

## DECONTAMINATION TECHNOLOGIES FOR FACILITY REUSE

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### ABSTRACT

As nuclear research and production facilities across the U.S. Department of Energy (DOE) nuclear weapons complex are slated for deactivation and decommissioning (D&D), there is a need to decontaminate some facilities for reuse for another mission or continued use for the same mission. Improved technologies available in the commercial sector and tested by the DOE can help solve the DOE's decontamination problems. Decontamination technologies include mechanical methods, such as shaving, scabbling, and blasting; application of chemicals; biological methods; and electrochemical techniques. Materials to be decontaminated are primarily concrete or metal. Concrete materials include walls, floors, ceilings, bio-shields, and fuel pools. Metallic materials include structural steel, valves, pipes, gloveboxes, reactors, and other equipment. Porous materials such as concrete can be contaminated throughout their structure, although contamination in concrete normally resides in the top quarter-inch below the surface. Metals are normally only contaminated on the surface. Contamination includes a variety of alpha, beta, and gamma-emitting radionuclides and can sometimes include heavy metals and organic contamination regulated by the Resource Conservation and Recovery Act (RCRA). This paper describes several advanced mechanical, chemical, and other methods to decontaminate structures, equipment, and materials.

### INTRODUCTION

Decontamination of structures, equipment, and materials costs money, takes time, and potentially exposes workers to radiological and chemical doses and industrial safety hazards. Therefore, a D&D project manager makes the decision to decontaminate structures, equipment, and materials only in situations where it provides greater benefit to the project than the time, cost, and health and safety concerns associated with the decontamination activity. There are several situations where decontamination can benefit the project. These include:

- Reduction in the amount of waste that is expensive to dispose (e.g., decontaminate materials classified as transuranic (TRU) waste to increase the volumetric proportion of low level waste (LLW) to TRU waste or convert mixed waste to LLW)

- Improvement in the safety and health conditions for workers in the area by reducing contamination
- Removal of loose contamination to prevent release and spread to the surrounding areas
- Reuse of equipment and facilities
- Meet transportation requirements to ship equipment and site license requirements to accept equipment
- Convert nuclear, RCRA, and/or mixed waste to sanitary waste

The reason for decontamination will often dictate the type of decontamination technology to be applied to the contaminated area. Table I lists some of the current state-of-the-art decontamination technologies.

Table I. Decontamination Technologies

<b>Technology Name</b>	<b>Vendor</b>	<b>Principle of Operation</b>
<i>Mechanical Decontamination Methods</i>		
<b>Integrated Vertical and Overhead Decontamination System</b>	FIU-HCET	Diamond concrete shaving unit attached to robot for floor, wall and ceiling decontamination
<b>2-D Linear Motion System (Wall Walker)</b>	Pentek, Inc.	Suitable for high, flat walls of concrete or sheet metal
<b>Concrete Shaver</b>	Marcrist Industries, Limited	Self-propelled, electric powered, diamond shaving machine used for concrete and coating removal
<b>En Vac Robotic Wall Scabbler</b>	MAR-COM, Inc.	Robotic abrasive steel grit blasting for wall decontamination
<b>MOOSE Remotely Operated Scabbler</b>	Pentek, Inc.	Remote-operated reciprocating scabbling pistons
<b>ROTO PEEN Scaler and Vac Pac System</b>	Pentek, Inc.	Hand-held milling technology
<b>Advanced Recyclable Media System</b>	Surface Technology Systems, Inc.	Open blast technology which uses a soft recyclable media consisting of a urethane foam matrix
<b>Soft Media Blast Cleaning</b>	AEA Technology Engineering Service, Inc.	Sponge blasting
<b>Centrifugal Shot Blasting</b>	Concrete Cleaning, Inc.	Abrasive blasting with steel shot
<i>Chemical Decontamination Methods</i>		
<b>CORPEX Nuclear Decontamination Process</b>	Corpex Technologies, Inc.	Nondestructive chemical cleaning method
<b>TechXtract</b>	Active Environmental Technologies	Nondestructive process for the extraction of PCBs, radionuclides, heavy metals, pesticides, and hazardous hydrocarbons from solid media
<b>Three-Phase Decontamination Process</b>	EAI	Three spray applications of proprietary chemical to dissolve contamination
<b>Electrochemical Decontamination</b>	Variety	Chemical decontamination assisted by electrical field
<i>Biological Decontamination Methods</i>		
<b>Biodegradation of Concrete</b>	BBWI	Microbiological process to be used for the decontamination of large concrete surfaces

<b>Biotechnology for the Decontamination of Surfaces Coated with Paint and Varnish</b>	Daymos, Ltd.	Naturally occurring microbes break down coatings
<i>Separation, Decontamination, and Recycle of Metals</i>		
<b>Mobile Integrated Piping Decontamination and Characterization System</b>	FIU-HCET	Field-mobile system for the decontamination and characterization of large-bore pipe of varying geometry
<b>Copper Cable Recycling</b>	NUKEM Nuclear Technologies	Shreds and grinds contaminated electric cable into small particles; separates copper from insulation by air classification

## MECHANICAL DECONTAMINATION METHODS

### Integrated Vertical and Overhead Decontamination System (IVODS)

The Integrated Vertical and Overhead Decontamination System (IVODS) is a robotic system designed by Redzone Robotics that acts as a transport and positioning device for a Marcris wall-shaving unit. The positioning device consists of two feet that provide a vacuum attachment to a wall or ceiling. Each foot is able to support the total weight of the device, allowing it to walk over a smooth surface moving one foot at a time. A safety harness is attached to the equipment to keep it suspended in case of a vacuum failure.

The wall shaver provides high production shaving with its 100 interlocking diamond blades. The system consists of an electric hydraulic power unit, shaver control panel, and shaver mast attached to the tool carrier. The mast is 2.2 meters long with three sprung feet from which the shaver head is deployed by a hydraulic cylinder. Travel per pass is approximately 1800 mm. The shaver head is 300 mm wide and is designed for optimal removal depths of 1 to 10 mm per pass. Accuracy to within 0.1 mm shaving depth is achieved through depth removal control device.

The IVODS also has an online measuring system integrated into it. This will allow the operator to determine if sufficient material is being removed. The online measuring system consists of two large gas proportional detectors, onboard electronics, a computer display, and a computer data recording system (1).

### Wall Walker 2-D Linear Motion System

The Wall Walker 2-D Linear Motion System is a remote operating system that can control and maneuver tools and instruments precisely over large vertical surfaces. The system consists of motorized pulleys with cables hooked to a holder for tools and instruments. The motor-driven pulleys can be attached to the wall temporarily with magnetic force on steel walls, or with anchors or vacuum force on concrete walls. The system is controlled at a remote station by a programmable controller. For locations with no ceiling obstruction, the pulleys can be attached to standoffs above the wall, thereby allowing the end effector to reach the full height of the wall. Otherwise, up to 1.8 vertical meters at the top of the wall cannot be reached. Similarly, if there are no sidewall

restrictions, the standoffs can be positioned to allow reaching the full wall width instead of missing 0.3 to 0.6 meters at the sides. The pulley assemblies weigh 22 kilograms. The system has sufficient payload capacity to remotely operate D&D and survey tools up to at least 136 kilograms. The holder can be retrofitted to operate a variety of survey or decontamination tools.

The Wall Walker 2-D Linear Motion System provides accurate and consistent scanning conditions for surveys (i.e., instruments can be accurately positioned and the scanning speed can be easily controlled). The system has proven easy to maneuver and to learn to use. The Wall Walker is compatible with a variety of software that can be adapted to provide survey data and/or automated mapping of measured radiation levels (such as the Laser-Assisted Ranging and Data System [LARADS]) (2).

### **Concrete Shaver**

The Marcris Industries Limited concrete shaver is a self-propelled, electric-powered, concrete diamond-shaving machine that can remove concrete surfaces with extremely accurate tolerances. This unit has a 25-centimeter-wide shaving drum that is suitable for flat or slightly curved floors and a vacuum port for dust extraction. For decontamination and decommissioning (D&D) projects, the shaver can be used for decontamination of large areas or hot spots on floors. The unit weight is 150 kilograms, and the cutting depth may vary from 0 to 1.3 centimeters. The shaver can operate within 7.5 centimeters from a wall/floor interface or other obstruction (3). Figure 1 shows the concrete shaver in use to decontaminate a wall.



Fig. 1. Concrete shaver decontaminating wall surface.

### **En-Vac Robotic Wall Scabber**

The En-Vac Robotic Wall Scabber is an abrasive blasting technology consisting of the En-Vac robot, a recycling unit, a filter, and a vacuum unit. The System uses abrasive

steel grit or steel shot as the surface removal media and can scabble, via the robot, on both horizontal and vertical surfaces. 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 robot adheres to working surface by vacuum contained in the sealed blasting chamber. The vacuum unit creates the vacuum to prevent any fugitive dust or grit emissions from the working surface of the blasting operation. The recycling unit continuously provides abrasive grit to the robot through the blast hose. Spent blast grit and blast residue are returned from the robot to the recycling unit through the vacuum hose. The recycling unit processes the spent abrasives and separates the blast residue. Blast residues are collected and stored for later disposal (4).

### **Remotely Operated Scabblers**

Pentek's remotely-operated Moose® is designed to scarify large concrete floors and slabs in environments which require stringent control of airborne contamination and debris. Three integral sub-systems comprise the Moose® scabblers: the scabbling head assembly, the on-board HEPA vacuum system, and the six-wheeled chassis. The scabbling head houses seven independent reciprocating tungsten carbide-tipped bits with the pistons being driven by compressed air. 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 allowing the Moose® to pirouette 360-degrees about its geometric center, resulting in a 29-inch turning radius. It is capable of scabbling to within approximately 6 inches of walls and other obstructions. The Moose® is operated by a control panel connected by a tether and can be located from 50-ft to 300-ft away from the scabblers (5).

### **ROTO PEEN Scaler and Vac Pac System**

The Pentek ROTO PEEN Scaler is a hand-held tool marketed to remove coatings from concrete, steel, brick, and wood. Manufactured of solid cast alloy, the ROTO PEEN Scaler is rugged, and its lightness makes it highly portable and easy to maneuver. It is designed to treat vertical and horizontal surfaces such as beams, girders, tank shells, and areas near walls and in confined spaces. Interchangeable cutting media are available for various applications. The operator can select from a variety of 3M™ Heavy-Duty ROTO PEEN Flaps for the removal of coatings, tight mill scale, or concrete scarification (6).

### **Advanced Recyclable Media System**

The Advanced Recyclable Media System (ARMS™) soft recyclable media system removes and absorbs low-level radioactive surface contaminants, oil, scales, greases, PCBs, paint, soot, lead, graphite, rust, and asbestos from metals, concrete, wood, and graphite. The blast media consists of a urethane foam-based matrix, which is manufactured in various grades of abrasiveness. The most aggressive media would be made of fiber and steel grit or aluminum oxide. These can remove up to 2-3 millimeters of paint, rust, or scale. The fiber media can be remade and reused twenty times, and typical decontamination factors are in the range of 300 for a single pass. The ARMS™ is

an open blast system, which is routinely used in a glovebox or contained area, and can clean almost any surface geometry including corners and the inside of air ducts.

The ARMS™ is divided into three units: the media feed unit, the sifter unit, and the media remake unit. The media is propelled from the feed unit toward the surface to be cleaned by a portable blast unit. The used media is then manually collected and placed into the sifter unit. Large debris (greater than 1/4-inch) and small fines (less than 1/16-inch) are discarded as waste, and the remaining media can be used for media remake or can be fed back into the feed unit for recycling (7).

### **Soft Media Blast Cleaning**

The Soft Media Blast Cleaning system relies on a pneumatically driven pump to propel soft blast media at a surface requiring decontamination. The portable pneumatic pump sends the media-laden air stream through a hose and nozzle system. There are also two additional stand-alone units that can be used in conjunction with the pump, hose, and nozzle: the Classifier Unit, which is used to separate the larger intact media from the finer pieces of disintegrated media, and the Blast Media Wash Unit, which washes the media so that it can be recycled.

The overall purpose in using the Soft Media Blast Cleaning system is to remove surface contaminants through the abrasive action of the soft blast media striking the contaminated surface. The media not only loosens and removes the contaminants, but also captures the contaminants in the media matrix and breaks apart after repeated use. The final result is a decontaminated surface and a waste composed of contaminants and soft blast media. The soft media can be recycled until it has broken apart sufficiently to be separated by the Classifier Unit (8).

### **Centrifugal Shot Blasting**

The Centrifugal Shot Blasting machine works by propelling hardened steel shot at high velocities (approximately 220 feet per second) onto concrete floor surfaces. The impact of the shot causes the concrete to fracture into small pieces, which are then captured by an integrated vacuum dust collection system. The majority of the steel shot rebounds back up into the machine where it is reused. Shot that is left on the floor is picked up by a large portable magnet and recycled back into the machine. The shot is continually reused until it is essentially reduced to the size of dust and is conveyed off in the dust collection system. Figure 2 shows a schematic of the Centrifugal Shot Blasting machine. The Centrifugal Shot Blasting machine cuts a 20-inch swath, approximately 1/8-inch to 3/8-inch-deep per pass, depending on the hardness of the concrete and speed at which the Centrifugal Shot Blasting machine travels over the area being scabbled.

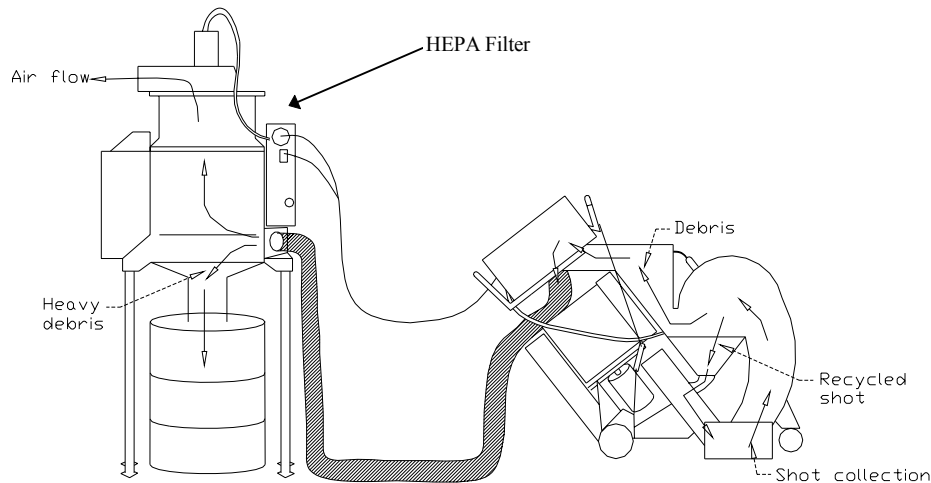


Fig. 2. Schematic of the Centrifugal Shot Blasting system.

The rotary drum planer contains a drum that is embedded with 62 replaceable tungsten-carbide teeth. The planer cuts a 16-inch wide swath up to 6 inches deep providing there is not wire or re-bar present in the concrete. The rotary drum planer technology has been widely used for the removal of concrete in highways and parking lots by the construction industry for many years.

Florida International University has integrated radiation sensors onto a commercial centrifugal shot blast machine and other mechanical decontamination equipment. By placing radiation sensors at the front and rear of these machines, operators can adjust the speed and depth of removal based on near real-time radiation measurements. The operator receives feedback on the amount of contamination that the machine is approaching and the amount of residual contamination remaining after the machine removes the surface. Feedback from the radiation sensors allows the operators to remove the optimal amount of surface per pass, thus minimizing the number of passes and reducing the quantity of radioactive waste. This approach will result in significant time savings compared to the baseline approach of sequential and multiple decontamination and survey operations (9)

## CHEMICAL DECONTAMINATION METHODS

### TechXtract

TechXtract® is a sequential chemical extraction process for the removal of radionuclides, PCBs, and other hazardous organic and inorganic substances from materials such as lead,

concrete, construction bricks, and steel. The technology uses chemical formulations and engineered applications to penetrate the materials and remove the contaminants from below the surface. The chemistry is based on hypotheses regarding contaminant migration and removal. For example, contaminants migrate into the pores and microscopic voids of a material, even for seemingly non-porous media. The mobility of the contaminants, time, and electrostatic forces often drive these contaminants deeper in the substrate. Furthermore, the contaminants tend to become chemically or electrostatically bonded to the substrate. In many cases, the time between the contamination event and decontamination efforts allows the contaminant migration pathways to become partially closed.

The chemical extraction is designed to:

- Reopen the pores and capillary pathways to the maximum possible extent
- Penetrate into the pores as deeply as possible
- Break the physical and chemical bonds that may be holding the contaminants in place
- Bind or sequester the contaminants in the chemical solutions to prevent recontamination.

The chemical solutions address each of these complex needs, using components that incorporate dissolution, oxidation, reduction, hydrolysis, wetting, complexation, microencapsulation, and flotation chemistry principles. The solution also compensates for situations in which the contamination is a mixture of pure elements, oxides, and related compounds with varying solubility indices. The spent chemical solutions do not contain any hazardous constituents (except for the extracted contaminants) and have been disposed of by incineration, solidification (and land disposal), and discharge to liquid effluent treatment systems.

The process is a sequence for applying and removing each of the chemicals. Chemicals can be applied in low volumes as a spray or dip to minimize the amount used and the volume of waste produced. The chemicals are scrubbed into the contaminated surfaces with ultrasonics for a defined time, and then rinsed and removed with vacuum. The application and removal of all solutions is one cycle of the process. Sampling and/or radiation surveys can be performed at the end of any step in the cycle, and they will often show reductions of 90% or more per step (10).

### **Three Phase Decontamination Process**

The technology is a tailored process for applying and removing chemicals in the right sequence and combinations to achieve optimal results. In most projects, three different chemical formulas are used. Chemicals are applied in low volumes, usually as a spray, to minimize consumption and secondary waste volume. After being applied, the chemicals are scrubbed into the contaminated surfaces, left to dwell for a defined time, and rinsed and removed. The application and removal of all three formulas constitutes one cycle of the process, and typically requires one day (24 hours). Sampling and/or surveys can be performed at the end of any cycle, and often shows reduction of 90% or more per cycle.



Normally, the number of cycles required can be accurately predicted, thereby reducing the need for intermediate sampling. Many projects can expect contaminant reduction rates in excess of 90% per cycle, and as high as 99% in some cases (11).

### **Electrochemical Decontamination of Gloveboxes**

The electrochemical decontamination system for gloveboxes, developed by Los Alamos National Laboratory, functions as an electrolytic cell where the glovebox surface is the anode, and a movable fixture attached to the glovebox surface is the cathode. Electrolyte flows between the glovebox surface and the fixture head. As current is applied between the fixture head and the glovebox wall, the metal surface, including radioactive contaminants, dissolves and is carried away with the electrolyte. The contaminants are removed from the electrolyte in a recycle treatment system and recycled to the fixture head. The filtered solids are easily recovered from the system, and may be moved out of the glovebox for additional processing. The electrochemical decontamination system has achieved an average decontamination factor (original activity/final activity) of 100 (12).

## **BIOLOGICAL DECONTAMINATION METHODS**

### **Biodegradation of Concrete**

Biodegradation of Concrete is a technology developed by British Nuclear Fuels, PLC (BNFL) and the Idaho National Engineering and Environmental Laboratory (INEEL) that utilizes this naturally occurring phenomenon for removing surface material of radionuclide contaminated concrete. The technology can be described in three stages: application of microbes and nutrients; maintenance of microbial activity; and removal and packaging of surface material for waste disposal. The process is a passive one that essentially leaves the bacteria to actively degrade the cement matrix until the concrete surface material is loosened for easy removal to a desired depth. Figure 3 shows loosened surface material on concrete.



Fig. 3. Loosened surface material on concrete. Inset: Microscopic image of degraded surface material.

The process requires 6-18 months for completion, depending on the depth and extent of contamination. Application of the bacteria and nutrients can be conducted in a fraction of the time required to physically remove concrete surface material. The maintenance phase, which essentially consists of environmental control, requires only minimum attention, primarily to monitor progress. Removal of the degraded surface material again results in reduced labor due to the ease of removal of the already loosened material. In addition, the depth of removal can be controlled such that the waste volume is greatly reduced. These reductions in labor requirements inherently result in lower costs and potential exposure risks to personnel. All phases can be conducted remotely if necessitated by high radiation fields (13).

### **Biotechnology for the Decontamination of Surfaces Coated with Paint and Varnish**

Daymos, Ltd., of Russia, is developing Biotechnology for the Decontamination of Surfaces Coated with Paint and Varnish. Surface paint and varnish coatings are subjected to degradation over time because of spontaneous destruction via microbial processes. Microorganisms (microbes, bacteria, fungi, yeast) cause destruction of coatings as a result of their vital activities, which loosens radioactively contaminated surface layers and turns them into porous structures that can then be easily removed using mechanical decontamination methods.

Destruction of paint and varnish coatings on metal, concrete, and other materials is accompanied by utilization of certain coating components as nutrition sources. Destructors also can use organic coating pollutants as nutrients. Among the fungal metabolites, enzymes and some organic acids are the most efficient at destruction of paint and varnish coatings (14).

## **SEPARATION, DECONTAMINATION, AND RECYCLE OF METALS**

### **Mobile Integrated Piping Decontamination and Characterization System**

The Mobile Integrated Piping Decontamination and Characterization (MIP-DC) system consists of four modules based on functionality. They are the decontamination module, the ventilation module, the characterization module, and the off-loading module. The system also includes a conveyor belt to carry the pipes through the different modules.

The decontamination module holds the grit-blasting unit, which is capable of cleaning the pipes both internally and externally. The contaminated pipes are fed into the MIP-DC system through this module. For blasting the external surface of the pipe, the centrifugal force provided by four 15-horsepower gear-driven motors is used. The mechanism for the internal blasting of the pipe includes a pipe rotation mechanism and a blast lance. The pipe and the pipe rotation mechanism can be lifted into an inclined position by a hydraulic pump. The rotation mechanism includes three pairs of tires capable of closing on a pipe of any diameter in the range 6 to 24 inches. A 0.5-horsepower motor powers the grit releasing blast lance, which is used for cleaning the internal surface of the pipe.

The ventilation module removes the contaminated air (dust and airborne particles) from the decontamination module through a hose and discharges it as clean air to the atmosphere. It consists of a dust collector and HEPA filters. The module directs the collected waste and used steel grit into a waste collection drum.

The characterization module consists of 4 gamma detectors. These detectors are capable of detecting free release levels of reactor contaminants, such as Cs-137, Co-60, U-238, Th-228, etc., on both the internal and external surfaces of the pipes. The pipes are characterized in this module after decontamination.

The offloading module segregates the characterized pipes into clean and contaminated sides. A sensor in the characterization module indicates to the offloading module if the pipe is contaminated or clean. Accordingly, the offloading module will segregate the pipes. Each of these modules is enclosed in strong tight containers and loaded on trailers for transportation (15).

### **Copper Cable Recycling**

Copper Cable Recycling technology was developed in Stuttgart, Germany, by RADOS, who licenses the technology to NUKEM Nuclear Technologies in the United States. RADOS has used this technology in Europe to successfully recover many tons of contaminated wire for free release and reuse. The Copper Cable Recycling system will process a wide variety of contaminated cables regardless of cable type or size. The cables are pre-sized, placed on a conveyor, and fed into a pre-shredder where the cables are shredded into small pieces that can be more efficiently processed by the grinder. During the grinding process, the copper is separated from the insulation. The processed cable is separated into a clean copper, slightly contaminated insulation, and contaminated dust. Figure 4 shows clean copper ready for reuse. Contaminated dust generated by the grinding process is filtered through several stages of filtration to prevent the release of airborne contamination. The Copper Cable Recycling process is operated under a negative pressure from the time the wire enters the pre-shredder until it exits the separator. The exhaust air is filtered through a HEPA ventilation system (16).



Fig. 4. Clean copper ready for reuse.

## SUMMARY

This paper illustrates that the D&D project manager has a suite of advanced technologies in the D&D toolbox to decontaminate structures, equipment, and materials when decontamination will provide benefit to the project. These technologies use mechanical, chemical, electrochemical, and other methods to remove the contamination. These technologies have been evaluated in demonstrations and deployments at various DOE sites and found to have improvements compared to baseline approaches for decontamination.

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