INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0416

Steam Vacuum Cleaning

Deactivation and Decommissioning Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Steam Vacuum Cleaning

OST Reference #1780

Deactivation and Decommissioning
Focus Area

Demonstrated at
Fernald Environmental Management Project – Building 1A
Fernald, Ohio

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Introduction

The United States Department of Energy (DOE) continually seeks safer and more cost-effective remediation technologies for use in the decontamination and decommissioning (D&D) of nuclear facilities. To this end, the DOE sponsors Large-Scale Technology Demonstrations (LSTD) where developers and vendors of improved or innovative technologies showcase products that are potentially beneficial to DOE's D&D projects, and to others in the D&D community.

The D&D Implementation Plan of the DOE's Fernald Environmental Management Project (FEMP) requires that debris and segmented process components be washed before placement in the FEMP's on-site disposal facility (OSDF). Debris is considered appropriate for placement in the OSDF if, on visual inspection, they satisfy the following criteria:

> *''.... surfaces shall be free of visible process material as determined by a FERMCO representative. The definition of visible process material is: Visible process residues (green salt, yellow cake, etc.) on the interior or exterior surfaces of materials that is obvious to the eye, and when rubbed, would be easily removed. Stains, rust, corrosion, and flaking do not qualify as visible process material.".*

Measurement of residual activity or other quantifiable parameters is not required.

The baseline technology currently used for washing debris is a high-pressure water cleaning (HPWC) system. The system used at the FEMP is the Hotsy®[1] Model 550B HPWC shown in Figure 1. Although the HPWC technology has functioned satisfactorily, improvements are being sought in areas related to reduced liquid waste volume, increased productivity, increased washing effectiveness, and decreased airborne contamination. An innovative technology that offers potential improvements in these areas is a steam vacuum cleaning (SVC) system that integrates high-pressure steam cleaning with a vacuum recovery sub-system that simultaneously collects dislodged contaminants thereby reducing airborne contamination. The SVC system selected for demonstration at the FEMP was the Kelly™ [2] Decontamination System shown in Figure 2.

This report provides comparative performance and cost analyses between the Hotsy HPWC system and the Kelly Decontamination System. Both technologies were demonstrated at the FEMP site located at Fernald, Ohio from July 29, 1996 through August 15, 1996. The demonstrations were conducted at the FEMP Plant 1 as part of the LSTD project sponsored by the Deactivation and Decommissioning Focus Area (DDFA) of the U.S. DOE's Office of Science and Technology.

At the very outset, it should be noted that the Kelly Decontamination System was designed for thorough cleaning and decontamination of large general areas in nuclear facilities. In the FEMP demonstration, the steam/vacuum cleaning tools functioned best on large smooth surfaces, but could not easily negotiate and clean irregularly shaped objects. Such objects make up a large proportion of the debris removed from Plant 1. In addition, the thorough cleaning performed by the Kelly system required more time and effort than the baseline HPWC system, and the debris was cleaned well beyond the washing and visual inspection criteria described above. While the demonstration concluded that the Kelly system is not cost effective for washing debris at the FEMP, it should nonetheless perform well when utilized for the purpose for which it was designed – i.e. thorough cleaning and decontamination of large areas. The cost and production data on the Kelly Decontamination System that are presented in this report should, therefore, prove useful to D&D Managers who are considering using an SVC for the decontamination of large general areas.

[1] **Hotsy**® is a registered trademark of the Hotsy Corporation of Englewood, Colorado.

[2] **Kelly**™ is a trademark of Container Products Corporation of Wilmington, North Carolina.

Technology Description

Baseline Technology

The Hotsy Model 550B HPWC system uses the kinetic energy of a stream of pressurized heated water to dislodge contaminants from the surfaces of debris. A detergent may be added to the pressurized water stream to improve washing effectiveness. The stream is delivered to the debris via a hand-held spray wand. Plastic lining and dikes around the work area collect the contaminated liquid waste stream that splashes or runs off the debris. During the demonstration, the system was operated without the addition of a detergent and without heating the water.

Figure 1: Photo A shows the Hotsy Model 550B HPWC System. Photo B shows a worker using the Hotsy spray wand to wash a pallet of D&D debris.

Innovative Technology

The Kelly Decontamination system also uses the kinetic energy of superheated pressurized water to dislodge surface contaminants from the debris. The superheated water is delivered to the debris 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 (see Appendix D). The superheated water stream flashes to steam when it impacts the surface of the debris. The hood of the steam/vacuum cleaning head traps and collects dislodged contaminants, steam and water droplets. The waste stream passes through 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. During the demonstration, the water was heated to a temperature between 250 ^{o}F and 300 ^{o}F, but the system was operated without the addition of a detergent.

Technical and/or Economic Advantages expected from Innovative Technology

The Kelly Decontamination System's vacuum recovery sub-system was expected to significantly reduce airborne contamination, personnel exposure to contaminated waste, and personal protective equipment (PPE) requirements. In addition, the use of steam was expected to increase washing effectiveness, reduce water usage, and reduce secondary liquid waste volume.

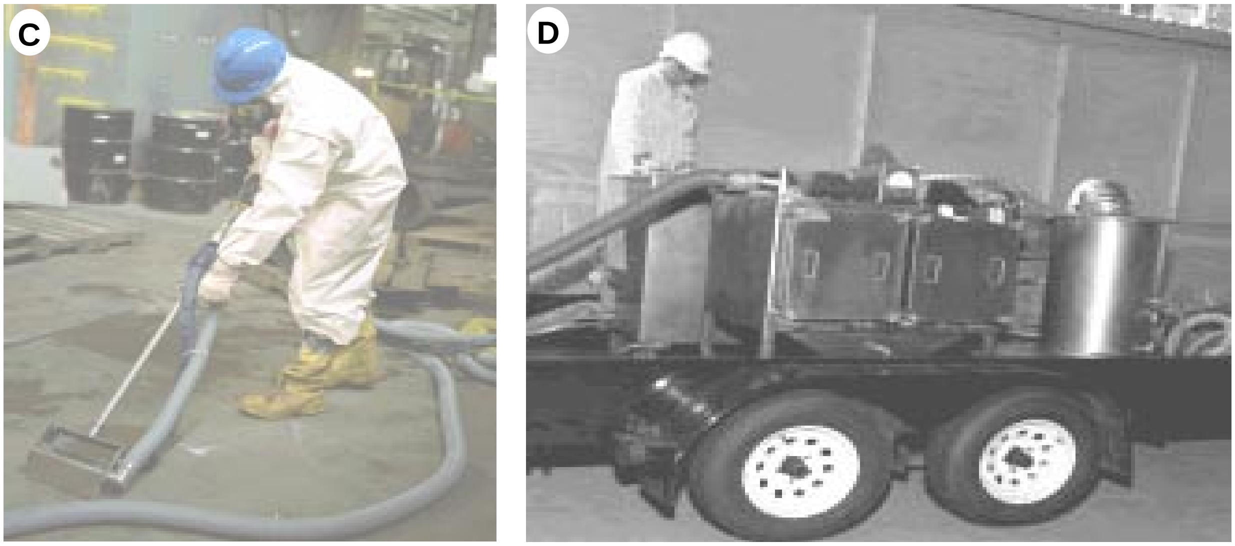

Figure 2: Photos of the Kelly Decontamination SVC System. Photo C shows a worker demonstrating the 10-inch swivel steam/vacuum tool for cleaning floors and large surfaces. Photo D shows a worker operating the Main Control Unit. In front is the Demister/HEPA Filter Unit, and to the right is the Vacuum Unit. All three units were mounted on a trailer outside Building 1A.

Technology Status

Status of Innovative Technology and Current Application(s)

The Kelly Decontamination System is a fully developed and commercially available decontamination technology. Its principal application has been in the decontamination of rooms, walls, large components, and other large and/or smooth surfaces. Although the Kelly System has seen only limited application within the DOE-Complex, it has been used by several commercial nuclear facilities. Appendix C contains a partial list of customers who have used the Kelly Decontamination System.

Permits, Licenses and Regulatory Considerations

The Kelly Decontamination System was leased from Container Products Corporation (CPC) and operated during the demonstration by the FEMP's D&D contractor, B&W Nuclear Environmental Services, Inc. (B&W NESI). CPC provided the necessary training to the operators of the system. The Hotsy 550B was owned and operated by B&W NESI. No permits or licenses were required for demonstrating either system. The demonstration was managed and coordinated by Fluor Daniel Fernald (FDF), a subsidiary of Fluor Daniel, Inc. FDF also provided support in the areas of radiation protection, health and safety, and ensured compliance with Federal regulations governed by the Occupational Safety and Health Administration (OSHA). The United States Army Corps of Engineers (USACE) performed the cost analysis.

Key Results

The debris that was washed during the demonstration consisted of segmented process equipment and components (see Appendix E) that were removed from Building 1A as part of the decommissioning of Plant No. 1 at the FEMP. Only debris that had neither contained, nor been used in the processing of, enriched materials was used in the demonstration.

The key results of the demonstration are:

Equipment Performance

- The Kelly Decontamination System is a well-designed and very effective steam vacuum cleaning system. It is most suited for thorough cleaning and decontamination of large flat surfaces. The most outstanding feature of the Kelly System is its vacuum recovery sub-system and assortment of steam/vacuum cleaning heads that simultaneously collect dislodged contaminants and liquid waste generated during the washing process. This reduces worker health and safety risks, and virtually eliminates airborne contamination.
- A large proportion of the debris removed from the FEMP Plant 1 consists of pumps, motors, fixtures, pipes, structural steel beams, and other irregularly shaped objects. During the demonstration, workers had great difficulty maneuvering the Kelly System's steam/vacuum cleaning heads in and around these irregularly shaped objects. This was due to the size and geometry of the cleaning heads that were not designed for cleaning such objects.
- Use of the steam/vacuum cleaning heads was expected to result in decreased water usage and liquid waste, higher productivity and washing effectiveness, minimal airborne contamination, decreased individual PPE usage, and increased worker comfort and productivity. In all likelihood, these objectives would be achieved if the Kelly System were used for purposes for which it was designed. These objectives were not achieved because the steam/vacuum cleaning heads were simply the wrong tools for washing irregularly shaped objects.
- The Kelly System's spray wand attachment performed as well as the Hotsy's spray wand on all types of debris, but neither uses a vacuum recovery sub-system to contain the contaminated waste stream.
- The Kelly Decontamination System comprises four large pieces of equipment (see Table 2 for dimensions). Each unit has wheels and is portable. Despite its size, it is very easy to set up and operate.

Table 1 is a compilation of the key cost and performance factors that were measured during the demonstration.

Table 1. Summary of key performance factors

	Hotsy Model B550 System High-Pressure Water Cleaning System (Baseline Technology)	Kelly Decontamination System Steam Vacuum Cleaning System (Innovative Technology)
Demonstration Scale	1,150 ft^2	587 ft^2
Productivity	6.05 ft^2/min	2.42 ft^2/min
Variable Unit Cost for Performing D&D Work	$1.53 / ft^2	$1.90 / ft^2
Fixed Cost	$2,417	$6,895
Total (variable + fixed) Unit Cost	$3.63 / ft^2	$13.64 / ft^2
Water usage	0.36 gal/ft^2	0.37 gal/ft^2

Productivity

- During the demonstration, the Kelly System achieved an overall average productivity of 2.4 square feet per minute versus 6.1 square feet per minute for the Hotsy HPWC system (see Table 4). Water usage by both systems was about the same - 0.36 gallons per square foot of debris washed.
- To use the Kelly Decontamination System's steam/vacuum cleaning heads effectively, the operator had to bend at the waist. This resulted in increased worker fatigue, more rest breaks, and reduced productivity.

Cost of Performing D&D Work

- Table 1 shows that the fixed cost of operating the Kelly Decontamination System is significantly more than for the Hotsy HPWC. This is primarily due to its higher capital cost ($194,000 versus $5,530 for the Hotsy Model 550B HPWC), transportation cost, and equipment decontamination cost (see Table 7, Section 5 for details).

  The variable cost of performing D&D work (i.e. the costs that are dependent on the amount of work done) is also higher for the Kelly Decontamination System because of its lower productivity, higher labor costs, and higher PPE requirements. Regardless of the amount of D&D work performed, both the fixed and variable costs of using the Kelly Decontamination System for washing debris at the FEMP were always higher than those of the Hotsy HPWC and, therefore, there is no break even point for the two systems (i.e. the point at which the total cost (fixed plus variable) of performing one unit of D&D work ($\$/ft^2$) is the same for both systems).

Personal Protective Equipment

- Operators of the Kelly Decontamination System were able to wear less restrictive and less costly PPE when using the steam/vacuum cleaning tools. However, overall PPE usage was higher because the system required one additional worker, and more work hours were required to complete a job due to the system's lower productivity.

Airborne Contamination

- Contaminated waste generated by the Kelly Decontamination System is simultaneously vacuumed into, and contained by, its vacuum recovery and filtration sub-system. Although this virtually eliminated airborne contamination, the equipment itself became contaminated and required considerable time and cost for decontamination.

Further Development Required

The Kelly Decontamination System would benefit from design improvements to address the following problems encountered during the demonstration.

- Overheating of the vacuum return hose caused worker discomfort and increased the risk of skin burns. Sleeving of the hose should alleviate this problem.

- Worker fatigue resulted from bending at the waist to operate the cleaning tools. A more ergonomic redesign of the tools is desirable.

- The cleaning tools were ineffective in removing surface grease. Increasing the pressure and/or temperature of the cleaning stream might enhance grease removal without having to use a detergent.

Contacts

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Web Site

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SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

All interior and exterior surfaces of D&D debris that is to be placed in the FEMP's OSDF must first be washed to remove visible process contamination such as grease, green salt and yellow cake. Segmented components and equipment removed from buildings undergoing D&D are transported by forklift to a wash area where they are placed on a wooden pallet, washed, allowed to dry, visually inspected to ensure that contaminants have been removed, and then transported to the OSDF for placement. The baseline technology used for washing debris is a high-pressure water cleaning system. The HPWC system does not have a waste containment and recovery sub-system and contaminants that are dislodged by the high-pressure cleaning stream are splashed throughout the work area or become airborne.

The Kelly Decontamination System is a steam vacuum cleaning system that uses a vacuum recovery sub-system to collect the waste stream generated during the cleaning process. The system uses pressurized superheated water to dislodge contaminants from the surface of the debris. The water flashes to steam on impact with the debris surface and the steam and dislodged contaminants are collected by the vacuum recovery sub-system. Figure 4 illustrates the four functional units that make up the system. The Kelly Decontamination System may be used with either a spray wand, or any of a series of cleaning heads (see Appendix D) which integrate spray jet nozzles in a hood connected to the vacuum recovery sub-system. All units are constructed of stainless steel to minimize contamination and to facilitate equipment decontamination.

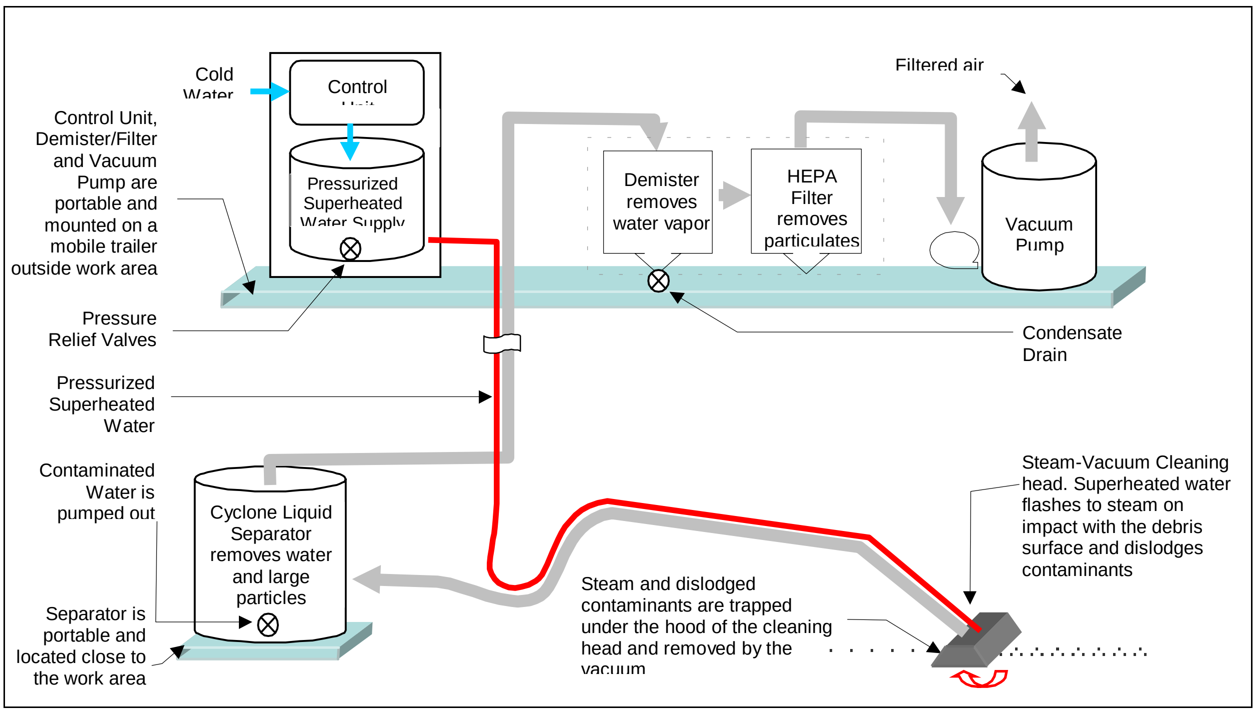

Figure 3: Schematic of the Kelly Decontamination System.

Main Control Unit and Superheated Water Supply - 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.

Cyclone Liquid Separator - The waste stream and debris removed during the washing process are drawn through the Cyclone Liquid Separator by the Vacuum Unit. The Separator traps large debris in a stainless steel sieve, and extracts water droplets from the air/water/debris stream. A peristaltic pump that is also a part of the unit periodically pumps the extracted liquid waste from the Separator to a waste sump. The Separator Unit is typically located close to the work area.

Demister and HEPA Filter - From the Cyclone Separator, the effluent air stream is drawn 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. From the demister, the effluent air stream 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.

Vacuum Pump – This unit uses a liquid-ring vacuum pump that draws the waste stream from the cleaning heads, through the entire waste separation and filtration mechanism, and exhausts clean, dry air to the atmosphere.

Cleaning Tools – The Kelly Decontamination System is designed to work with either a spray wand or any of a series of hooded steam/vacuum cleaning heads (see Appendix D).

System Configuration and Operation

Before the demonstration, the crew members were trained in the operation of the Kelly System, and thoroughly briefed on related regulatory, precautionary, and health and safety issues. Table 2 summarizes the operational parameters and conditions of the demonstrations, and required materials, utilities and other resources.

Table 2. Operational parameters and conditions of demonstration

	Hotsy Model 550B HPWC System	**Kelly Decontamination System**
Working Conditions		
Work area location	Southwest quadrant of the first floor in Building 1A.	Northeast quadrant of the first floor in Building 1A.
Work area access	Accessible by forklift to facilitate material placement and removal.	
Work area description	A section of each work area was designated as a holding site where recently washed material could be held until dry, pending inspection. Material washed with the Kelly System dried rapidly as a result of using hot water and the steam/vacuum heads. Therefore, a smaller holding area was required for the Kelly System. The material to be washed was mounted on a pallet to avoid its sitting in contaminated liquid waste on the floor of the washing area.	
Work crew	Two-person crew to: 1. operate the system and use the spray wand; 2. assist in turning over the material being washed.	Three-person crew to: 1. operate the Main Control Unit and Superheated Water Supply; 2. use the cleaning tools; 3. assist in turning over the material being washed.
Additional support personnel	A part-time forklift operator to move material to be washed to and from the washing area, and a full-time data taker.	

Table 2. Operational parameters and conditions of demonstration

	Hotsy Model 550B HPWC System	Kelly Decontamination System
Work area hazards	Open stream of pressurized water, open stream of hot water (Kelly System only), splashing of contaminated liquid waste, tripping hazard from hoses, and airborne contaminants.	
Equipment configuration	The Hotsy 550B System was located in Building 1A, immediately outside of the washing area.	The Cyclone Liquid Separator was located immediately outside of the work area. All other units were located on a trailer just outside Building 1A.
Primary waste generated	Contaminated liquid waste stream.	Contaminated liquid waste stream.
Secondary waste generated	Disposable PPE and materials used to construct liquid waste-containment dike.	Disposable PPE, vacuum hoses, and HEPA filter.
Waste containment and disposal	The washing area was diked to contain the liquid waste stream that was then channeled to a nearby waste sump.	Liquid waste was collected by the steam/vacuum heads and then discharged to a nearby waste sump.
Equipment Specifications, Operational Parameters and Portability		
System design purpose	High-pressure water cleaning.	Decontamination of general areas in nuclear facilities.
Cleaning mechanism	Pressurized heated water to dislodge contaminants. The water was not heated during the demonstration.	Pressurized *superheated* water to dislodge contaminants.
Cleaning tools	Spray wand.	Spray wand, and various multi-purpose steam/vacuum cleaning heads.
Water pressure (psi) • Mfr. Spec. (max) • Range during demo • Norm during demo	 1,000 800 – 1,000 800	 250 198 - 270 240
Water temperature (^{o}F) • Mfr. Spec. (max) • Range during demo • Norm during demo	 210 45 - 55 45 - 55	 300 250 - 300 300
Water flow rate (gal/min) • Mfr. Spec. (max) • Range during demo • Norm during demo	 2 - 4 2 - 4 2 - 4	 0.4 - 2 0.59 - 1.73 0.8
Water heating mechanism	Kerosene fueled water heater (not used during demonstration)	Electric water heater (used during demonstration)
System able to use detergent	Yes (not used during demonstration)	Yes (not used during demonstration)
Waste containment and collection	No – dike to contain liquid waste had to be constructed	Yes – steam/vacuum heads contain and collect waste stream
Dimensions (in) (height x depth x width)	38 x 44 x 26	Control unit 44 x 30 x 46 Cyclone 45 x 28 x 25 Demister/filter 45 x 29 x 36 Vacuum 42 x 21 x 55
Portability	Equipped with wheels	All units are equipped with wheels

Table 2. Operational parameters and conditions of demonstration

	Hotsy Model 550B HPWC System	Kelly Decontamination System
Weight (lb.)	270 (excluding fuel)	Control unit 950 Cyclone 175 Demister/filter 375 Vacuum 600
Materials Used		
Construction	Materials to construct liquid waste containment dike.	None.
Personal Protective Equipment	• Cotton coveralls, hood and booties • Rubber shoe covers (two pairs) • Impermeable Saranex® disposable suit • Nytrile gloves (two pairs) • Rubber boots	When using steam/vacuum heads: • Cotton coveralls, hood and booties • Rubber shoe covers (two pairs) • Semi-permeable Tyvek® disposable suit • Nytrile gloves (two pairs) • **No** rubber boots required When using the spray wand, PPE requirements were the same as for the Hotsy 550B.
Utilities		
Water supply	Minimum 2.2 gal/min at 20 to 80 psi	Minimum 3 gal/min at 40 psi
Power	115 V, 60 A, 1 phase	Vacuum Pump: 480 V, 15 A, 3 phase Control Unit: 480 V, 60 A, 3 phase Separator: 110 V, 6 A, single phase.

Assessment of Innovative Technology Operation

Throughout the demonstration, both the Hotsy and the Kelly Systems performed without any significant mechanical problems. The following is an overview of the Kelly Decontamination System's operation as assessed by the work crew that operated the equipment.

Operational Strengths of the Kelly Decontamination System

- The system was easy to learn and use.
- Despite its many components, setting up the system was simple, straightforward and fast.
- When used with the spray wand attachment, its operation was very similar to the Hotsy 550B System, and the operator was able to work in a normal upright position.
- The steam/vacuum cleaning heads were easy to change. 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. For example, because the cyclone separator was not washed daily as recommended, it clogged during the last day of the demonstration. The clog was easily cleared by the workers.
- As a result of using superheated water, the washed debris dried quickly and could be moved into and out of the work area at a much faster rate than could be done with the Hotsy.

Operational Weaknesses of the Kelly Decontamination System

- 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 workers reported that the grease was merely “moved around on the surface”.
- 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.
- 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).

SECTION 3

PERFORMANCE

Demonstration Plan

The purpose of the demonstration was to assess the Kelly Decontamination System as an alternative to the baseline Hotsy 550B HPWC System for the washing of D&D equipment and segmented components before placing them in the FEMP's OSDF. The Kelly Decontamination System was assessed based on its performance, relative to the Hotsy 550B System, in achieving the following demonstration objectives:

- 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.

Both systems were used to wash actual process equipment and debris removed from the FEMP's Plant No. 1. Only debris and components that had neither contained, nor been used in the processing of, enriched materials were used. Material washed included tank segments, gears and gearboxes, electric motors, pipes, angle iron, cables, oxygen bottles, light fixtures and I-beams. The debris sent to the Kelly System included a greater proportion of flat tank segments to accommodate the system's steam/vacuum tools, most of which were designed for washing flat surfaces. The determination of whether or not debris had been satisfactorily washed was made by visual inspection according to the criteria described in Section 1 of this report.

The demonstrations were photographed and videotaped to facilitate data collection and verification, and to communicate the technologies to potential users. Evaluators from B&W NESI collected performance data that are tabulated in Appendix E.

Treatment Performance

Table 3 summarizes the overall performance results of the Kelly Decontamination System and the Hotsy 550B HPWC System for each of the demonstration objectives listed above.

Table 3. Performance Comparison between the Hotsy 550B HPWC System and the Kelly Decontamination System

Performance Factor	Hotsy 550B HPWC System	Kelly Decontamination System
Productivity (ft^2/min) (see Table 4)	Higher. Range: 0.89 to 45.48 **Avg.: 6.05**	Lower. Range: 0.88 to 4.69 **Avg.: 2.42**
Work-hours	Lower work hours because of the higher productivity of the system.	Higher work-hours because of lower productivity of the system. Also required an additional crewmember.
Water usage (gal/ft^2) (see Table 4)	Range: 0.05 to 2.48 **Avg.: 0.36**	Range: 0.23 to 1.80 **Avg.: 0.37**
Washing effectiveness	Effective in performing required washing.	Effective except some difficulty in removing grease from surfaces.

Table 3. Performance Comparison between the Hotsy 550B HPWC System and the Kelly Decontamination System

Performance Factor	Hotsy 550B HPWC System	Kelly Decontamination System
PPE usage	Lower. Each donning required more PPE than Kelly, however, a smaller work crew and less work hours resulted in lower overall PPE usage.	Higher. When using the wand, the PPE worn by each crewmember was the same as that for the Hotsy System. The steam/vacuum heads required less PPE to be worn. In both cases however, more work hours due to lower productivity, plus the need for an additional work crew member, resulted in higher overall PPE usage.
Secondary waste (other than PPE)	Higher. A waste stream containment dike had to be constructed, disassembled, and then disposed of as contaminated waste.	Lower (only the vacuum hoses).
Off-site burial shipments	None. No high-level materials were used during the demonstration. Therefore, there was no need for off-site burial.	None. No high-level materials were used during the demonstration. Therefore, there was no need for off-site burial.
Airborne contamination	Higher. Dislodged surface contaminants became airborne when the washing stream splashed and turned to mist or vapor.	Lower. Airborne contamination was virtually eliminated when the system was used with the steam/vacuum cleaning heads.

Productivity and Work-Hours

Table 4 summarizes the daily productivity and water usage data for the Hotsy HPWC system and Kelly Decontamination System. The Hotsy System's productivity was more than double that of the Kelly System. Over the period of the demonstration, the Hotsy System's overall average productivity was *6.05 ft^2/min* and daily averages ranged from 0.89 ft^2/min to 45.48 ft^2/min. The Kelly System's overall average productivity was *2.42 ft^2/min* and daily averages ranged from 0.88 ft^2/min, to 4.69 ft^2/min. The difference in productivity between the two systems is primarily due to their usage, and the purposes for which each was designed.

- **Operation of the Kelly Decontamination System**
  - 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. This resulted in some surfaces being cleaned more than once, and more thoroughly than required by the cleaning criteria for placement of debris in the FEMP's OSDF.
  - The steam used by the system caused surfaces to dry quickly and the operator could not always distinguish whether some area had been cleaned before or not. As such, some areas may have been cleaned more than once.
  - The cleaning heads (other than the spray wand) were used for cleaning surfaces for which they were not designed. 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.

- **Operation of the Hotsy System**
  - The system was designed for high-pressure water cleaning.
  - The operator's primary attention and cleaning emphasis was on visible residue on the debris (as per the washing criteria defined in Section 1). Although all surfaces of the debris were sprayed, only areas with visible contaminants were washed thoroughly.

The variance in the productivity of each system from one day to the next is attributable to two factors:

- The mix of debris delivered to the work areas for washing varied from day to day, and was simply a result of the type of material that was being dismantled in Plant No. 1.

- When workers are observed in the workplace, their activities and work effort tend to be more measured and deliberate. This change in behavior was observed on days when the demonstrations were being photographed and videotaped, as well as on days when onlookers were in adjacent work areas observing other technology demonstrations.

Since these factors applied to both the Hotsy and the Kelly Systems during the demonstration, neither of the two systems was disadvantaged.

Water Usage and Liquid Waste Generated

Both the Hotsy and the Kelly Systems used about the same volume of water per square foot of debris washed. Over the period of the demonstration, the Hotsy System's *overall average water usage was* *0.36g/ft^2* and daily averages ranged from 0.05 g/ft^2 to 2.48 g/ft^2. The Kelly System's *overall average usage was* *0.37 g/ft^2* and daily averages ranged from 0.23 g/ft^2 to 1.80 g/ft^2.

It is worth noting that although the Hotsy System's water flow rate (2.2 gal/min) was almost three times that of the Kelly System (0.8 gal/min), the two systems used about the same amount of water per unit of debris washed, because the Hotsy System's productivity was almost three times that of the Kelly System.

Cleaning Effectiveness

Both the Kelly and the Hotsy Systems were effective in washing D&D debris in accordance with the criteria described in Section 1 of this report. However, the operators of the systems noted that, despite using steam, the Kelly System was not as effective as the Hotsy System in removing grease, and such instances required additional washing effort. This is likely due to the much lower pressure at which the Kelly System was operated (250 psi) compared to the Hotsy System (1,000 psi), as well as the lower kinetic energy of steam compared to water. The Kelly System's effectiveness in this area could be improved by adding a detergent to its washing stream, or increasing the pressure and/or temperature of the water.

PPE Usage

The Hotsy System required less PPE overall than the Kelly System (see Appendix F). When the Kelly System was used with the steam/vacuum cleaning heads, splashing of the contaminated waste stream was eliminated and workers wore less restrictive PPE. However, total PPE requirements were higher because the Kelly System requiring one additional worker. In addition, the lower productivity of the Kelly System required more work-hours to complete a job and, therefore, more changes of PPE.

Off-Site Burial Shipments

This objective was not evaluated since only low-level debris was used for the demonstration, and there was no need for shipment of waste or debris to off-site locations.

Airborne Contamination

Measurements of airborne contamination were not taken during the demonstration, however, the Kelly System's vacuum recovery and HEPA filtration sub-system was expected to virtually eliminate airborne contaminants. Use of the spray wands of both the Hotsy and Kelly Systems resulted in contaminated waste becoming airborne when the high-pressure washing stream splashed or atomized on impact with the surface of the debris.

TABLE 4: Productivity and water usage data

	Hotsy 550B	Kelly Decontamination System		
	Spray Wand	Spray Wand	Brush [a]	Wall Tool [a]
Day 1				
Type of material cleaned	Pipes, tank flats, cable	N/A	Gearbox, motor, pipes, pump frame	N/A
Surface area cleaned (ft^2)	94.72		108.81	
Spray time[b] (minutes)	85.00		48.00	
Daily avg. productivity (ft^2/min)	**1.11**		**2.27**	
Water usage (gallons)	187.00		29.12	
Daily avg. water usage (g/ft^2)	**1.97**		**0.27**	
Day 2				
Type of material cleaned	Oxy bottles	Elec motor, pipes	N/A	N/A
Surface area cleaned (ft^2)	20.94	26.52		
Spray time[b] (minutes)	5.00	30.00		
Daily avg. productivity (ft^2/min)	**4.19**	**0.88**		
Water usage (gallons)	11.00	47.76		
Daily avg. water usage (g/ft^2)	**0.53**	**1.80**		
Day 3				
Type of material cleaned	Light fixtures, Oxygen bottles	N/A	N/A	Tank flats
Surface area cleaned (ft^2)	39.94			264.51
Spray time[b] (minutes)	45.00			117.00
Daily avg. productivity (ft^2/min)	**0.89**			**2.26**
Water usage (gallons)	99.00			91.18
Daily avg. water usage (g/ft^2)	**2.48**			**0.34**
Day 4				
Type of material cleaned	I-beams, elec box, motor, gears, stairs, tank flats	Tank flats	Tank flats	N/A
Surface area cleaned (ft^2)	403.34	168.66	18.94	
Spray time[b] (minutes)	42.00	36.00	12.00	
Daily avg. productivity (ft^2/min)	**9.60**	**4.69**	**1.58**	
Water usage (gallons)	92.40	39.48	7.20	
Daily avg. water usage (g/ft^2)	**0.23**	**0.23**	**0.38**	
Day 5				
Type of material cleaned	Conduits, pipes, elec boxes, light fixtures, steel plates/sheets	N/A	N/A	N/A
Surface area cleaned (ft^2)	591.20			
Spray time[b] (minutes)	13.00			
Daily avg. productivity (ft^2/min)	**45.48**			
Water usage (gallons)	28.60			
Daily avg. water usage (g/ft^2)	**0.05**			
Total surface area cleaned (ft^2)	1150.14	195.18	127.75	264.51
Total spray time (minutes)	190.00	66.00	60.00	117.00
Overall avg. productivity (ft^2/min)	**6.05**	**2.96**	**2.13**	**2.26**
Total water usage (gallons)	418.00	87.24	36.32	91.18
Overall avg. water usage (g/ft^2)	**0.36**	**0.45**	**0.28**	**0.34**

Kelly Total: Wand + Brush + Wall Tool	
surface area cleaned (ft^2)	587.44
spray time (minutes)	243.00
avg. productivity (ft^2/min)	**2.42**
water usage (gallons)	214.74
avg. water usage (g/ft^2)	**0.37**

a - Used with vacuum recovery system

b - Spray time is the actual time spent in cleaning debris. It excludes time spent in preparing for, and following cleaning.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

The Kelly Decontamination System is a fully developed and commercially available steam vacuum system designed for the thorough cleaning and decontamination of general areas in nuclear facilities. It has seen wide usage within the commercial nuclear sector (see Appendix C for a partial list of users), but more limited application within the DOE-Complex. The principal application for the Kelly System has been in the decontamination of rooms, pool walls, large components, and other large and/or smooth surfaces.

The main advantage that the Kelly Decontamination System offers over the baseline HPWC technology is its ability to simultaneous collect and contain dislodged contaminants. This feature significantly reduces airborne contamination, and decreases the risk of workers being splashed by the contaminated waste stream. In turn, this decreases health risks to workers, and reduces the PPE required to be worn by each. The system's spray wand does not offer this advantage, and its operation is comparable to the Hotsy's spray wand.

The paramount consideration in selecting the Kelly Decontamination System for demonstration was its ability to contain waste. This feature was expected to lead to attainment of the demonstration's objectives in the areas of health and safety, airborne contamination, PPE usage, work hours, and secondary waste. However, the Kelly System's steam/vacuum cleaning heads were not designed for cleaning irregularly shaped objects such as those that comprise a large proportion of the debris at the FEMP. A spray wand is much more maneuverable and effective on this type of debris. The Kelly System is better suited for thorough washing and decontamination of large, flat surfaces.

Competing Technologies

The baseline technology with which the Kelly Decontamination System competes is high-pressure water cleaning. HPWC systems are used extensively throughout the DOE-Complex for washing D&D debris. The HPWC technology has functioned well, but the high-pressure washing stream causes significant splashing and misting of the contaminated waste stream. This results in elevated levels of airborne contaminants, and requires more restrictive PPE. Other competing technologies include:

Dry Ice Pellet Blasting

Solid CO_2 pellets are propelled at high speed toward the surface being washed. On impact, they shatter and the resulting pellet fragments penetrate and disrupt the surface media. Sublimation of the dry ice fragments provides additional lifting force to dislodge surface media. Depending on the speed of the pellets, varying degrees of surface cleaning, decontamination or coating removal can be achieved. This technology is effective on coating and rust removal, but soft contaminants such as grease and oil tend to splatter or become airborne requiring further clean up. On porous surfaces, CO_2 blasting tends to drive contaminants further into the surface of the material being cleaned. It also generates considerable noise, airborne contamination, and CO_2 buildup in the work area, as well as projectile hazards from ricocheting pellets and dislodged contaminants. Secondary waste from CO_2 blasting is minimal because the CO_2 pellets vaporize, leaving behind the dislodged contaminants. CO_2 pellet blasting is a fully mature technology that is available from numerous vendors.

Soft Media Blast Washing (Sponge Jet Blasting)

This technology was also demonstrated as part of the FEMP's LSTD project. Absorbent sponge pellets (normally a urethane foam matrix) are propelled at high speed toward the surface being cleaned. On impact, surface contaminants become embedded in the absorbent sponge media. The process results in minimal airborne contamination, and no liquid waste stream is generated. The sponge media is available in various grades of abrasiveness suitable for jobs from surface cleaning to surface removal. The media may be recycled through the blasting process several times before losing its effectiveness. Sponge jet blasting is a fully mature and commercially available technology. The system that was demonstrated at the FEMP is available from AEA Technology of Pittsburgh, Pennsylvania.

Patents/Commercialization/Sponsor

The Kelly Decontamination System is a fully developed and commercially available technology. It has been patented by its developer, Container Products Corporation, under one or more of the following U.S. patents: 4,371,092; 4,426,927; 4,521,935; 4,608,062; 4,625,891; 4,630,750; 4,732,331; 4,782,944; 4,922,815; 4,928,440; 4,993,199. Other domestic and international patents are pending.

SECTION 5

COST

Methodology

This cost analysis compares the relative costs of using the Hotsy Model 550B high-pressure water cleaning system and the Kelly Decontamination steam vacuum cleaning system for washing debris in preparation for placement in the FEMP's OSDF. The analysis presents information that will assist D&D managers in deciding whether the innovative technology is cost-effective for their particular D&D projects. It strives to develop realistic estimates that are representative of work performed within the DOE-Complex, however, the reader should be aware that it is only a limited representation because it uses only data that were observed during the demonstration. Some of the observed costs have been eliminated or adjusted to make the estimates more realistic. These adjustments are allowed only when they do not distort the fundamental elements of the observed data (i.e., they do not change productivity rates, quantities, work elements, etc.), or when activities are atypical of normal D&D work. 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 the Fernald Environmental Management Project.

Cost and performance data were collected for each technology during their respective demonstrations. 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 necessary training)
- D&D work
- Waste disposal
- Demobilization (including equipment decontamination)
- Personal protective equipment

Mobilization costs include the cost of transporting equipment to the demonstration site, costs for training the crew members on use of the equipment (or costs for site training vendor-provided personnel), installation of temporary work areas, and installation of temporary utilities.

D&D work includes items such as the cost of labor, utilities consumed, supplies and the use of equipment for washing debris.

Demobilization includes removal of temporary work areas and utilities, decontamination of technology equipment, dismantlement of temporary work areas and corresponding waste disposal, disconnection of utilities, and equipment decontamination and removal from the site.

PPE costs include all protective clothing, respirator equipment, etc., required for protection of crew members during the demonstration. These costs are duration dependent. Normally, four changes of PPE clothing items (both disposable and reusable) are required for each crew member per day. Reusable PPE items were estimated to have a life expectancy of 200 hours. Disposable PPE items were assumed to have a life expectancy of 10 hours - the length of the daily shift. The cost of laundering reusable PPE clothing items is included in the analysis (see Appendix F).

Data were collected during the demonstration for the cost elements described above. Work was measured and unit costs determined on the basis of square feet of surface area washed. For each element, detailed costs were determined from the data collected. For labor-intensive activities, such as D&D work, a production rate was calculated from the performance data.

For work activities performed by the D&D contractor, labor rates used in the analysis were those actually in effect at the FEMP. Contractor indirect costs were omitted from the analysis, since overhead rates can vary greatly among contractors and locations. Site-specific costs such as engineering, quality assurance, administrative costs and taxes were also omitted from the analysis. Where necessary, D&D Managers may modify the base unit costs determined by this analysis to include their respective site-specific indirect costs.

Equipment costs were based on the cost of ownership. Hourly equipment rates were calculated using the method outlined in EP 1110-1-8*, Construction Equipment Ownership and Operating Expense Schedule, Region II*, US Army Corps of Engineers, August 1995. The hourly rate was calculated using a spreadsheet based on EP 1110-1-8. The hourly rate is based on the capital cost of the equipment, a discount rate of 5.6%, equipment life of 22,000 operating hours as advised by the vendor, estimated yearly usage of 1,040 hours, and estimated operating and maintenance costs.

Costs for the on-site disposal of solid and liquid waste streams from the demonstrations were provided by the FEMP's Integrating Contractor Team (ICT). Since the on-site OSDF was not in place during the demonstrations, the ICT provided estimated unit costs for waste disposal.

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.

Comparative unit costs were calculated for each technology.

Cost Conclusions

Table 5 summarizes the major cost drivers associated with using the Hotsy and Kelly systems for cleaning debris at the FEMP. Details of the cost elements that comprise each major cost driver are presented in Appendix F. Also shown in Appendix F are detailed listings of the PPE used during the demonstration of each of the two systems.

Table 5. Summary of major cost drivers

	High-Pressure Water Cleaning System HOTSY Model 550B (Baseline)		**Steam Vacuum Cleaning System Kelly Decontamination System** (Innovative)	
Cost Driver	**Cost**	**Production Rate**	**Cost**	**Production Rate**
Mobilization[1]	$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	-	$1.19 / ft^2	-
Demobilization[1]	$100	-	$3,207	-
PPE	$0.18 / ft^2	-	$0.21 / ft^2	-

[1] These are total costs that are independent of the quantity of D&D work performed.

Cost Comparison

Mobilization costs were higher for the Kelly Decontamination System because the equipment consists of several large pieces that must be transported to the site. The Hotsy Model 550B is one, smaller unit. No costs were identified for mobilization of the Hotsy Model 550B because it was already at the site; however, actual mobilization costs would be minimal. Costs for training and equipment familiarization were also higher for the Kelly system.

The cost of performing D&D work was higher for the Kelly system due to its higher capital cost of equipment, its need for one additional crew member, and its lower production rate relative to the Hotsy system.

Waste disposal costs for both systems were about the same. Because it used steam for surfacing cleaning as opposed to a water stream, the Kelly system was expected to use less cleaning water and generate less waste water than the Hotsy Model 550B. The data collected during the demonstration showed the Kelly system used about the same amount of water per square foot and generated about the same amount of liquid waste per square foot as the Hotsy system.

Demobilization costs were significantly higher for the Kelly system due to the cost of equipment decontamination. The equipment for both technologies was located outside the debris washing area. However, the Kelly system captures contaminated wash water and circulates it through a cyclone separator and a HEPA filter chamber. This equipment required a number of man-hours for decontamination. The Hotsy Model 550B does not recover wash water and decontamination of the equipment was not required.

The Kelly system allowed the use of a less costly outer layer of PPE. However, because it required an additional crew member, overall PPE costs were higher.

Based on the variable cost elements for the two technologies (1.53/ft^2 for the Hotsy HPWC and \$1.90/ft^2 for the Kelly Decontamination System), for the demonstrated application, the Kelly system offered no cost savings over the Hotsy HPWC. A sensitivity analysis was not performed because the net unit costs for the cost drivers dependent on quantity of work were higher in all instances for the Kelly System than for the Hotsy System.

Cost-Variable Factors

The DOE-Complex presents a wide range of D&D working conditions because of the variety of functions carried out, and the diversity of the facilities. The working conditions at each site directly affect the manner in which D&D work is performed and, consequently, the costs related to each job. The estimates for the technologies presented in this analysis are based on a specific set of factors, conditions and/or work practices found at the FEMP and these are presented in Table 6. This information is provided as an aid to D&D managers and other potential technology users who may needs to make appropriate adjustments for differences between the operating conditions at their facilities and those at the FEMP.

Table 6. Summary of cost-variable factors

Cost-Variable Factor	Hotsy Model B550 HPWC System	Kelly Decontamination System
Scope of Work		
Quantity (surface area) of material washed	1,150 ft^2	587 ft^2
Type of material washed	Miscellaneous debris including I-beams, channels, steel plates, pipes, light fixtures and cylinders.	Mostly segmented tank flats. Some miscellaneous pieces including pipes, a gearbox, a pump frame, and motors.
Location of test area	The test area was easily accessed by forklift for placement and removal of debris.	
Washing criteria	Debris was deemed clean and acceptable for placement in the FEMP's OSDF based on visual inspection only. Radiological or other measurements were not required.	
Work Environment		
Contaminants	Non-nuclear. The debris selected for washing had neither contained, nor been used in the processing of enriched materials.	
Ventilation	The kerosene burning water heater was not used. This eliminated the need for special ventilation to exhaust the fumes.	The Kelly System uses an electrical water heater that does not require special ventilation.
Ambient temperature	70-85^{o}F	70-85^{o}F
Work Performance		
Work crew size	2	3

Table 6. Summary of cost-variable factors

Cost-Variable Factor	Hotsy Model B550 HPWC System	Kelly Decontamination System
Scope of Work		
Personal protective equipment	When using a wand with either the Hotsy or the Kelly System: • Cotton coveralls, hood and booties • Rubber shoe covers (two pairs) • Impermeable Saranex disposable suit • Nytrile gloves (two pairs) • Rubber boots	When using the steam/vacuum cleaning heads with the Kelly System: • Cotton coveralls, hood and booties • Rubber shoe covers (two pairs) • Semi-permeable Tyvek disposable suit • Nytrile gloves (two pairs) • No rubber boots required
Production rate	363 ft^2/hr	145 ft^2/hr
Capital cost of equipment	$5,530	$194,000
Equipment decontamination	None required	96 work hours required
Waste water generated	0.36 gal/ft^2	0.39 gal/ft^2

Table 7 compares the estimated total cost of using the Hotsy Model 550B HPWC and the Kelly Decontamination System for washing D&D debris of varying job sizes.

Table 7. Estimated total costs for washing D&D debris depending on total surface area

			Total Cost for Washing a Surface Area of:				
	Fixed Cost	**Variable Cost**	**1,000 ft^2**	**5,000 ft^2**	**10,000 ft^2**	**15,000 ft^2**	**20,000 ft^2**
Hotsy HPWC	$2,417	$1.53 / ft^2	$ 3,947	$ 10,067	$ 17,717	$ 25,367	$ 33,017
Kelly Steam Vacuum	$6,895	$1.90 / ft^2	$ 8,795	$ 16,395	$ 25,895	$ 35,395	$ 44,895

Figure 4 compares the individual cost drivers associated with washing a typical job comprising debris with total surface area of 5,000 square feet.

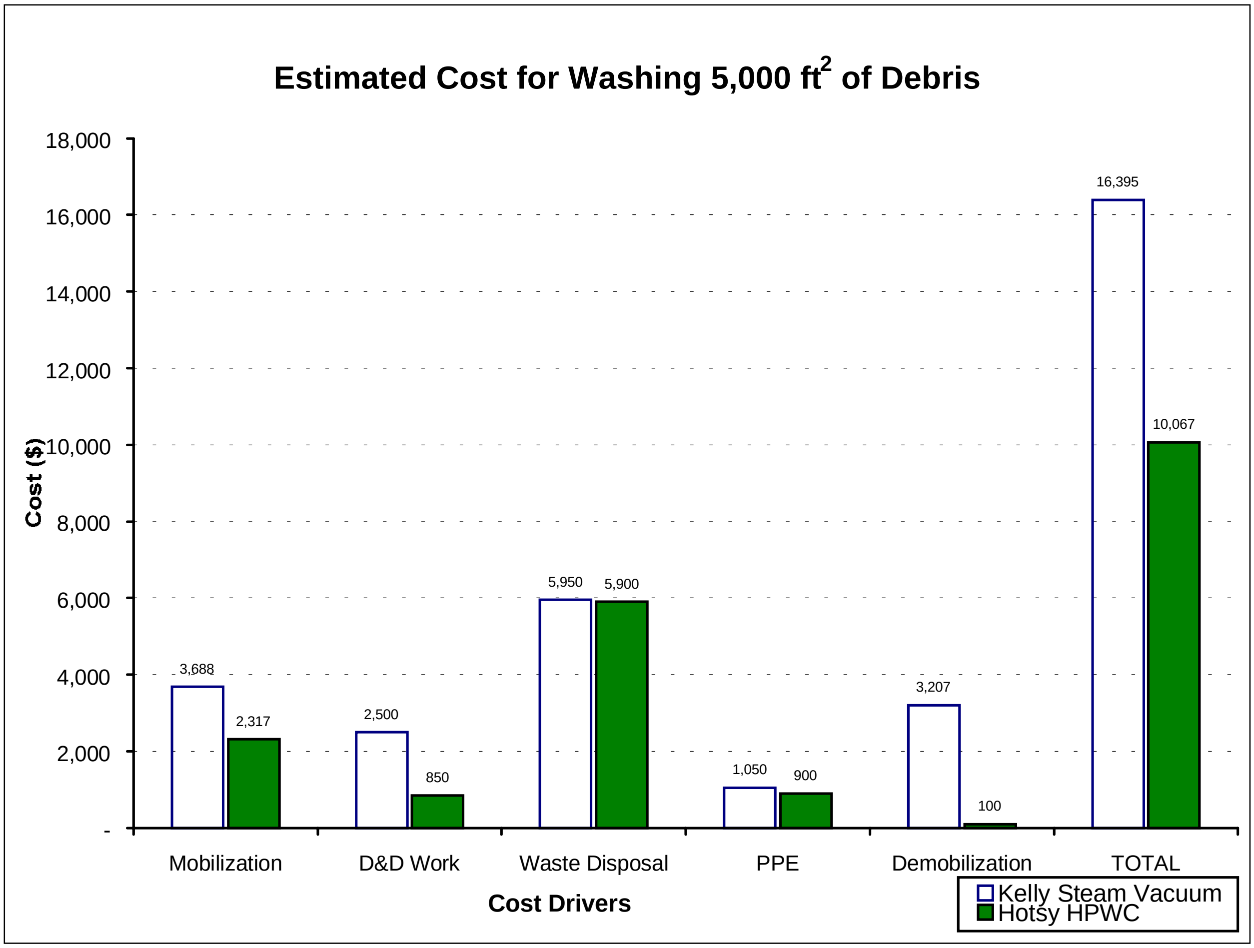

Figure 4. Comparison of Cost Drivers Associated with Washing D&D Debris with Total Surface Area of 5,000 ft^2.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

The regulatory/permitting issues that governed the operation of the Hotsy HPWC system and the Kelly decontamination System at the FEMP Plant No. 1 site are:

- **Occupational Safety and Health Administration (OSHA) 29 CFR 1926**

- 1926.300 to 1926.307	Tools – Hand and Power
- 1926.400 to 1926.449	Electrical – Definitions
- 1926.28	Personal Protective Equipment
- 1926.52	Occupational Noise Exposure
- 1926.102	Eye and Face Protection
- 1926.103	Respiratory Protection

- **Occupational Safety and Health Administration (OSHA) 29 CFR 1910**

- 1910.211 to 1910.219	Machinery and Machine Guarding
- 1910.241 to 1910.244	Hand and Portable Powered Tools and Other Hand-Held Equipment
- 1910.301 to 1910.399	Electrical Definitions
- 1910.95	Occupational Noise Exposure
- 1910.132	General Requirements (Personal Protective Equipment)
- 1910.133	Eye and Face Protection
- 1910.134	Respiratory Protection
- 1910.147	The Control of Hazardous Energy (Lockout/Tagout)

In addition, waste material was segregated, tested and containerized in accordance with the B&W NESI Waste Handling Work Plan (WP556-1A-1001).

Safety, Risks, Benefits, and Community Reaction

The Hotsy System produces a 1,000 psi stream of water capable of causing bodily harm at close distances. The Kelly System operates at a lower, yet still elevated, water pressure (about 250 psi), however, the water is heated to 300 ^{o}F and is capable of scalding inadequately protected skin. These hazards and appropriate precautions were addressed as part of the workers' training.

The Hotsy System does not incorporate a vacuum waste-recovery system, and contaminants dislodged during the washing process become airborne or are splashed about the work area. The Kelly System minimizes airborne contamination and this could lead to an easing of respiratory protection and PPE requirements, increased worker efficiency, increased productivity, and reduced costs.

The Kelly Decontamination System would likely gain higher community acceptance than the Hotsy System because of its ability to contain waste and minimize airborne contaminants when used with the steam/vacuum cleaning heads.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The Kelly Decontamination System is a fully developed and commercially available technology. The following observations are intended to apprise potential users of factors that should be considered before implementation.

- 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) that 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.

Technology Limitations and Needs for Future Development

The Kelly Decontamination System would benefit from the following design improvements.

- 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 redesign 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.

Technology Selection Considerations

The Kelly Decontamination System is an effective steam vacuum cleaning system designed for the decontamination of general areas in nuclear facilities. During the FEMP demonstration, it did not perform as well as the Hotsy HPWC for two key reasons. Firstly, it was used to thoroughly clean all surfaces of the debris whereas the Hotsy HPWC system was used to remove only visible contamination. Secondly, the steam/vacuum cleaning heads were used to clean irregularly shaped objects, a task for which they were not designed. Despite this misapplication, the Kelly Decontamination System should perform very well on large flat surfaces such as floors, pool walls, and other large smooth surfaces. When compared to an HPWC, the Kelly Decontamination System used with its steam/vacuum cleaning heads will significantly reduce airborne contamination and worker health and safety risks. It should also improve worker comfort because of its less restrictive PPE requirements.

APPENDIX A

REFERENCES

Container Products Corporation, *Kelly Decontamination System Operations Manual*, Container Products Corporation, Wilmington, North Carolina.

The Hotsy Corporation, *Hotsy Model 550B Operating Instructions and Parts Manual*, The Hotsy Corporation, Englewood, Colorado.

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U.S. Army Corps of Engineers (USACE), *Productivity Study for Hazardous, Toxic, and Radioactive Waste Remedial Action Projects*, USACE, October 1994.

APPENDIX B

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Description**
CFR	Code of Federal Regulations
D&D	Deactivation and Decommissioning
DDFA	Deactivation and Decommissioning Focus Area (USDOE)
Decon	Decontamination
DOE	Department of Energy
ESH	Environment, Safety and Health
^{o}F	Degrees Fahrenheit
FDF	Fluor Daniel Fernald
FETC	Federal Energy Technology Center
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation (former name of FDF)
FIU	Florida International University
ft^2	Square feet
ft^2/min	Square feet per minute
ft^3	Cubic feet
gal/min	Gallons per minute
H&S	Health and safety
HCET	Hemispheric Center for Environmental Technology (at Florida International University)
HEPA (filter)	High efficiency particulate air (filter)
HPWC	High-pressure water cleaning
hr	Hour
HTRW	Hazardous, toxic, radioactive waste
IH	Industrial hygiene
in	Inches
lb.	Pounds
LLW	Low-level waste
LSTD (P)	Large-scale technology demonstration (project)
OEM	Office of Environmental Management (of the DOE)
OSHA	Occupational Safety and Health Administration
OSDF	On-site disposal facility
OST	Office of Science and Technology
PPE	Personal protective equipment
psi	Pounds per square inch
SVC	Steam vacuum cleaning
USACE	United States Army Corps of Engineers

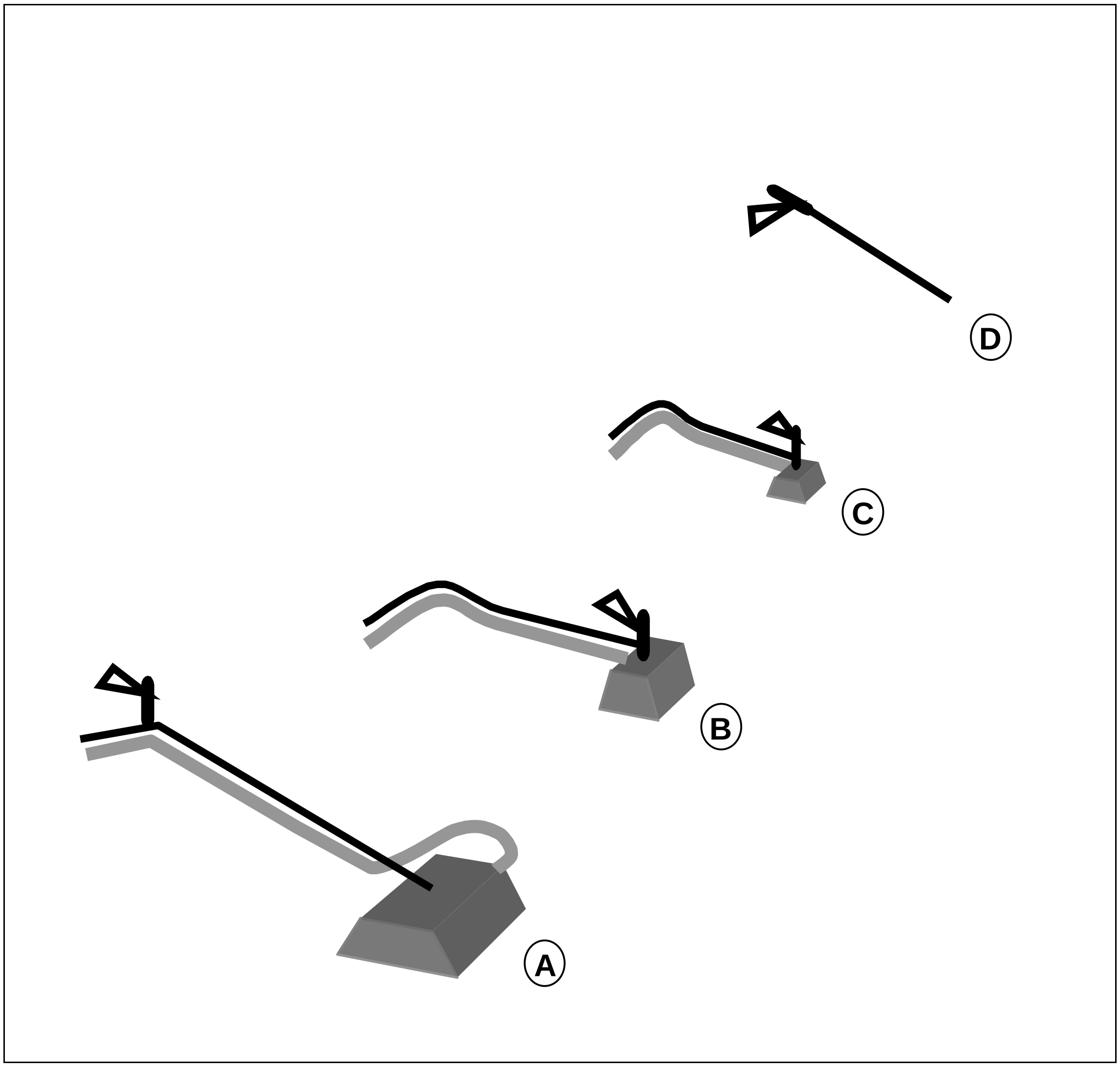
APPENDIX C

PARTIAL LIST OF USERS OF THE KELLY DECONTAMINATION SYSTEM

- Alabama Power Company
- Arkansas Power & Light Company
- Bechtel National
- Boston Edison Company
- British Nuclear Fuels Limited
- Commonwealth Edison Co.
- Consolidated Edison Company
- Duke Power Company
- EG&G Rocky Flats Company
- FERMCO
- GEC Alsthom Engineering System Limited
- Georgia Power Company (2 systems)
- GPU Nuclear Corporation (3 systems)
- Los Alamos National Laboratory
- Louisiana Power & Light Co.
- New York Power Authority
- Northern States Power Company
- Pacific Gas & Electric Company
- Pennsylvania Power & Light Company
- Philadelphia Electric Company
- Public Service Electric & Gas Company
- Rockwell International Corporation
- Sacramento Municipal Utility District
- South Carolina Electric & Gas Company
- Southern California Edison Company
- Tennessee Valley Authority (2 systems)
- Union Electric Company
- Union Electric Company
- Westinghouse Hanford Co. (2 systems)
- Westinghouse Idaho Nuclear Co. (2 systems)
- Westinghouse Savannah River Co. (6 systems)

APPENDIX D

KELLY DECONTAMINATION SYSTEM CLEANING TOOLS



A – 10 in. Swivel Floor Tool
B – 9 in. Handheld Wall Tool
C – 6 in. Handheld Ceiling Tool
D – 18 in. or 36 in. Spray Wand

APPENDIX E

PERFORMANCE DATA

Table E.1. Baseline Technology Data Summary Hotsy Model 550B HPWC System

Day	Item Washed		Washing Tool	Item Dimensions# (in)	Surface Area (in^2)	Surface Area (ft^2)	Total Wash Time (min.)	Spray Flow Rate (gal/ min)	Total Water Used (gal)
2 (8/6)	1	Pipe	Wand	5.0 dia x 108	1,696.32	11.78	5	2.2	11
2 (8/6)	2	Pipe	Wand	5.0 dia x 108	1,696.32	11.78	5	2.2	11
2 (8/6)	3	Pipe	Wand	2.0 dia x 48	300.96	2.09	5	2.2	11
2 (8/6)	4	Pipe	Wand	2.0 dia x 48	300.96	2.09	5	2.2	11
2 (8/6)	5	Pipe	Wand	2.0 dia x 108	678.24	4.71	15	2.2	33
2 (8/6)	6	tank – flat	Wand	30x30x 0.25	1,800.00	12.50	5	2.2	11
2 (8/6)	7	tank – flat	Wand	30x30x 0.25	1,800.00	12.50	5	2.2	11
2 (8/6)	8	tank – flat	Wand	30x30x 0.25	1,800.00	12.50	5	2.2	11
2 (8/6)	9	tank – flat	Wand	30x30x 0.25	1,800.00	12.50	5	2.2	11
2 (8/6)	10	Cable	Wand	0.625 dia x 75 ft	1,766.88	12.27	30	2.2	66
3 (8/26)	11	Oxygen bottle	Wand	10 dia x 48	1,507.68	10.47	2.5	2.2	5.5
3 (8/26)	12	Oxygen bottle	Wand	10 dia x 48	1,507.68	10.47	2.5	2.2	5.5
4 (8/27)	13	Light fixture	Wand	6x12x72	2,736.00	19.00	15	2.2	33
4 (8/27)	14	Oxygen bottle	Wand	10 dia x 48	1,507.68	10.47	15	2.2	33
4 (8/27)	15	Oxygen bottle	Wand	10 dia x 48	1,507.68	10.47	15	2.2	33
5 (10/14)	16	I beam	Wand	6.5x 8 web x 72	3,024.00	21.00	8.4	2.2	18.48
5 (10/14)	17	I beam	Wand	6.5x 8 web x 60	2,520.00	17.50	8.3	2.2	18.26
5 (10/14)	18	I beam	Wand	6.5x 8 web x 48	2,016.00	14.00	8.3	2.2	18.26
5 (10/14)	19	Pipe	Wand	2 dia x 24	149.76	1.04	1	2.2	2.2
5 (10/14)	20	elect box	Wand	12x16x54	1,684.80	11.70	1	2.2	2.2
5 (10/14)	21	Pipe	Wand	0.5 dia x 36	7.20	0.05	0.5	2.2	1.1
5 (10/14)	22	Conduit	Wand	0.5 dia x 36	7.20	0.05	0.5	2.2	1.1
5 (10/14)	23	tank – flat	Wand	30x48x 0.25	2,880.00	20.00	0.5	2.2	1.1
5 (10/14)	24	elect motor	Wand	11 dia x 16	1,641.60	11.4	1	2.2	2.2
5 (10/14)	25	Railing	Wand	2x2x48	388.80	2.70	0.5	2.2	1.1
5 (10/14)	26	plate steel	Wand	36x84x2	6,523.20	45.30	1	2.2	2.2
5 (10/14)	27	plate steel	Wand	60x60x2.5	7,804.80	54.20	1	2.2	2.2
5 (10/14)	28	Stairs	Wand	8x2.5x84	1,800.00	12.50	2	2.2	4.4
5 (10/14)	29	Stairs	Wand	8x2.5x72	1,555.20	10.80	2	2.2	4.4
5 (10/14)	30	plate steel	Wand	18.5x36x 0.75	1,411.20	9.80	1	2.2	2.2
5 (10/14)	31	plate steel	Wand	18.5x24x 0.75	950.40	6.60	1	2.2	2.2
5 (10/14)	32	5 gears	Wand	avg. 30 dia x 4	8,956.80	62.20	1	2.2	2.2
5 (10/14)	33	8 gears	Wand	avg. 22 dia x 0.5	6,364.80	44.20	1	2.2	2.2
5 (10/14)	34	4 steel sheets	Wand	30x30x2.5	8,395.20	58.30	2	2.2	4.4
6 (10/16)	35	70 cond/pipe	Wand	avg. 1.5 dia x 60	19,728.00	137.00	2	2.2	4.4
6 (10/16)	36	6 PVC pipes	Wand	5.5 dia x 84	17,280.00	120.00	2	2.2	4.4
6 (10/16)	37	21 elect boxes	Wand	8x16x18	23,515.20	163.30	2	2.2	4.4
6 (10/16)	38	4 elect boxes	Wand	8x13x27	5,371.20	37.30	1	2.2	2.2
6 (10/16)	39	12 door plates	Wand	13x20x 0.25	6,235.20	43.30	2	2.2	4.4
6 (10/16)	40	6 light fixtures	Wand	6x14x50	13,003.20	90.30	4	2.2	8.8
		Totals				**1,150.1**	**190.0**		**418.0**

- All steel plates assumed to be 0.25 inches thick unless otherwise indicated.

Table E.2. Innovative Technology Data Summary Kelly Decontamination System

Day	Item Washed		Cleaning tool	Item Dimensions# (in)	Surface Area (in^2)	Surface Area (ft^2)	Total Spray Time (min)**	Spray Flow Rate (gal/ min)	Total Water Used (gal)
1 (8/5)	1	gearbox	Brush	35x22x40	6,099.84	42.36	18.0	0.59	10.62
1 (8/5)	2	pump frame	Brush	28x53x16	5,559.84	38.61	10.0	0.65	6.50
1 (8/5)	3	elect. motor	Brush	18x24x29	3,300.48	22.92	10.0	0.60	6.00
1 (8/5)	4	pipe	Brush	2.5 dia x 67	525.60	3.65	5.0	0.60	3.00
1 (8/5)	5	pipe	Brush	2.0 dia x 29	182.88	1.27	5.0	0.60	3.00
2 (8/6)	6	elect. motor **	Wand	16x17x29	2,458.08	17.07	18.0	1.50	27.00
2 (8/6)	7	pipe **	Wand	0.75 dia x 92	217.44	1.51	3.0	1.73	5.19
2 (8/6)	8	pipe **	Wand	2.0 dia x 92	577.44	4.01	3.0	1.73	5.19
2 (8/6)	9	pipe **	Wand	0.75 dia x 62	145.44	1.01	3.0	1.73	5.19
2 (8/6)	10	pipe **	Wand	1.0 dia x 67	210.24	1.46	1.5	1.73	2.60
2 (8/6)	11	pipe **	Wand	1.0 dia x 67	210.24	1.46	1.5	1.73	2.60
3 (8/7)	13	tank – flat	Short wall	35x38x 0.25	2,659.68	18.47	10.0	1.00	10.00
3 (8/7)	14	AFD	Short wall	26x26x31	4,576.32	31.78	30.0	1.00	30.00
3 (8/7)	15	tank – flat	Short wall	39x56x 0.25	4,367.52	30.33	6.0	0.63	3.78
3 (8/7)	16	tank – flat	Short wall	40x44x 0.25	3,519.36	24.44	12.0	1.00	12.00
3 (8/7)	17	tank – flat	Short wall	40x51x 0.25	4,079.52	28.33	6.0	0.60	3.60
3 (8/7)	18	tank – flat **	Short wall	40x64x 0.25	5,120.64	35.56	6.0	0.60	3.60
3 (8/7)	19	tank – flat	Short wall	40x43x 0.25	3,440.16	23.89	5.0	0.60	3.00
3 (8/7)	20	tank – flat **	Short wall	21x57x 0.25	2,394.72	16.63	24.0	0.60	14.40
3 (8/7)	21	tank - flat	Short wall	42x63x 0.25	5,292.00	36.75	6.0	0.60	3.60
3 (8/7)	22	tank - flat **	Short wall	33x40x 0.25	2,639.52	18.33	12.0	0.60	7.20
4 (8/8)	23	tank - flat	Wand/brush	34x100x 0.25	6,799.68	47.22	6.0	1.06	6.36
4 (8/8)	24	tank - flat **	Wand/brush	36x45x 0.25	3,240.00	22.50	6.0	1.04	6.24
4 (8/8)	25	tank - flat **	Wand/brush	35x64x 0.25	4,479.84	31.11	6.0	1.04	6.24
4 (8/8)	26	tank - flat **	Wand/brush	33x51x 0.25	3,366.72	23.38	6.0	1.20	7.20
4 (8/8)	27	tank - flat **	Wand/brush	25x40x 0.25	2,000.16	13.89	6.0	1.13	6.78
4 (8/8)	28	tank - flat **	Wand/brush	44x50x 0.25	4,400.64	30.56	6.0	1.11	6.66
4 (8/8)	29	tank - flat **	Wand/brush	31x44x 0.25	2,727.36	18.94	12.0	0.60	7.20
		Totals				**587.40**	**243.0**		**214.80**

- All steel plates are assumed to be 0.25 inches thick unless otherwise indicated.

** Times adjusted to reflect spray time from the run time meter on the machine.
All steel plate assumed to be 0.25 in. in thickness unless otherwise indicated.

APPENDIX F

SUMMARY OF COST ELEMENTS

Table F.1. Breakdown of major cost elements

Fixed Costs

Description	Quantity	Unit	Man hrs	Labor	Equipm't	Materials	Other	Total
Hotsy HPWC	1150	ft^2						
Mobilization	1	EA	26	$726	$4	$1,587	$0	$2,317
Demobilization	1	EA	0	$0	$0	$0	$100	$100
Total Hotsy HPWC	**1150**	ft^2	**26**	**$726**	**$4**	**$1,587**	**$100**	**$2,417**
Kelly Decon System	587	ft^2						
Mobilization	1	EA	41	$1,044	$14	$1,380	$1,250	$3,688
Demobilization	1	EA	60	$1,801	$469	$907	$30	$3,207
Total Kelly Decon System	**587**	ft^2	**101**	**$2,845**	**$483**	**$2,287**	**$1,280**	**$6,895**

Variable Costs

Description	Quantity	Unit	Man hrs	Labor	Equipm't	Materials	Other	Total	Unit Cost
Hotsy HPWC	1150	ft^2							
D&D Work	1150	ft^2	6	$190	$5	$0	$0	$195	$0.17
Disposal	1150	ft^2	0	$0	$0	$0	$1,354	$1,354	$1.18
PPE	1150	ft^2	0	$0	$0	$0	$208	$208	$0.18
Total Hotsy HPWC	**1150**	ft^2	**6**	**$190**	**$5**	**$0**	**$1,562**	**$1,757**	**$1.53**
Kelly Decon System	587	ft^2							
D&D Work	587	ft^2	8	$235	$61	$0	$0	$296	$0.50
Disposal	587	ft^2	0	$0	$0	$0	$696	$696	$1.19
PPE	587	ft^2	0	$0	$0	$0	$121	$121	$0.21
Total Kelly Decon System	**587**	ft^2	**8**	**$235**	**$61**	**$0**	**$817**	**$1,113**	**$1.90**

Total Cost

Description	Quantity	Unit	Man hrs	Labor	Equipm't	Materials	Other	Total	Unit Cost
Hotsy HPWC	1150	ft^2							
Mobilization	1	EA	26	$726	$4	$1,587	$0	$2,317	$2,317
D&D Work	1150	ft^2	6	$190	$5	$0	$0	$195	$0.17
Disposal	1150	ft^2	0	$0	$0	$0	$1,354	$1,354	$1.18
Demobilization	1	EA	0	$0	$0	$0	$100	$100	$100
PPE	1150	ft^2	0	$0	$0	$0	$208	$208	$0.18
Total Hotsy HPWC	**1150**	ft^2	**32**	**$916**	**$9**	**$1,587**	**$1,662**	**$4,174**	**$3.63**
Kelly Decon System	587	ft^2							
Mobilization	1	EA	41	$1,044	$14	$1,380	$1,250	$3,688	$3,688
D&D Work	587	ft^2	8	$235	$61	$0	$0	$296	$0.50
Disposal	587	ft^2	0	$0	$0	$0	$696	$696	$1.19
Demobilization	1	EA	60	$1,801	$469	$907	$30	$3,207	$3,207
PPE	587	ft^2	0	$0	$0	$0	$121	$121	$0.21
Total Kelly Decon System	**587**	ft^2	**109**	**$3,080**	**$544**	**$2,287**	**$2,097**	**$8,008**	**$13.64**

Table F.2. Personal protective equipment requirements
Hotsy HPWC System

Crew Size:	1	
Daily Shift Length:	10	hrs
Useful Life of Reusable PPE Items:	200	hrs

Reusable PPE - Daily Requirements[1]

Item	Quantity	Unit	Unit Cost	Total Cost
Cotton coveralls (yellow)	4	EA	$5.90	$23.60
Cotton hoods (yellow)	4	EA	1.16	4.64
Cotton shoe covers (yellow)	4	Pair	1.84	7.36
Leather welding apron	0	EA	20.00	0.00
Leather welding gloves	0	Pair	7.00	0.00
Full-face respirators	4	EA	174.00	696.00
Reusable PPE laundry costs[2]	1	Load	1.39	1.39
Hourly Reusable PPE Cost				**$3.66**

Disposable PPE - Daily Requirements[3]

Item	Quantity	Unit	Unit Cost	Total Cost
Tyvek suits	0	EA	$4.09	$0.00
Saranex suits	4	EA	23.77	95.08
Mar-mac fire-resistant coveralls	0	EA	3.36	0.00
Cotton glove liners	4	Pair	0.28	1.12
Cotton work gloves	0	Pair	0.54	0.00
Nytrile gloves	4	Pair	0.24	0.96
Rubber shoe covers	4	Pair	12.28	49.12
Rubber boots	4	Pair	29.30	117.20
Ear plugs	0	Pair	0.12	0.00
Ear protectors	0	EA	18.72	0.00
Respirator cartridges	4	Pair	11.74	46.96
Hourly Disposable PPE Cost				**$31.04**
TOTAL HOURLY PPE COST				**$34.71**

[1]Requires four changes per worker each day. Expected life = 200 hours.

[2]One day's reusable PPE for one crew member is one laundry load. Cost per laundry load is $1.39. Data provided by Fluor Daniel Fernald.

[3]Requires four changes per worker each day. Expected life = 10 hours (length of shift).

Table F.3. Personal protective equipment requirements
Kelly Decontamination System

Crew Size:	1	
Daily Shift Length:	10	hrs
Useful Life of Reusable PPE Items:	200	hrs

Reusable PPE - Daily Requirements[1]

Item	Quantity	Unit	Unit Cost	Total Cost
Cotton coveralls (yellow)	4	EA	$5.90	$23.60
Cotton hoods (yellow)	4	EA	1.16	4.64
Cotton shoe covers (yellow)	4	Pair	1.84	7.36
Leather welding apron	0	EA	20.00	0.00
Leather welding gloves	0	Pair	7.00	0.00
Full-face respirators	4	EA	174.00	696.00
Reusable PPE laundry costs[2]	1	Load	1.39	1.39
Hourly Reusable PPE Cost				**$3.66**

Disposable PPE - Daily Requirements[3]

Item	Quantity	Unit	Unit Cost	Total Cost
Tyvek suits	4	EA	$4.09	$16.36
Saranex suits	0	EA	23.77	0.00
Mar-mac fire-resistant coveralls	0	EA	3.36	0.00
Cotton glove liners	4	Pair	0.28	1.12
Cotton work gloves	0	Pair	0.54	0.00
Nytrile gloves	4	Pair	0.24	0.96
Rubber shoe covers	4	Pair	12.28	49.12
Rubber boots	0	Pair	29.30	0.00
Ear plugs	0	Pair	0.12	0.00
Ear protectors	0	EA	18.72	0.00
Respirator cartridges	4	Pair	11.74	46.96
Hourly Disposable PPE Cost				**$11.45**
TOTAL HOURLY PPE COST				**$15.12**

[1]Requires four changes per worker each day. Expected life = 200 hours.

[2]One day's reusable PPE for one crew member is one laundry load. Cost per laundry load is $1.39. Data provided by Fluor Daniel Fernald.

[3]Requires four changes per worker each day. Expected life = 10 hours (length of shift).