INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0393

Personal Ice Cooling System (PICS)

Deactivation and Decommissioning
Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

November 1998

Innovative Technology Summary Report

Personal Ice Cooling System (PICS)

OST Reference # 1898

Deactivation and Decommissioning Focus Area

Demonstrated at
Fernald Environmental Management Project – Building 68
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."

TABLE OF CONTENTS

APPENDICES

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 Deactivation and Decommissioning Focus Area (DDFA) of the DOE's Office of Science and Technology sponsors Large-Scale Demonstration and Deployment Projects (LSDDPs) in which developers and vendors of improved or innovative technologies showcase products that are potentially beneficial to the DOE's projects and to others in the D&D community. Benefits sought include decreased health and safety risks to personnel and the environment, increased productivity, and decreased cost of operation.

As buildings are demolished as part of the DOE Fernald Environmental Management Project's (FEMP's) D&D Plan, many of the activities are performed in hot weather and usually require use of various types and layers of personal protective equipment (PPE). While PPE is designed to protect the worker from contamination, it also significantly compromises the body's ability to cool itself, leading to potentially serious heat stress situations. This report describes a comparative demonstration between the methodology currently used for heat stress management (i.e., limited stay times and cool-down rooms) and an alternative personal ice cooling suit technology.

The baseline methodology for heat stress management is limited stay times when working in hot conditions. The FEMP's Safety Performance Requirements outline the procedures and stay times to be followed and consider the temperature of the working environment, work load, and the type and amount of PPE required for the job. While these are common criteria for determining stay times, other sites may have different requirements. This demonstration investigates the feasibility of using the personal ice cooling suit as a tool for managing heat stress in workers at the FEMP.

This report provides a comparative analysis of the productivity of work using the baseline heat stress management approach currently used at the FEMP and the innovative personal ice cooling suit technology.

Technology Summary

Baseline Technology

The baseline technology for core body temperature control of heat stress is limiting worker stay times, physiological monitoring, and use of a cool-down room. When exiting the work area after the limited time, the workers have their temperatures and pulses measured to monitor for heat stress. They are then allowed to doff respirators and hoods and rest in the cool-down room for 30 minutes or half the stay time (whichever is longer) after which they may return to work if their physiological signs are within established safety limits. Depending on the work location, the cool-down room can often be on a different floor or in another building than the work, requiring the workers to travel between locations for their heat stress relief and adding additional non-productive time to the work/rest cycle.

Innovative Technology

The Personal Ice Cooling System (PICS) is a self-contained core body temperature control system that uses ice (made with tap water) as a coolant and circulates cool water through tubing that is incorporated into a durable and comfortable, full-body garment suit similar to long underwear (see Figure 1). The torso shirt of the garment can be used without the pants and hood when less rigorous temperature control is warranted. The suits come in various sizes from small to extra large.

Figure 1. The PICS garment with the cooling tubes sewn into the fabric.

Water is frozen in two-liter bottles that can be worn either inside or outside of anti-contamination PPE in a sealed, insulated bag with a circulating pump attached to a comfortable support harness system (see Figure 2). The two-speed, battery-powered pump circulates the coolant via an umbilical tube (with a PPE pass-through connector if worn outside of PPE) to tubing in the garment. The pump speeds (off, low, high) on the circulation system allow the wearer to control his rate of cooling based on work load. The total weight of the system with a two-liter ice bottle is approximately 12 pounds, and lighter weight systems are available. Because the close-to-skin garment suit is worn inside of the first layer of anti-contamination PPE, it is considered personal clothing, not a contamination control barrier. The suit can be monitored through the monitoring control system and if not contaminated, released for normal laundering and reuse. The garment can be laundered hundreds of times and has a life expectancy as long as most other reusable PPE. The external components of the PICS, i.e., harness, bottle, pump, and insulated bag, can remain in the contaminated area until the work is complete. Coolant circulation tubing connections are a quick-connect type and are leak proof and self-sealing even when disconnected.

The PICS can allow a worker to remain in the contaminated work zone longer and change ice bottles without having to doff the PPE, thus increasing worker productivity. Even if the ice bottle is worn inside the PPE, a support person in the buffer zone can change the ice bottle without fully doffing the worker's PPE. In addition, the PICS cooling lasts approximately twice as long as ice vests, thus reducing the change out times for replacing coolant. Figure 3 shows the PICS in use underneath PPE.

The total cost of the PICS, including all components, is $1,406. Annual maintenance costs are estimated at $170, which includes money for general maintenance every 500 hours of use and an overhaul every 2,000 hours. General maintenance includes items such as replacing broken connectors or damaged lead tubes, while an overhaul involves repairing stitching or torn fabric and replacing worn out parts in the pump. The only other supporting equipment needed is a freezer and temporary cold storage (such as an ice chest or cooler) for the ice bottles.

Figure 2. A worker wears the pump unit backpack.

Figure 3. A worker wears the PICS underneath PPE while working.

Technology Summary

The PICS technology was demonstrated in Building 68 at the FEMP from September 16, 1997 through September 18, 1997. The purpose of the demonstration was to assess using a personal cooling technology as a viable alternative to management of heat stress by limiting stay times and using cool-down rooms.

The PICS technology was not demonstrated side by side with the baseline, as the baseline simply followed the FEMP's Safety Performance Requirement stay times. However, actual work area temperatures were measured and the corresponding stay durations calculated for the comparison.

The type of work performed during the demonstration included assembling and removing scaffolding, climbing scaffolding (up to 30 feet), and scraping and painting. The temperatures in the work area ranged between 80 and 105ºF, and workers wore anti-contamination PPE with full-face airline respirators. Throughout the demonstration, the workers' temperatures and pulses were monitored regularly and were always within acceptable limits.

The objectives of the demonstration were:

- to determine whether worker stay times and worker productivity could be increased over the current baseline procedure by providing core body cooling with the PICS, and
- to assess whether heat stress can be safely managed by using the PICS.

Key Results

The key results of the demonstration were:

- The PICS allowed the workers to maintain a comfortable body temperature.
- Worker stay times were greatly increased as a result of wearing the PICS. On the days of the demonstration where work area temperatures exceeded 100ºF, stay times were more than four times longer with the PICS than the baseline.
- The higher the temperature in the work area, the greater the increase in stay times and the greater the productivity increase as a result of the PICS. Significant advantages occur when the work area temperature is over 85º Fahrenheit (F).
- The amount of PPE required for a specific task affects the productivity gain with the PICS. Significant advantages occur with the PICS when impermeable PPE and/or respirators are required for a task.
- Workers preferred the PICS over ice vests (not evaluated in this demonstration) and over not wearing any cooling devices. They found the PICS more comfortable, less fatiguing, and felt it allowed them to perform more work. One worker also commented that he felt his energy level was much greater with the PICS.
- Based on the stay times observed during the demonstration (see Table 1), the cost savings resulting from the use of the PICS are $47/hour per two-person crew (a 39% savings) for work area temperatures between 70 and 85ºF and $159/crew-hour (a 66% savings) for temperatures greater than 85ºF. Cost savings are based on D&D labor, equipment, and disposable PPE. The pay-back period (time for cost recovery for buying the system) for the PICS is 30 crew-hours of work at temperatures between 70 and 85ºF and only 9 crew-hours at temperatures greater than 85ºF.

- The logistics support for operating the PICS is minimal and easy. The PICS uses tap water as a cooling medium, and the water bottles are frozen in standard freezers. Bottles can be stored near the work area in either ice chests or freezers.

- The use of PICS decreases the consumption of disposable PPE because workers don and doff PPE fewer times since they can stay in the work area longer.

- The PICS equipment used to circulate cooling water through the suit is portable and easy to set up and use. Ice bottles can be changed in a buffer area without workers having to decontaminate, doff PPE, and leave the hot zone.

Table 1 lists the key performance and cost factors that were measured or determined during the demonstration.

Table 1. Summary of key performance factors

	Heat Stress Management by Limited Stay Times (Baseline Technology)	Heat Stress Management Using the PICS (Innovative Technology)
Average Stay Time (70 - 85ºF)	100 min.	160 min.
Average Stay Time (> 85ºF)	23 min.	92 min.
Average Rest Time due to Heat Stress Management[1] (70 - 85ºF)	50 min.	0 min.
Average Rest Time due to Heat Stress Management[1] (> 85ºF)	30 min.	0 min.
Work Efficiency[2] (70 - 85ºF)	44%	62%
Work Efficiency[2] (> 85ºF)	23%	54%
Pay-Back Period	30 crew-hours of work (70 - 85ºF) 9 crew-hours of work (> 85ºF)	

[1] These rest times only include breaks for managing heat stress and do not include other regular breaks throughout the work day.
[2] Work efficiency is based on productive hours available for the entire shift. Non-productive hours include paid time for the crew outside of the field due to heat stress management, safety meetings, and regular breaks.

Permits, Licenses and Regulatory Considerations

Fluor Daniel Fernald (FDF) carried out the PICS demonstration with laborers from Wise Services, a labor subcontractor at Fernald. No permits or licenses were required for demonstrating the technology.

The demonstration involved working in contaminated areas. FDF provided technical support in the areas of radiation protection, health and safety, and regulatory compliance.

Technology Limitations and Needs for Future Development

Wearing the backpack containing the ice bottle, pump, and battery adds bulk for the worker who is also wearing PPE and possibly other equipment, such as a lapel air sampler and a battery powered respirator and while performing tasks such as climbing scaffolding. However, the cooling benefits far exceed the limitations and generally make up for the added weight that is carried. Smaller and thus lighter weight ice bottles are available but provide less cooling time.

The only other major limitation is the amount of cooling capacity in two liters of ice. If a chemical cooling medium other than water is used to increase cooling capacity, the safety and ease of using tap water is then lost.

Contacts

Technology Vendor

Kirk Dobbs, Delta Temax, Inc.
320 Boundary Road, Pembroke, Ontario, Canada K8A 6W5
Telephone: (613) 735-3996

Technology Demonstration

Larry Stebbins, Technology Development Manager, Fluor Daniel Fernald
P.O. Box 538704, Mail Stop 50, Cincinnati, Ohio, 45253-8704
Telephone: (513) 648-4785

Marty Prochaska, Project Specialist, Fluor Daniel Fernald
P.O. Box 538704, Mail Stop 50, Cincinnati, Ohio, 45253-8704
Telephone: (513) 648-4089

Don Krause, Engineer, B&W Services, Inc.
P.O. Box 11165, Lynchburg, VA 24506-1165
Telephone: (804) 522-6848

FEMP Large-Scale Demonstration and Deployment Project

Steve Bossart, Project Manager, Federal Energy Technology Center
3610 Collins Ferry Road, Morgantown, West Virginia, 26507-0880
Telephone: (304) 285-4643

Rod Warner, Technology Program Officer, DOE Fernald Area Office
P.O. Box 538705, Mail Stop 45, Cincinnati, Ohio, 45253-8705
Telephone: (513) 648-3156

Terry Borgman, Plant Nos. 1 & 4 D&D Construction Manager, Fluor Daniel Fernald
P.O. Box 538704, Mail Stop 44, Cincinnati, Ohio, 45253-8704
Telephone: (513) 648-5357

Paul Pettit, Project Manager, Technology Programs, Fluor Daniel Fernald
P.O. Box 538704, Mail Stop 50, Cincinnati, Ohio, 45253-8704
Telephone: (513) 648-4960

Cost Analysis

Fred Huff, Civil Engineer
US Army Corps of Engineers
502 Eighth Street, Huntington, West Virginia, 25701-2070
Telephone: (304) 529-5937

Web Site

The FEMP Internet web site address is http://www.fernald.gov.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The PICS demonstrated at the FEMP consists of a pump circulating cooling water through tubes sewn into a cotton/polyester undergarment suit. This technology was investigated as a means of managing heat stress of workers in high temperature environments, common in buildings at the FEMP during the late spring to early fall. The current baseline approach for managing heat stress is to limit stay times in the work area and require rest periods in cool-down rooms. This approach, however, significantly reduces work efficiency. In addition, workers become fatigued, less alert, and more prone to injury.

Figure 4 illustrates the cooling process of the PICS vest. Additional tubes connect to the pants and hood.

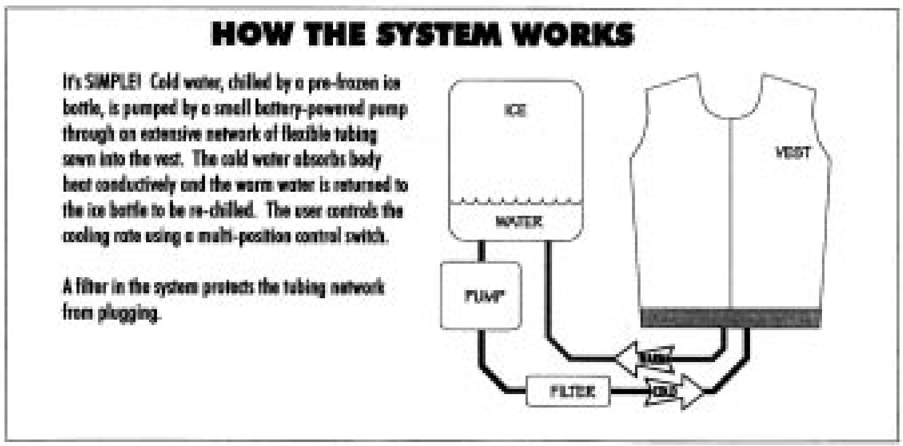

Figure 4. Schematic of the PICS.

System Operation

The PICS PPE demonstration was conducted in Building 68 at Fernald. In order to evaluate a range of tasks for the suit, several activities were evaluated, including assembling, moving, and climbing scaffolding, scraping, and painting.

The PICS suit used during the demonstration was the Delta T350 three-piece cooling garment. The fabric demonstrated was a cotton/polyester blend, but the suit is also available in Nomex® for flame retardancy. The Delta CD2-A6R2 pump unit was used, which is simple, totally portable, self-contained, and is powered by four D-cell batteries. Flow of the cold water is controlled by the user with a 2-speed rotary switch. Other suits and pump units are available from the vendor.

During the demonstration, the PICS suits were worn and operated by D&D laborers. This was done to demonstrate the system's operation in an actual D&D project setting.

Donning, doffing, and operation of the PICS required basic training related to the connection of the water bottles, pumps, and suits. A Delta Temax representative who came to the demonstration site provided approximately five hours of training. An additional five hours of training was provided for FEMP-specific requirements.

The PPE used for the PICS demonstration was the same as the baseline, except for the addition of the PICS.

Table 2 summarizes the operational parameters and conditions of the PICS demonstration.

Table 2. Operational parameters and conditions of the PICS demonstration

Working Conditions	
Work area location	Building 68 at the FEMP site.
Work area description	Exposed indoor structural steel framing being cleaned and painted.
Work area hazards	Hot temperatures in the work area. Limited mobility due to PPE. Scaffolding.
Labor, Support Personnel, Specialized Skills, Training	
Work crew	Normal work crew with one additional part-time support person to aid in donning and doffing the pump backpack and to change ice bottles.
Additional support personnel	Full-time demonstration data taker. Radiation Technician and a Health and Safety Officer to monitor work in progress.
Training	No additional training was required, as the D&D laborers were already working at the site.
Equipment Specifications, Operational Parameters, and Portability	
Equipment design purpose	To provide core body temperature cooling.
Dimensions/weight	Pump unit: 8.5 lbs. fully loaded (including 2 liters of water). Three piece garment: 3.5 lbs. Ice bottle: 2 liters, 8”x6”x3”
Portability	The Pump Unit is worn on the body with a harness and can be mounted on the back, chest, or waist. A backpack was used for this demonstration.
Cooling Duration	A 2-liter ice bottle provides approximately 30 to 50 minutes of operation.
Materials Used	
Ice	The 2-liter ice bottles are filled with tap water and frozen.
Personal protective equipment	Tyvek disposable suit. Cotton glove liners. Nitrile gloves. Rubber shoe covers. Respirator (full-face, airline).
Utilities/Energy Requirements	
Equipment	Pump Unit requires four alkaline D cell batteries. Freezer. Portable cooler for storage of ice bottles.
Utilities	Electricity for freezer. Water for ice.

.

SECTION 3

PERFORMANCE

Demonstration Plan

Demonstration Site Description

The PICS was demonstrated in Building 68 at the FEMP site. Because the technology demonstrated is not in itself a decontamination technology, the location and types of contamination and equipment at the site are not important. Instead, the site allowed normal types of D&D work to be performed under standard conditions (in this case moving and climbing scaffolding and cleaning and painting structural steel). The PICS was demonstrated over a period of three days and over a range of temperatures in the work areas evaluated. The work area temperatures for the demonstration periods on those days were 105, 80, and 102ºF.

Demonstration Objectives

The main objective of the demonstration was to assess heat stress management using the PICS as an alternative to the baseline of limiting stay times and using cool-down rooms. This investigation assessed the PICS based on its performance, relative to the baseline stay times, in achieving the following demonstration objectives:

- increased worker stay time,
- increased work productivity,
- reduced costs,
- increased worker well being and comfort,
- decreased consumption of PPE, and
- reduction in overall D&D schedules.

Demonstration Boundaries

The demonstration of the PICS evaluated productivity based only on total time worked (i.e., cumulative stay time) out of a 10-hour day. The amount of work performed (for example, square feet of surface cleaned or pounds of material removed) was not directly measured due to the varied tasks being performed during the demonstration period. Also, the productivity increase for a specific job or task was not determined; rather, the PICS was evaluated to determine its effect on productivity for a variety of tasks in actual DOE working situations.

Treatment Performance

The PICS technology was demonstrated over three days during which workers were cleaning and painting structural steel in Building 68. The performance of the PICS was assessed against the demonstration objectives outlined above.

Performance relative to demonstration objectives

Table 3 summarizes the overall performance results of the baseline and PICS technologies for each of the demonstration objectives listed above.

Table 3. Performance Comparison between Baseline and PICS Technologies

Performance Factor	Limited Stay Times (Baseline)	PICS (Innovative)
Average Stay Time	100 min. (70 - 85ºF) 23 min (> 85ºF)	160 min. (70 - 85ºF) 92 min (> 85ºF)
Average Rest Time due to Heat Stress Management[1]	50 min. (70 - 85ºF) 30 min (> 85ºF)	0 min. (70 - 85ºF) 0 min (> 85ºF)
Cost per Productive Crew-Hour[2]	$120.25/hr (70 - 85ºF) $242.88/hr (> 85ºF)	$73.35/hr (70 - 85ºF) $83.68/hr (> 85ºF)
PPE Usage	Cost of $14.93/man-hour for PPE	Cost of $8.12/man-hour for PPE
Worker Comfort	Very uncomfortable conditions while in PPE in a hot working environment. Workers experience fatigue, are less alert, and more susceptible to heat stress.	Cooler body temperature and less fatigue as a result of the PICS. One worker commented that he felt his energy level was much greater with the PICS.
Overall D&D Schedule	Limited stay times reduce the amount of work performed in a work shift.	Longer stay times and resulting higher productivity could accelerate D&D schedules.

[1] These rest times only include breaks for managing heat stress and do not include other regular breaks throughout the work day.

[2] The Cost per Productive Crew-Hour is the average cost of a two-person crew to conduct one hour of field work considering both productive time in the field and non-productive time outside of the field including breaks needed for heat stress management, safety meetings, and regular breaks.

Increased Worker Stay Time and Productivity

Worker stay times are defined by the FEMP's Safety Performance Requirements (see Appendix C for an excerpt) and are based on temperature in the work area, work load (light, moderate, or heavy), and work clothing and PPE. For example, allowed stay times dramatically decrease at temperatures over approximately 85ºF and when impermeable PPE and respirators are required. However, with the PICS, the workers were able to stay much longer, and in one case more than four times as long. These lengthened stay times dramatically improved work productivity, because less time is lost to cool-down breaks and additional donning and doffing of PPE.

Reduced Costs

Cost savings from using the PICS come largely from the increase in productivity, resulting from longer stay times and fewer work stoppages. More work can be accomplished in a work shift than in the baseline situation. Cost advantages are also realized in the decrease of PPE usage. Since the workers don and doff less disposable PPE because of the fewer cool-down breaks, overall PPE costs per hour of productive labor are reduced.

Costs calculated for this report were for a task that would require a crew of two working one 40-hour week if there were no requirements for breaks, safety meetings, or heat stress management (80 total productive man-hours). The 80 hours were divided by the efficiency calculated for each scenario (baseline and PICS for both temperature ranges) to determine the number of actual labor hours required for the task. The cost calculations are then based on those labor hours and associated labor costs and the cost of PPE. The PPE costs were developed on a per-man-hour basis.

Increased Worker Well Being and Comfort

The use of anti-contamination PPE significantly stifles the body's own ability to cool itself, which can lead to uncomfortable working conditions, fatigue, injury, and, at worst, a serious life-threatening medical condition. By wearing the PICS, the workers were able to stay cooler in the hot work environment. While this improvement is difficult to quantitatively measure, positive feed back from the workers wearing the PICS indicates that the technology is very effective. Comments included a "one hundred percent better comfort level" than wearing an ice vest as well as improved energy levels, particularly while performing strenuous activities such as climbing scaffolding.

Decreased Consumption of PPE

Because the PICS allows longer stay times, fewer rest periods will be required per shift. Therefore, fewer doffings of disposable PPE are required, decreasing overall consumption of PPE.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

The PICS PPE suit is a mature and commercialized technology for reducing core body temperature. The post-demonstration assessment of the PICS is summarized below.

- The stay times in the work area are greatly increased when using the PICS. The higher the temperature in the work area, the more effective the suit.
- The PICS reduces elevated core body temperature and creates a safer work environment by reducing the likelihood of heat related stress and injuries. The higher the temperature in the work area, the better the benefit of the PICS.
- The PICS provides a much more comfortable work environment. One worker noted the difference in amount of energy he had when wearing the PICS over PPE alone with no cooling.

The PICS PPE suit is an applicable technology for use at Fernald and other D&D sites. The large numbers of tasks to be performed in high temperature work areas (primarily in non-air conditioned buildings in the summertime) warrant its use as a more effective means of performing the work. Cost savings for PPE and improved safety also make the PICS superior to using only limited stay-times.

Competing Technologies

The major competing technology to the PICS is an ice vest. Ice vests use cooling gel (ice packs) in pockets front and rear on a torso vest. The user wears the vest over the first layer of PPE (cloth overalls at FEMP), and the ice packs are inserted into the vest pockets. The initial cooling with the ice is often extreme, which can make workers too cold. Also, the ice packs in the vest are effective for a limited time, and then the vest must be changed, requiring a doffing of PPE and exit from the contaminated area of work. Many laborers do not like to wear the ice vests and prefer to take more frequent rest and cool-down breaks.

Another technology is Oceaneering Space Systems' Advanced Worker Protection System (AWPS), a self-contained, extended-service-time breathing and cooling system. The AWPS uses a liquid-air backpack to provide air to workers for both breathing and cooling. Breathing air is provided to a pressure-demand respirator worn by the worker. Air is also used to cool water that is circulated in a liquid-cooled garment worn against the worker's skin.

Patents/Commercialization/Sponsor

The technology has been patented by the technology developer, Delta Temax Inc., from which it can be purchased. The PICS has been used in industry, defense, motorsports, security, and medical markets worldwide. There are no issues related to patents, commercialization, or sponsorship.

SECTION 5

COST

Introduction

A cost analysis was performed to evaluate the PICS and the baseline heat stress management approach and to determine the potential cost savings the PICS may offer. The objective is to assist decision makers who are selecting from among competing technologies. The analysis strives to develop realistic estimates that represent actual D&D work within the DOE weapons complex. However, this is a limited representation of actual cost, because the analysis uses only data observed during the demonstration. Some observed data were eliminated or adjusted to make the estimates more realistic. These adjustments were made only when they would not distort the fundamental elements of the data (i.e., did not change the production rate, quantities, work elements, etc.). Only those activities judged atypical of normal D&D work were eliminated. Any adjustments made to observed data are described in later portions of the cost analysis. The *Detailed Technology Report for the PICS* provides additional cost information and is available from the FEMP.

Methodology

The cost analysis compares an innovative PPE system, the PICS, to a baseline heat stress management approach without cooling used to perform D&D work at the FEMP. The innovative PPE system was demonstrated at Fernald Building No. 68 by a D&D subcontractor performing cleaning and painting of the structural steel framing inside Building No. 68. For the baseline approach, a scenario was created for the same work activities. Performance data for the baseline approach was based on the Fernald Safety Performance Requirements, SPR 12-10, Revision 0.2, which establishes work/rest cycles for various PPE systems and ambient temperature ranges.

The PICS is designed to reduce the heat stress experienced by workers. Heat stress is magnified by the PPE required for working in a controlled area at the FEMP. Baseline PPE worn at the FEMP typically consists of anti-contamination PPE with air purifying respirators (Level C). During periods of warm weather, ambient temperatures in work areas can exceed 100ºF. According to the *Productivity Study for Hazardous, Toxic and Radioactive Waste Remediation Projects* (US Army Corps of Engineers, October 1994), workers performing heavy work activities in Level C PPE at temperatures above 85ºF have significantly diminished productivity. Much of the productivity loss under these conditions is due to mandatory heat stress breaks, which account for losses of about 3 hours out of an 8-hour day. A PPE system that can prolong worker stay times should increase productivity, thus decreasing both the duration and cost of D&D activities.

To analyze the cost effectiveness of the PICS, workers performing D&D work within Building 68 were monitored while wearing Level C PPE with the PICS. Data collected were used to calculate the average stay times wearing the PICS. Temperature variations experienced during the demonstration allowed data to be collected for two of the temperature ranges found in the *Productivity Study for Hazardous, Toxic and Radioactive Waste Remediation Projects*: 70 - 85ºF and > 85ºF. Stay times for the baseline PPE system were based on the work/rest cycles outlined in SPR 12-10. The baseline PPE system evaluated was single anti-contamination PPE with full-face airline respirator.

Average stay times were determined from the data collected and used to calculate the relative efficiency rates for crews wearing baseline and innovative PPE systems. An MCACES cost estimate was created for D&D work using identical crews. The unit of measure used in MCACES was crew-hours with a crew size of two. The calculated efficiency rates were used as the production rates in the cost estimate. This gave a unit cost for the D&D work that reflects savings due to the extended stay times and higher efficiencies provided by the PICS innovative PPE system.

Cost Analysis

Workers at the FEMP work a four-day work week with four 10-hour days. This 10-hour day was used in calculating crew efficiency rates for the PPE systems.

About 10 hours of training per worker was allowed for orientation and familiarization with the PICS.

Tables 4 and 5 show the average stay times and rest times. Values for the PICS were observed during the demonstration. Values for the baseline were determined from the FEMP SPR 12-10.

Table 4. Average Stay Times

Temperature Range (ºF)	PICS w/Level C PPE (Innovative)	Level C PPE (Baseline)
70 - 85	160 minutes	100 minutes
> 85	92 minutes	23 minutes

Table 5. Average Rest Times due to Heat Stress Management[1]

Temperature Range (ºF)	PICS w/Level C PPE (Innovative)	Level C PPE (Baseline)
70 - 85	0 minutes	50 minutes
> 85	0 minutes	30 minutes

[1] These rest times only include breaks for managing heat stress and do not include other regular breaks throughout the work day.

Efficiencies were calculated for each temperature range and PPE system as shown in Appendix D. These efficiencies represent the number of productive work hours available for each paid 10-hour shift. Non-productive hours include paid time for the crew outside of the field due to heat stress management, PPE donning and doffing, safety meetings, and regular breaks. The efficiencies of baseline and innovative PPE systems are shown in Table 6.

Table 6. Efficiencies

Temperature Range (ºF)	PICS w/Level C PPE (Innovative)	Level C PPE (Baseline)
70 - 85	62.1%	44.2%
> 85	54.0%	23.3%

The relative costs of the two PPE systems are shown in Table 7. A summary of cost elements is presented in Appendix E.

Table 7. Relative PPE System Costs

PPE System	PICS w/Level C PPE (Innovative)	Level C PPE (Baseline)
Initial Cost[1]	$1,618	$212
Life Expectancy	4,800 hr for PICS, same as baseline for other PPE items	200 hr for reusable PPE items, 10 hr for disposable PPE items
Maintenance/Repair Costs[2]	$170/year	N/A
Cost per man-hour[3]	$8.12	$14.93

[1] Initial cost is for one complete set of PPE items. The initial cost for the innovative PPE system includes the cost of one set of baseline PPE items.
[2] Maintenance and repair costs are for an individual PICS unit.
[3] Cost per man-hour is based on two changes of PICS PPE per day and four changes of baseline PPE per day as observed during the demonstration.

Cost Conclusions

The cost analysis shows that for ambient temperatures between 70 and 85ºF, the PICS has a productivity gain of about 40%. For ambient temperatures greater than 85ºF, the PICS has a productivity gain of nearly 132%. The unit cost savings (per crew of two) that result from use of the PICS are (rounded to the nearest dollar):

$47/crew-hour - 70 - 85ºF
($120.25/crew-hour baseline minus $73.35/crew-hour PICS)

$159/crew-hour - > 85ºF
($242.88/crew-hour baseline minus $83.68/crew-hour PICS)

The pay-back period for the PICS was calculated by dividing the $1,406 capital cost difference between the two PPE systems by the unit cost savings for each ambient temperature range. This calculation shows that pay-back is achieved for the PICS as follows:

30 crew-hours - 70 - 85ºF

9 crew-hours - > 85ºF

The analysis also shows that the cost savings resulting from use of the PICS increase as the ambient temperature increases.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

The regulatory and permitting regulations related to the use of the PICS technology consist of compliance with Occupational Safety and Health Administration (OSHA) regulations. Since the PICS was designed specifically for worker comfort, there are no regulatory requirements to apply CERCLA's nine evaluation criteria.

Safety, Risks, Benefits, and Community Reaction

Worker safety issues are of highest importance when using the PICS. While the PICS is designed to effectively manage heat stress, physiological monitoring and the recognition of the onset of heat stress symptoms are still critical. It is also important to recognize that each worker's susceptibility to heat stress can be different, affected by factors such as personal physical fitness and health (weight, age, heart and respiratory condition), the worker's state of acclimatization, fluid replacement, personal habits (alcohol intake, smoking habits), pre-existing dehydration, and medication (diuretics, sedatives, tranquilizers, blood pressure medication). Monitoring by an industrial hygienist should always be provided while working in hot temperatures, even if the PICS is used.

There are no socioeconomic impacts or negative community perceptions associated with the PICS.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The PICS is a very successful and effective piece of technology and should be used at the FEMP and other sites to manage heat stress in workers. The higher the temperature in the work area, the more effective the PICS in increasing worker well being and productivity.

There are no major implementation considerations regarding the PICS due to the technology's relative simplicity. Extra don and doff time for PPE and the availability of a freezer for the ice bottles are the biggest implementation factors. If the ice bottles are to remain in the contamination zone during the project, a freezer should also be located in the same area to prevent cross-contamination by bringing the bottles in and out on a frequent basis.

Technology Limitations and Needs for Future Development

The PICS performed without any significant technical or mechanical problems during the demonstration, and there appears to be no need for future development.

Technology Selection Considerations

The PICS is recommended as an excellent technology to manage heat stress in situations involving hot work environments. Only when the tasks to be performed are shorter than the health and safety stay times (based on temperature and type of PPE worn) would the PICS not be recommended. The opportunity to reduce a facility's overall D&D schedule, provide cost savings, and reduce health and safety risks for the D&D laborers are compelling reasons to justify the selection of the PICS as the baseline technology for heat stress management.

Size selection of the garment is important in providing effective cooling. The garment should be body-snug to allow efficient heat transfer from the body to the cooling tubes. If too large a size is used, the suit may not contact the body in all areas.

APPENDIX A

REFERENCES

Fernald Environment Management Program, *SPR Manual, RM-0021*, "Safety Performance Requirements, Working in Hot Temperatures, SPR-12-10, Revision 0.2," U.S. Department of Energy's Fernald Environmental Management Project, Cincinnati, Ohio, April 1996.

Fluor Daniel Fernald, *Detailed Technology Report for the Personal Ice Cooling System, Large Scale Demonstration and Deployment Project*, U.S. Department of Energy's Fernald Environmental Management Project, Cincinnati, Ohio. To be published.

U.S. Army Corps of Engineers (USACE), *Hazardous, Toxic, and Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary*, USACE, 1996.

U.S. Army Corps of Engineers (USACE), *Construction Equipment Ownership and Operating Expense Schedule*, Washington D.C., August 1995.

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**
AWPS	Advanced Worker Protection System
CFR	Code of Federal Regulations
D&D	Decontamination and Decommissioning
DDFA	Deactivation and Decommissioning Focus Area
DOE	Department of Energy
^{o}F	Degrees Fahrenheit
FDF	Fluor Daniel Fernald
FETC	Federal Energy Technology Center
FEMP	Fernald Environmental Management Project
Hr	hour
LSDDP	Large-Scale Demonstration and Deployment Project
Min	minute
OEM	Office of Environmental Management (of the DOE)
OSHA	Occupational Safety and Health Administration
OST	Office of Science and Technology
PICS	Personal Ice Cooling System
PPE	Personal protective equipment
SPR	Safety Performance Requirements
USACE	United States Army Corps of Engineers

APPENDIX C

EXCERPT FROM SAFETY PERFORMANCE REQUIREMENTS

Table C.1. Heat Stress Work Limit Guidelines

Protective Clothing (number of layers)			Respiratory Protection		Work Area Temperature (ºF)	Work Stay Time
Anti-Cs	Semipermeable	Impermeable	Negative Pressure	Air Supplied		
1					83 90 96	120 minutes 60 minutes 30 minutes
1	1				60 67 75 83 90 96	150 minutes 120 minutes 90 minutes 60 minutes 35 minutes 20 minutes
1		1			60 67 75 83 90 96	90 minutes 60 minutes 45 minutes 30 minutes 15 minutes 10 minutes
1			Respirator		83 90 96	90 minutes 40 minutes 25 minutes
1	1		Respirator		60 67 75 83 90 96	105 minutes 90 minutes 60 minutes 45 minutes 25 minutes 15 minutes
1		1	Respirator		60 67 75 83 90 96	45 minutes 30 minutes 20 minutes 15 minutes 10 minutes 5 minutes
1				Full face airline	75 83 90 96 105*	110 minutes 100 minutes 45 minutes 25 minutes 20 minutes*
1	1			Full face airline	60 67 75 83 90 96	120 minutes 100 minutes 75 minutes 50 minutes 30 minutes 15 minutes
1		1		Full face airline	60 67 75 83 90 96	75 minutes 45 minutes 30 minutes 20 minutes 15 minutes 10 minutes

* During the demonstration, the health and safety officer reduced the stay time to 20 minutes even though not specifically called for in the SPRs.

The above table was excerpted from the FEMP's Safety Performance Requirements.

APPENDIX D

EFFICIENCY CALCULATIONS

Data are available from the PICS demonstration and the FEMP's Safety Performance Requirements (SPR12-10). Shift length at the FEMP is 10 hours.

Baseline Work Cycle:

For 70-85 ºF
Stay time = 100 min
PPE don time = 10 min
PPE doff time = 10 min
Rest time = 50 min
Work cycle = 100 + 10 + 10 + 50 = <u>170 minutes</u>

For >85 ºF (102º and 105º)
Average Stay time = (20 + 25)/2 = 22.5 min
PPE don time = 10 min
PPE doff time = 10 min
Rest time = 30 min
Work cycle = 22.5 + 10 + 10 + 30 = <u>72.5 minutes</u>

PICS Work Cycle:

For 70-85 ºF
Stay time = 160 min
PPE don time = 20 min
PPE doff time = 13 min
Rest time = 0 min
Work cycle = 160 + 20 + 13 + 0 = <u>193 minutes</u>

For >85 ºF (102º and 105º)
Average Stay time = (80 + 103)/2 = 91.5 min
PPE don time = 21.5 min
PPE doff time = 14 min
Rest time = 0 min
Work cycle = 91.5 + 21.5 + 14 + 0 = <u>127 minutes</u>

Total Work Hours per Day:

Morning planning/safety meeting = 30 min
Mandatory breaks (2 @ 15 min) = 30 min
Lunch period = 60 min
Evening clean up = 30 min
Total breaks = 30 + 30 + 60 + 30 = 150 minutes = 2.5 hours
Total work hours = 10 – 2.5 = <u>7.5 hours/day available</u>

Baseline Efficiency:

For 70-85 ºF

$$\frac{7.5\text{ hr}}{\text{day}}\times\frac{1\text{ cycle}}{170\text{ min}}\times\frac{60\text{ min}}{\text{hr}}=2.65\text{ cycles / day}$$

$$\frac{2.65\text{ cycles}}{\text{day}}\times\frac{100\text{ min}}{\text{cycle}}\times\frac{1\text{ hr}}{60\text{ min}}=4.42\text{ hr / day productive}$$

$$\frac{4.42\text{ hr}}{10\text{ hr}}=44.2\%\text{ efficiency}$$

For >85 ºF

$$\frac{7.5\text{ hr}}{\text{day}}\times\frac{1\text{ cycle}}{72.5\text{ min}}\times\frac{60\text{ min}}{\text{hr}}=6.21\text{ cycles / day}$$

$$\frac{6.21\text{ cycles}}{\text{day}}\times\frac{22.5\text{ min}}{\text{cycle}}\times\frac{1\text{ hr}}{60\text{ min}}=2.33\text{ hr / day productive}$$

$$\frac{2.33\text{ hr}}{10\text{ hr}}=23.3\%\text{ efficiency}$$

PICS Efficiency:

For 70-85 ºF

$$\frac{7.5\text{ hr}}{\text{day}}\times\frac{1\text{ cycle}}{193\text{ min}}\times\frac{60\text{ min}}{\text{hr}}=2.33\text{ cycles / day}$$

$$\frac{2.33\text{ cycles}}{\text{day}}\times\frac{160\text{ min}}{\text{cycle}}\times\frac{1\text{ hr}}{60\text{ min}}=6.21\text{ hr / day productive}$$

$$\frac{6.21\text{ hr}}{10\text{ hr}}=62.1\%\text{ efficiency}$$

For >85 ºF

$$\frac{7.5\text{ hr}}{\text{day}}\times\frac{1\text{ cycle}}{127\text{ min}}\times\frac{60\text{ min}}{\text{hr}}=3.54\text{ cycles / day}$$

$$\frac{3.54\text{ cycles}}{\text{day}}\times\frac{91.5\text{ min}}{\text{cycle}}\times\frac{1\text{ hr}}{60\text{ min}}=5.40\text{ hr / day productive}$$

$$\frac{5.40\text{ hr}}{10\text{ hr}}=54.0\%\text{ efficiency}$$

APPENDIX E

SUMMARY OF COST ELEMENTS

Table E.1. Details of Major Cost Elements

Fixed Costs

Description	Man hrs	Labor	Equipment	Materials	Other	Total
Baseline						
Mobilization (training)	0	$0	$0	$0	$0	$ 0
Total	**0**	**$ 0**	**$ 0**	**$ 0**	**$ 0**	**$ 0**
PICS						
Mobilization (training)	20	$268	$0	$0	$0	$ 268
Total	**20**	**$ 268**	**$ 0**	**$ 0**	**$ 0**	**$ 268**

Variable Costs

Description	Quantity	Unit	Man hrs	Labor	Equipment	Materials	Other	Total	Unit Cost
Baseline (70<T<85)	40	crew-hrs							
D&D Work			181	$2,346	$75	$0	$0	$2,421	**$ 60.53**
PPE			0	$0	$0	$0	$2,389	$2,389	**$ 59.73**
Total	**40**	**crew-hrs**	**181**	**$2,346**	**$ 75**	**$ 0**	**$2,389**	**$4,810**	**$ 120.25**
Baseline (T>85)	40	crew-hrs							
D&D Work			343	$4,451	$143	$0	$0	$4,594	**$ 114.85**
PPE			0	$0	$0	$0	$5,121	$5,121	**$ 128.03**
Total	**40**	**crew-hrs**	**343**	**$4,451**	**$ 143**	**$ 0**	**$5,121**	**$9,715**	**$ 242.88**
PICS (70<T<85)	40	crew-hrs							
D&D Work			129	$1,670	$54	$0	$0	$1,724	**$ 43.10**
PPE			0	$0	$0	$0	$1,210	$1,210	**$ 30.25**
Total	**40**	**crew-hrs**	**129**	**$1,670**	**$ 54**	**$ 0**	**$1,210**	**$2,934**	**$ 73.35**
PICS (T>85)	40	crew-hrs							
D&D Work			148	$1,921	$62	$0	$0	$1,983	**$ 49.58**
PPE			0	$0	$0	$0	$1,364	$1,364	**$ 34.10**
Total	**40**	**crew-hrs**	**148**	**$1,921**	**$ 62**	**$ 0**	**$1,364**	**$3,347**	**$ 83.68**

Total Costs

Description	Quantity	Unit	Man hrs	Labor	Equipment	Materials	Other	Total	Unit Cost
Baseline (70<T<85)	**40**	**crew-hrs**	**181**	**$2,346**	**$75**	**$0**	**$2,389**	**$4,810**	**$120.25**
Baseline (T>85)	**40**	**crew-hrs**	**343**	**$4,451**	**$143**	**$0**	**$5,121**	**$9,715**	**$242.88**
PICS (70<T<85)	**40**	**crew-hrs**	**149**	**$1,929**	**$62**	**$0**	**$1,210**	**$3,201**	**$80.03**
PICS (T>85)	**40**	**crew-hrs**	**168**	**$2,180**	**$70**	**$0**	**$1,364**	**$3,614**	**$90.35**

Table E.2. Personal Protective Equipment Costs and Requirements per Crew Member

Cost Assumptions:

Daily Shift Length:	10	hrs
Useful Life of Reusable PPE Items:	200	hrs
Useful Life of PICS:	4800	hrs

Reusable PPE - Daily Requirements[1]			Heat Stress Management by Stay Times (Baseline)		Heat Stress Management using PICS (Innovative)	
Item	**Unit Cost**	**Unit**	**Quantity**	**Total Cost**	**Quantity**	**Total Cost**
Full-face respirators	$174.00	ea.	4	$696.00	2	$348.00
Hourly Reusable PPE Cost				**$ 3.48**		**$ 1.74**

Reusable PPE – PICS Suits			Heat Stress Management by Stay Times (Baseline)		Heat Stress Management using PICS (Innovative)	
Item	**Unit Cost**	**Unit**	**Quantity**	**Total Cost**	**Quantity**	**Total Cost**
Personal Ice Cooling System	$1,406.00	ea.	0	$0.00	2	$2,812.00
PICS maintenance costs	170.00	ea.	0	0.00	2	340.00
Hourly PICS Cost				**$ 0.00**		**$ 0.66**

Disposable PPE - Daily Requirement[2]			Heat Stress Management by Stay Times (Baseline)		Heat Stress Management using PICS (Innovative)	
Item	**Unit Cost**	**Unit**	**Quantity**	**Total Cost**	**Quantity**	**Total Cost**
Tyvek suits	$4.09	ea.	4	$16.36	2	$8.18
Cotton glove liners	0.28	pair	4	1.12	2	0.56
Nitrile gloves	0.24	pair	4	0.96	2	0.48
Rubber shoe covers	12.28	pair	4	49.12	2	24.56
Respirator cartridges	11.74	pair	4	46.96	2	23.48
Hourly Disposable PPE Cost				**$11.45**		**$5.73**
TOTAL HOURLY PPE COST				**$ 14.93**		**$ 8.12**

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

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