the remotely operated scabbler demonstration. Labor, equipment, production rates, and productivity loss factors (PLF) were provided by site personnel at ANL or from similar work being performed elsewhere. Baseline information has been developed from the following sources:

- the existing CP-5 budget or planning documentation,
- historical experience at ANL, and
- the experienced-based judgment of D&D personnel at ANL.

A summary of the performance of the two technologies appears in Exhibit 3-39 (DOE 1998f).

The remotely operated scabbler offers the following performance characteristics:

- The simultaneous collection of dust and debris by an on-board vacuum system which significantly reduces the amount of airborne dust generated during the D&D process,
- Remote operation which allows the operator to remain from 50 to 300 feet away from the equipment,
- Removal of an average of 1/8-inch concrete from 620 square feet of flooring at a rate of 130 ft^2/hour for a crew of two persons,
- Removal of coatings from within 7-8 inches of the floor-wall interface,
- Excellent maneuverability due to its 26-inch width and ability to turn on its geometric center, and
- Remote operation which eliminates any arm/hand vibrations from the equipment, thereby improving worker comfort, reducing fatigue, and increasing safety.

The shortcoming of the Moose® is the fact that it will only accommodate the 23-gallon waste drums. The drums become filled after 45 minunte of scabbling, and they require two people to don personal protective equipment, enter the area, and change the drum. While the majority of the 5-minute drum change can be completed with only one person, the second person is required to help lower the heavy (over 200 pound) drum to the floor.

Removal of concrete from the floor by the Moose® reduced the contamination levels in the demonstration from a maximum of 105,000 dpm/100 cm^2 total beta/gamma fixed contamination to a new maximum level of 3,500 dpm/100 cm^2 with the majority of the contamination now at or below background levels. Contamination found on the unit after the demonstration was located on moving pieces where there was exposed grease.

Exhibit 3-39. Performance of the Scabbling Technologies

Criteria	Remotely-Operated Scabbling	Manual Mechanical Scabbling
Applicable Surface	1/8-in concrete removal from floor	1/4-in concrete removal from floor
Production rate (removal only)	130 ft^2/h for a crew of two	200 ft^2/h for a crew of two
Amount and type of primary waste generated	37 ft^3 of a mixture of powdery and small pieces of paint chips and concrete	An estimated 24 ft^3 of a mixture of powdery and large pieces of paint chips and concrete
Type of secondary waste generated	Roughing filters: three units HEPA filter: three units Vacuum hose: 4-ft section	Tent-enclosure materials, worn pistons and scabbling bits
Airborne radioactivity generated by equipment	All airborne radiological measurements were at or below background levels	As the technology is not connected to a vacuum system, up to 10 % of debris generated can become airborne
Noise level	106 dBA at Moose®, hearing protection is required	84 dBA (per vendor, not measured)
Capability to access floor-wall unions	No closer than 7-8 in; 14-16 in around circular walls	No closer than 1 in
Development status	Commercially available	Commercially available Compatible vacuum systems are also available
Ease of use	Training: service provided. Operator can be located outside of contamination area.	Training required: 2 hours per person. Moderate-to-heavy vibrations can cause operator fatigue
End-point condition	Concrete surface is slightly rough but is even	Paint coating is removed, leaving a rough, bare concrete surface
Worker safety	Tripping hazard caused by multiple hoses	Flying concrete poses a potential eye hazard
Source: DOE 1998f		

3.15.7 Capital and Operating Costs

The Department of Energy study (DOE 1998f) provides an extensive cost analysis of scabbling for decontamination of concrete surfaces in the LSDP demonstration. The study cautions that the analysis is only a limited representation of the technologies.

Cost data collected during the demonstration include the following:

- Activity duration,
- Work-crew composition,
- Equipment and supplies used to perform the work steps,
- Frequency and cost of worn parts and replacement of worn parts, and
- Utility consumption.

The standard labor rates established by ANL for estimating D&D work were used in this analysis for the portions of the work performed by local crafts. Costs for site-owned equipment are based upon an hourly rate for government ownership that is computed using the Office of Management and Budget (OMB) Circular No. A-94. Quoted rates for the vendor's costs are used in this analysis for performing the work and include the vendor's general and administrative, overhead, and fee mark-up costs. Additionally, a 9.3 percent cost for procurement is added by ANL to all vendor charges. The analysis uses an 8-hour work day with a 5-day week. The production rates and observed duration used in the cost analysis do not include "non-productive" items such as work breaks, loss of dexterity (due to cumbersome personal protective equipment), and heat stress. These "non-productive" items are accounted for in the analysis by including Productivity Loss Factors (PLF). PLF is a historically based estimate of the fraction of the workday that the worker spends in non-productive activities.

The cost analysis performed by DOE (DOE 1998f) is summarized in Exhibit 3-40 and Exhibit 3-41 below.

Exhibit 3-40. Equipment Costs for the Pentek Moose®

Acquisition Option	Item	Cost
Equipment purchase	Pentek Moose®	$165,000
Vendor provided service	Daily rate, which includes two trained operators, Moose® remote scabbler and hoses, ground transportation, and travel and living expenses	$1,995
	Weekly rate, which includes items listed above for the daily rate but based on 40 hour work week.	$8,125
	Overtime rate	$270/h for each hour in excess of 8 h/day
	Replacement Parts (includes HEPA filters, roughing filters, replacement hoses, and worn scabbling bits)	$2,400 one-time flat rate charge and $68.90 for each disposable 23-gal waste drum
Equipment rental	Pentek had no established rental rate for just the equipment.	
Source: DOE 1998f.		

Exhibit 3-41. Summary of Unit Costs and Production Rates (620 ft^2 of floor)

Remotely Operated Scabbler			Baseline technology		
Cost element	**Unit cost***	**Production rate**	**Cost element**	**Unit cost**	**Production rate**
Set up equipment in the work area	$618.00/each	2.5 h/each	Set up a containment tent at the work area	$3.11/$ft^2$	4.8 ft^2/min
Remove concrete using Moose®	$6.68/$ft^2$ (1)	130 ft^2/h for 1/8-in of concrete removal	Move equipment to work area and set up	$211/each	2 h/each
			Remove concrete	$1.85/$ft^2$ (1)	200 ft^2/h for 1/4-in of concrete removal
			Dismantle the temporary tent	$0.80/$ft^2$	4.8 ft^2/min

Source: DOE 1998f.

*The unit cost for concrete removal includes actual concrete removal, waste drum changes, and associated costs. It does not include fees for waste disposal since these are specific to ANL and are calculated at the same rate for both technologies. The unit cost also does not include setting up equipment, technician support, PPE, costs associated with productivity loss, or vendor service acquisition costs (for ANL, 9.3 percent of vendor incurred costs). The unit cost has been calculated by summing related costs and dividing them by the area of concrete removal (approximately 620 ft^2).

The cost analysis performed by DOE shows that using the Moose® to decontaminate floor areas greater than 2,100 square feet should result in cost savings over the baseline technology.

3.15.8 Commercial Availability

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Appendix A

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Appendix B

List of Vendors

Exhibit B-1. Vendor Contact Information

Technology	Vendors
TechXtract	Active Environmental Technologies, Inc. 40 High St., Suite 100 Mount Holly, NJ 08060 U.S. Phone: (800) 328-2613 Fax: (609) 702-1521 http://www.active-env.com
Strippable Coatings	1. Stripcoat TLC Free Bartlett Services, Inc. Phone: 800-225-0385 (outside Massachusetts only) Phone: (508) 746-6464 (within Massachusetts) Fax: (508) 830-0997 http://www.numanco.com/ http://www.bartlettinc.com/ 2. ALARA 1146 Williams Power Company One Williams Center Tulsa OK 74172 U.S. Phone: (800) 945-5426 http://www.williams.com NLB Corporation 29830-T Beck Rd. Wixom, MI 48393-2824 U.S. Phone: (800) 441-5059 http://www/nlbcorp.com Nilfisk-Advance America 300 Technology Dr. Malvern, PA 19355 U.S. Phone: (877) 215-8663 http://www.n-aa.com

Technology	Vendors
Centrifugal Shot Blasting	Mike Connacher, Owner Concrete Cleaning, Inc. 5110 N. Ormond Ohs Orchards, WA 99027 U.S. Phone: (509) 226-0315 E-mail: conclsrs@aol.com
Concrete Grinder	CS Unitec 22 Harbor Ave. Norwalk, CT 06850 U.S. Phone: (203) 853-9522 or (800) 700-5919 Fax: (203) 853-9921 E-mail: info@csunitec.com http://www.csunitec.com Andrews Machinery Construction 1757 First Ave. South Seattle, WA 98134 U.S. Phone: (206) 622-1121
Concrete Shaver	The Marcrist Industries Sandall Stones Rd. Kirk Sandall Industrial Estate Doncaster, South Yorkshire DN3 1 QR United Kingdom. Phone: +44 (0) 1302 890 888
Concrete Spaller	Pacific Northwest National Laboratory P.O. Box 999 Richland, WA 99352 U.S. Phone: (509) 372-4069 (Mark Mitchell)
Dry Ice Blasting	CryoGenesis Units N1/N2 Riverside Industrial Estate Little Hampton, West Sussex, BN175DF United Kingdom Phone:+ 44 (0) 1903 731 717 Fax: + 44 (0) 1903 731 933 E-mail: clive_curtis@btconnect.com http://www.cryogenesis.com

Technology	Vendors
Dry Ice Blasting	Cold Jet, LLC 455 Wards Corner Rd. Loveland, Ohio 45140 U.S. Phone: 513-831-3211 Fax: 513-831-1209 Email: info@coldjet.com http://www.coldjet.com
Dry Vacuum Cleaning	EQ Northeast Inc. (Previously Franklin Environmental Services) 185 Industrial Rd. Wrentham, MA 02093 U.S. Phone: 508-384-6151 Email: eqonline.com Pentek, Inc. 1026 Fourth Ave. Coraopolis, PA 15108 U.S. Phone: (412) 262- 0731 Fax: (412) 262-0731 http://www.pentekusa.com Ion Technology, Inc. 46 Whispering Pines Gansevoort, NY 12831 U.S. Phone: (501) 584-0166 Other Contact Information: David L. Schwartz National Energy Technology Laboratory U.S. Phone: (703) 566-0942 E-mail: david.Schwartz@netl.coe.gov
Electro - Hydraulic Scabbling	Textron Defense Systems, Inc. 2385 Revere Beach Parkway Everett, MA 02149 U.S. Phone: (617) 381-4325 Fax: (617) 381-4160

Technology	Vendors
En-vac Robotic Wall Scabbler	MAR-COM, Inc. 8970 N. Bradford St. Portland, OR 97203 U.S. Phone: (503) 285-5871 Fax: (503) 285-5974
Grit Blasting	MAR-COM, Inc. 8970 N. Bradford St. Portland, OR 97203 U.S. Phone: (503) 285-5871 Fax: (503) 285-5974 Progressive Technologies 4201 Patterson SE Grand Rapids, MI 49512 - 4018 U.S. Phone: (800) 968-0871 Phone: (616) 957-0871 Fax: (616) 957-3484 E-mail: ptisales@ptihome.com http://www.ptihome.com Composition Materials Co., Inc. 125 Old Gate Lane Milford, CT 06460 U.S. Phone: (203) 874-6500 Phone: (800) 262-7763 Fax: (203) 874-6505 E-mail: info@compomat.com Burwell Technologies Sydney - Head Office 291 Milperra Rd. Revesby, NSW 2212 Australia Phone: (02) 9792-2733 Fax: (02) 9792-2866 E-mail: mail@burwell.com.au

Technology	Vendors
Grit Blasting	Bartlett Services, Inc. Phone: 800-225-0385 (outside Massachusetts only) Phone: (508) 746-6464 (within Massachusetts) Fax: (508) 830-0997 http://www.numanco.com/ http://www.bartlettinc.com/
High Pressure Water	AccuStream, Inc. 4757 Mustang Circle Mounds View, MN 55112 U.S. Phone: (763) 717-7099 Fax: (763) 717-7097 E-mail: info@accustream.com http://www.accustream.com All Jetting Technologies, Inc. 2740 Martin Downs Blvd., #318 Palm City, FL 34990 U.S. Phone: (772) 286-1218 Fax: (772) 286-8988 E-mail: waterjet@bellsouth.net http://www.alljetting.com Canyon Creek Industries, Inc. P.O.Box 169 Greenbank, WA 98253 U.S. Phone: (800) 870-1859 Fax: (360) 678-0299 http://www.canyon-creek.com E-mail: pat@canyon-creek.com (Pat Groce, Tech. Sale) E-mail: macshearer@hotmail.com (Mac Shearer, President) E-mail: nicole@canyon-creek.com (Nicole Shearer, Marketing) High Pressure Equipment Company 1222 Linden Ave. Erie, PA 16505 U.S. Phone: (800) 289-7447 Fax: (814) 838-6075

Technology	Vendors
High Pressure Water	International Waterjet Parts 1299 A St. Southeast Ephrata, WA 98823 U.S. Phone: (509) 754-3284 Fax: (509) 754-3292 E-mail: iwp@iwpwaterjet.com http://www.iwpwaterjet.com NLB Corporation 29830 Beck Rd. Wixom, MI 48393-2824 U.S. Phone: (810) 624-5555 Fax: (810) 624-0908 Ormond, LLC 1505 Central Ave. South Kent, WA 98032 U.S. Phone: (253) 854-0796 Phone: (253) 852- 1298 E-mail: contact@ormondinc.net http://www.ormondllc.com Pressure Plus P.O.Box 130124 The Woodlands, TX 77393-0124 U.S. Phone: (281) 296-2569 Fax: (281) 367-8129 E-mail: herriford1@aol.com QualJet LLC 12819 SE 38 St. #240 Bellevue, WA 98006 U.S. Phone: (866) QUALJET (782-5538) Fax: (206) 830-9078 E-mail: gary@qualjet.com (Gary Genova) web: www.qualjet.com

Technology	Vendors
High Pressure Water	Richel, Inc. 4485 Crystal Parkway, Suite 100 Kent, OH 44240-8016 U.S. Phone: (330) 677-9100 Fax: (330) 677-9121 E-mail: richel@richel.com (Richard Ward) http://www.richel.com http://www.usedwaterjets.com
Soft Media Blast	Sponge-Jet, Inc. 235 Heritage Ave., Suite 2 Portsmouth, NH 03801 U.S. Phone: (800) 776-6435 (USA only) Phone: (603) 431-6435 Fax: (603) 431-6042 E-mail: sjadmin@spongejet.com Other Contact Information: Martin Prochaska Fluor Daniel Fernald Phone: (513) 648-4089 E-mail: marty.prochaska@fernald.gov
Steam Vacuum Cleaning	Container Products Corporation 112 North College Rd. P.O.Box 3767 Wilmington, NC 28406 U.S. Phone (910) 392 - 6100 Fax: (910) 392-6778 Container Products Corporation 100 Meco Lane Oak Ridge, TN 37830 U.S. E-mail: sales@c-p-c.com

Appendix C

Basic Terms, Types and Units of Radiation

Activity - The quantity of a radioactive nuclide present at a particular time, expressed in terms of the mean rate of nuclear transformations The special name for the SI unit of activity (s^{-1}) is Becquerel (Bq). The conventional unit is the curie (Ci). 1Ci = 3.7 x 10^{10} Bq

Background Radiation - The radiation in man's natural environment, including cosmic rays and radiation (which may vary from location) from the naturally radioactive elements, both outside and inside the bodies of humans and animals. It is also called natural radiation.

Becquerel - The SI unit of radioactivity, defined as the activity of a quantity of radioactive material in which one nucleus decays per second. It has units of s^{-1}.

Coulombs -The amount of electricity transported by a current of one ampere flowing for one second.

Curie (Ci) - The curie is a unit used to measure a radioactivity. One curie is that quantity of a radioactive material that will have 37,000,000,000 transformations in 1 second. Often radioactivity is expressed in smaller units like: thousandths (mCi), millionths (Ci), billionths (nCi), or even million-millionths (pCi) of a curie. The relationship between becquerels and curies is: 3.7 X 10^{10} Bq in 1 curie [or 1 Bq = 27 pCi].

Decay Constant - The fraction of the amount of a radionuclide that undergoes transition per unit time. Lambda (λ) is the symbol for decay constant.

Dose - A general term denoting the quantity of radiation or energy absorbed. For special purposes it should be appropriately qualified. If unqualified, it refers to absorbed dose.

Erg - The unit of energy in the centimeter–gram–second system of physical units, that is, one dyne-centimeter. One erg is equal to 10 -7 joule

Ion - Atomic particle, atom, or chemical radical bearing an electric charge, either negative or positive.

Ionization - The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionization.

Ionizing radiation - Any radiation capable of removing electrons from atoms or molecules, thereby producing ions**.** Examples are alpha and beta particles**.**

Isotope - One of several nuclides having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore, in the mass number. Almost identical chemical properties exist between isotopes of a particular element. The use of this term as a synonym for nuclide is to be discouraged.

Non-ionizing radiation - Non-ionizing radiation is radiation without enough energy to remove tightly bound electrons from their orbits around atoms. Examples are microwaves and visible light.

Radiation - The emission and propagation of energy through space or through material in the form of electromagnetic waves or particles.

Radioactive Decay - The process by which a spontaneous change in nuclear state takes place. This process is accompanied by the emission of energy in various specific combinations of electromagnetic and corpuscular radiation and neutrinos.

Radioactivity - The property of certain nuclides of spontaneously emitting particles or gamma radiation during nuclear transformations.

Rad (radiation absorbed dose) - The conventional unit for absorbed dose of ionizing radiation. One rad is defined as the absorption of 100 ergs per gram (0.01 J/kg) of material. 1 rad - 0.01 Gy. The rad unit can be used for any type of radiation absorbed in any material but does not describe the biological effect on that material.

Rem (roentgen equivalent man) - The rem is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or mrem. To determine equivalent dose (rem), you multiply absorbed dose (rad) by a quality factor (Q) that is unique to the type of incident radiation.

Roentgen - The roentgen is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and X rays, and only in air. One roentgen is equal to depositing 2.58 E-4 coulombs per kg of dry air. It is a measure of the ionizations of the molecules in a mass of air. The main advantage of this unit is that it is easy to measure directly, but it is limited because it is only for deposition in air, and only for gamma and x rays.

Appendix D

Sources of Information

A comprehensive review of available information was performed to identify technologies appropriate for reduction in the level of radioactive contaminants on building surfaces and equipment. The primary sources of information were Internet searches and vendors identified by the searches. Other sources included open literature, databases, direct survey of technology vendors and users, and personal communication with experts in the field. The open literature consisted of government publications such as the *DOE's Decommissioning Handbook*, the DOE's Office of Science and Technology's Innovative Technology Summary Reports (ITSRs), the U.S. Army Corps of Engineers *Decommissioning of Nuclear Facilities Technical Manual*, and trade magazines such as Nuclear News Buyer's Guide. The databases consisted of DOE's Federal Energy Technology Center's Phoenix Decontamination & Decommissioning Technology Module Database, the DOE's Office of Science & Technology's Technology Management System (TMS) database, the EPA Technology Innovation Office's Vendor Information System for Innovative Treatment Technologies (VISITT), and the DOE's Remedial Action Program Information Center (RAPIC) bibliographic database. Vendors were contacted by phone and/or facsimile. Other vendor information was gathered from technical and marketing publications.

An exhaustive Internet search was conducted using the common commercially available search engines such as Google, Copernic, etc., with a special focus on science and engineering related sites and tools such as SCIRUS, a specialized science based search engine (http://www.scirus.com/srsapp/); SITEATLAS (http://www.sitesatlas.com and focusing on specific subdirectories such as "Science: Technology: Energy: Nuclear"); the Thomas Register (http://www.thomasregister.com/); the Techknow database (http://www.techknow.org/) ; the Gateway to Environmental Technology database (http://www.dandd.org/default.aspx); and the Army Technology database (http://www.army-technology.com/contractors/index.html). In addition a set of decontamination related Internet sites was used, including the Decontamination and Decommissioning Focus Area Home Page, the DOE Large Scale Demonstration Project (LSDP) pages, the EPA Office of Superfund Remediation and Technology Innovation's Cleanup Information (CLU-IN) page and Superfund Innovative Technology Evaluation (SITE) Program page, and a variety of vendor and trade pages pertaining to particular technologies.

Appendix E

Suitability of Surface Decontamination Technologies for Use in an Urban Environment

Though this Guide is primarily designed for Superfund site managers, Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), and their contractors, the technologies obviously have wider application. An area of significant current concern is the technology base that would be available to respond to widespread radioactive contamination in an urban environment. The following table provides an assessment of the suitability of technologies considered in the Guide for use in addressing the consequences of such an event. The assessment is, of necessity, a general summary since there are many factors, such as the specific radionuclides that would be present in such an event, that could affect the choice of technology. The table is offered as a quick and ready assessment and can not address all factors and issues that would need to be considered in such a situation.

Exhibit E-1. Technology Suitability Assessment

Technology	Suitable	Notes
Chelation and Organic Acids	Yes	Can be tailored to wide range of contaminants. Safer than other chemical techniques.
Strong Mineral Acids	Possible	Likely to be too aggressive; major safety concerns; however, effective and readily available.
Chemical Foams and Gels	Yes	Long dwell time for vertical surfaces
Oxidizing and Reducing (REDOX) Agents	No	Suitable REDOX chemistry is essential so unlikely to be useful in emergency
TechXtract	Possible	The technology is best used in batch operations or on small areas
Strippable Coatings	Yes	Expense may be a problem
Centrifugal Shot Blasting	Yes	Wide availability of similar technologies from numerous industrial applications
Concrete Grinder	Yes	Wide availability of similar technologies from numerous industrial applications
Concrete Shaver	No	The technology is designed for floors
Concrete Spaller	No	The technology is slower best used for removal of comparatively large depths
Dry Ice Blasting	Possible	Wide availability of similar technologies from numerous industrial applications, but good enclosures needed.

Technology	Suitable	Notes
Dry Vacuum Cleaning	Yes	Wide availability of similar technologies from numerous industrial applications
Electro- Hydraulic Scabbling	No	The technology is designed for operation with a layer of water
En-vac Robotic Wall Scabbler	No	The technology is designed for unimpeded walls and requires well positioned support
Grit Blasting	Yes	Wide availability of similar technologies from numerous industrial applications
High Pressure Water	Yes	Wide availability of similar technologies from numerous industrial applications
Soft Media Blast Cleaning	Yes	Wide availability of similar technologies from numerous industrial applications
Steam Vacuum Cleaning	Yes	Wide availability of similar technologies from numerous industrial applications
Piston Scabbler	Yes	The technology is primarily aimed at horizontal surfaces

Appendix F

Emerging Decontamination Technologies

Many phenomena have been and continue to be examined for use as decontamination technologies. The following capsule summaries are presented on some of the more promising technologies. At the time of writing this Guide these technologies are not mature enough to be considered available, but are presented here as an indication of the type of progress that is being achieved and as a source for further investigation of potentially available options.

Bio-Decontamination

Certain types of bacteria, such as the sulfur oxiding bacteria Thiobacillus Thioxidans, are known to promote the microbially influenced degradation (MID) of concrete. These bacteria are naturally occurring, widespread, and harmless to humans. They adhere to surfaces through the production of natural binding agents, and hen provided with a supply of sulfur and nutrients they produce sulfuric acid which is able to dissolve concrete. They have been examined since they offer an inexpensive path to large-scale decontamination. Among the advantages they offer are:

- Depth of removal of surface can be controlled,
- "Hands-off" approach so worker exposure should be reduced, chance of accidents should be reduced and safety should be improved,
- Inexpensive, and
- Elimination of airborne contamination.

Disadvantages include:

- Long time period to effect the decontamination,
- Constant monitoring of the slow process, and
- Bacterial growth may be inhibited by certain surface components and this effect may not become known until considerable time has elapsed.

Electrokinetic Decontamination

In the electrokinetic decontamination of concrete, the concrete is soaked with solution containing electrolytes for conductivity and specific solubilizing agents (e.g. chelating agents or carbonate for uranium removal) and an electrical potential is established between the concrete (through simple insertion of a metal electrode) and an absorbent pad. The electrical potential is then used to drive the solubilized contaminants into the pad where they are captured and removed. The technology offers great reductions in the amounts of secondary waste generated.

Microwave Scabbling

Microwave scabbling of concrete uses microwave energy directed at the concrete surface to heat the concrete and water (naturally present or added specifically for the application of the technology) present in the concrete. The heating can rapidly produce steam and pressure-induced mechanical stresses result causing the concrete surface to break.

Laser, Light or Photon Ablation

Light ablation, including high energy flashlamps, uses the absorption of light energy and its conversion to heat to selectively remove surface coatings and with them contaminants. The technology is primarily targeted at painted or coated surfaces. The contaminated surface coating is heated very rapidly by the laser or flash-lamp, vaporizing the surface layers and quickly removing them. Chemical reactions pyrolize organics while metal and mineral contaminants are contained in a residual ash. In comparison, laser ablation uses the laser pulse to create a plasma on the surface that "scours" and ejects the material; the main difference is that vaporization uses millisecond pulse width, while good ablation occurs at nanosecond (at least below microsecond) pulse widths. Innovations in this area include the use of fiber optics and tunable lasers that can target specific contaminants.

Appendix G

Treatment Defined by NCP

The concept of treatment is discussed in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) under §300.5, as follows:

> "Treatment technology" means any unit operation or series of unit operations that alters the composition of a hazardous substance or pollutant or contaminant through chemical, biological, or physical means so as to reduce toxicity, mobility, or volume of the contaminated materials being treated. Treatment technologies are an alternative to land disposal of hazardous wastes without treatment.

The NCP further states that

> "EPA expects to use treatment to address the principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials. " (See § 300.430 (a)(iii) (A))

The preamble to the NCP provides further clarification of treatment:

> "This goal [treatment expectation] reflects CERCLA's preference for achieving protection through the use of treatment technologies that destroy or reduce the inherent hazards posed by wastes and result in remedies that are highly reliable over time. The purpose of treatment in the Superfund program is to significantly reduce the toxicity and/or mobility of the contaminants posing a significant threat (i.e., "contaminants of concern") wherever practicable to reduce the need for long-term management of hazardous material. EPA will seek to reduce hazards (i.e., toxicity and/or mobility) to levels that ensure that contaminated material remaining on-site can be reliably controlled over time through engineering and/or institutional controls.
>
> Further, the Superfund program also uses as a guideline for effective treatment the range of 90 to 99 percent reduction in the concentration or mobility of contaminants of concern (see preamble discussion below on "reduction of toxicity, mobility or volume" under § 300.430(e)(9)). Although it is most important that treatment technologies achieve the remediation goals developed specifically for each site (which may be greater or less than the treatment guidelines), EPA believes that, in general, treatment technologies or treatment trains that cannot achieve this level of performance on a consistent basis are not sufficiently effective and generally will not be appropriate. [See 55 FR 8701]

Appendix H

Chemical Abstract Service Registry Number (CASRN) For Chemicals Cited

Chemical	CASRN
Aluminum	7429-90-5
Ammonium Bifluoride	12125-01-8
Ammonium Citrate	3012-65-5
Ammonium Oxalate	10028-22-5
Barium Sulfate	7727-43-7
Bis-Cyclohexanone Oxaldihydrazone (Cuprizone)	370-81-0
Calcium Carbonate	471-34-1
Calcium Hypochlorite	7778-54-3
Calcium Sulfate	7778-18-9
Carbon Dioxide	124-38-9
Chromium Oxalate	3444-31-3
Chromotropic Acid	5808-22-0
Citric Acid	77-92-9
Diethylenetriaminepentaacetic Acid (DTPA)	67-43-6
Ethylenediaminedisuccinic Acid (EDDS)	20846-91-7
Ethylenediaminetetraacetic Acid (EDTA)	60-00-4
Ferrous Oxalate	6047-25-2
Ferrous Oxide (FeO)	1345-25-1
Fluoroboric Acid	16872-11-0
Gluconic Acid	526-95-4
Hematite (Fe_2O_3)	1317-61-9
Hydrazine	302-01-2
Hydrochloric Acid	7647-01-0
Hydrofluoric Acid	7664-39-3
Hydrogen Peroxide	7722-84-1

Chemical	CASRN
Hydroxyethylenediaminetriacetic Acid (HEDTA)	150-39-0
Iron	7439-89-6
Iron Oxalate	7782-63-0
Lead	7439-92-1
Manganese Dioxide	1313-13-9
Magnesium Hydroxide	1309-42-8
Magnetite (Fe_3O_4)	1309-37-1
Nitric Acid	7697-37-2
Oxalic Acid	6153-56-6
Oxyethylidenediphosphonic Acid (OEDPA)	2809-21-4
Ozone	10028-15-6
Phosphoric Acid	7664-38-2
Picolinic Acid	98-98-6
Plutonium Dioxide	12059-95-9
Potassium Permanganate	7722-64-7
Silica (Silicon Dioxide)	14808-60-7
Sodium Bisulfate	7681-38-1
Sodium Fluoride	1333-83-1
Sodium Hypochlorite	7681-59-2
Sodium Hypophosphate	13721-43-2
Sodium Phosphate	7558-79-4
Sodium Polyphosphate	50813-16-6
Sodium Sulfate	7757-82-6
Sodium Triphosphate	7758-29-4
Strontium Sulfate	7759-02-6
Sulfuric Acid	7664-93-9
Sulfamic Acid	5329-14-6
Tritium	10028-17-8

Chemical	CASRN
Uranium Dioxide	1344-57-6
Zinc Phosphate	7779-90-0