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INNOVATIVE TECHNOLOGY
Summary Report

Sealed-Seam Sack Suits

Deactivation and
Decommissioning Focus Area

Prepared for
U.S. Department of Energy
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DISCLAIMER

INNOVATIVE TECHNOLOGY
Summary Report

Sealed-Seam Sack Suits

OST Reference #1954

Decontaminaton and
Decommissioning Focus Area

Demonstrated at
Hanford Site
Richland, WA

Purpose of this Document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if 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 online at http://em-50.em.doe.gov.

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SECTION 1

EXECUTIVE SUMMARY

Technology Summary

Sealed-seam sack suits are an improved/innovative safety and industrial hygiene technology designed to protect workers from dermal exposure to contamination. Most of these disposable, synthetic-fabric suits are more protective than cotton suits, and are also water-resistant and gas permeable. Some fabrics provide a filter to aerosols, which is important to protection against contamination, while allowing air to pass, increasing comfort level of workers. It is easier to detect body-moisture breakthrough with the disposable suits than with cotton, which is also important to protecting workers from contamination. These suits present a safe and cost-effective (6% to 17% less expensive than the baseline) alternative to traditional protective clothing.

This section summarizes the demonstration of an innovative technology, disposable sealed-seam sack suits, that protects workers from potential dermal exposure when performing work in contaminated areas. The suits that were demonstrated included four suits made by Kappler: NuFab, Pro/Shield 1 and 2, and Tyvek. Two other suits, Comfort Guard 150 and Frham KoolSuit, were also demonstrated. Each is designed for one-time use and is made of synthetic fabric, with sewn or bounded seams. Each suit has zippered closures with open necks. Except for one, all of the fabrics were found to be water-resistant and vapor permeable. This technology performed better than the cotton baseline suit at protecting workers from contamination, and it was easier to detect body moisture breakthrough, adding to the protectiveness of the suits.

Problem Addressed

The U.S. Department of Energy's (DOE) nuclear facility decontamination and decommissioning (D&D) program, managed at the Hanford Site by Bechtel Hanford, Inc. (BHI), needs to decontaminate and decommission buildings that are often highly contaminated. Conducting these D&D activities in a safe manner is a primary objective of the DOE. The DOE and BHI wanted to determine if there were safe, cost-effective alternatives to the commonly used protective clothing designed to prevent workers from dermal exposure to contamination. Therefore, a number of disposable sealed-seam sack suits were demonstrated as potential alternatives to the baseline technology, which is a washable cotton coverall.

Features

The sealed-seam sack suits used for this demonstration were:

- Comfort Guard 150
- Frham KoolSuit
- Kappler NuFab
- Kappler Pro/Shield 1
- Kappler Pro/Shield 2
- Kappler Tyvek.

The features common to the suits were:

- Disposable/one-time use
- Synthetic material
- Sewn seams (except for the Frham KoolSuit, which has bounded seams)
- Zipper closures with open necks
- Commercially available.

Potential Markets

The innovative technology is applicable wherever workers must perform duties in potentially contaminated or contaminated locations where personal protective clothing is necessary to protect workers from exposure. This technology can be used at DOE sites as well as U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency sites. It would be equally applicable to commercial facilities where contamination could exist.

Advantages of the Innovative Technology

The following table summarizes the advantages of the innovative technology against the baseline in key areas:

Category	Comments
Cost	Lower than baseline (6% lower with year-round use; 17% lower when combined with seasonal use of cotton suits)
Performance	Better than the baseline in providing overall contamination control
Implementation	No special site services are required for implementing the technology
Secondary Waste Generation	Disposable suits generate secondary compactible waste
ALARA/Safety	Use of this tool increases ALARA and safety compared to the baseline
Ease of use	As with baseline, training and use of the innovative suits are easy

Disadvantages/Concerns

The sealed-seam sack suits are part of personal protective equipment, and the prescribed contamination control practices should be implemented when they are used, especially when exiting a highly contaminated area. In addition, the innovative suits tear easier than the baseline suit when they come in contact with sharp objects.

Skills/Training

No special training is required for the use of the innovative technology. Because D&D workers are provided with training on personal protective equipment, required training of D&D workers in the use of the innovative technology was minimal (approximately 5 minutes of instruction and practical factor on-the-job training).

Demonstration Summary

This report covers the period from October 1996 to August 1997. During that time, sealed-seam sack suits were demonstrated during daily activities under normal working conditions at the C Reactor and under environmentally controlled conditions at the Los Alamos National Laboratory (LANL).

Demonstration Site Description

At its former weapons productions sites, the DOE is conducting an evaluation of innovative technologies that might prove valuable in D&D activities. As part of the Hanford Site Large-Scale Technology Demonstration at the C Reactor Interim Safe Storage Project, at least 20 technologies will be tested and assessed against baseline technologies currently in use. DOE's Office of Science & Technology/Deactivation & Decommissioning Focus Area, in collaboration with the Environmental Restoration Program, is undertaking a major effort of demonstrating improved and innovative technologies at its sites nationwide. If the demonstrated technologies are proven successful at the Hanford Site, they could be implemented at other DOE sites and similar government or commercial facilities.

Applicability

The DOE-Richland Operations Office (DOE-RL) has successfully completed a demonstration to verify the capabilities of sealed-seam sack suits. These suits represent an innovative technology that can be used where ever there is a need to protect personnel from dermal exposure to contaminants. The suits can be worn either indoors or outside in a range of temperatures and conditions. They are applicable for use in both federal facilities and commercial operations. Sealed-seam sack suits are available from many protective clothing distributors.

Key Demonstration Results

Although the performance of the sealed-seam sack suits would be impacted by site-specific environmental factors and the individuals using them, in general, the disposable suits were found to be as comfortable as the cotton baseline, and were easier to take off than the baseline. The site- and individual-specific factors that would impact performance of these suits include:

- The type and number of layers of protective clothing worn
- Heat generated within the body (metabolic heat)
- The heat gained, if any, from the environment
- Other environmental conditions (e.g., air temperature, air velocity, and humidity).

In spite of these performance factors, key results can be generalized for all the sealed-seam sack suits tested as follows:

- All suits were demonstrated to be essentially equivalent in terms of durability and level of comfort.

- These disposable suits reduced the chance of skin contamination over reusable garments, such as the baseline. (Laundering the reusable suits does not always remove all of the contamination; and/or screening laundered suits does not always detect the contamination).

- Body moisture breakthrough is more easily detected using disposable suits--particularly the Pro/Shield 1. (The protective barrier provided by contamination control clothing is typically degraded as body moisture increases; therefore, early detection of body moisture breakthrough is important to protection of workers.)

- Contaminated or used disposable suits require less handling (e.g., collection, transportation, laundry, drying, radiation monitoring, and delivery), and thereby reduces the potential for spreading contamination.

- The cost of using disposable suits was estimated to be less than the cost for using the baseline suit. Additionally, use of disposable suits eliminates the need for a laundry subcontract and thereby reduces account management costs.

- Four of the six disposable suits--Kappler Tyvek, Frham KoolSuit, Kappler NuFab, and Kappler Pro/Shield 2--were not included in the large-scale field demonstration at C Reactor either because of cost or heat transfer/comfort level problems. However, these suits are advertised as breathable and water-resistant/waterproof (based on manufacturers' data).

- Comfort Guard 150 and Pro/Shield 1 suits have been chosen for continued use at C Reactor because they are less costly than other suits and provide adequate level of protection required by the C Reactor safety and contamination controls. The Pro/Shield 1 suit was found to be cooler than the Comfort Guard 150 suit and was selected to be used in non-winter months.

Regulatory Issues

The sealed-seam sack suit is a contamination control and prevention technology for personnel protection from contaminants, and there are no special regulatory permits required for its use. This technology can be used in daily operations keeping in mind the requirements of 10 *Code of Federal Regulations* (CFR) Parts 20, 835, and proposed Part 834 for worker and environment protection from radiological contaminants and Occupational Safety and Health Administration (OSHA) worker safety (29 CFR).

Technology Availability

The demonstration of the sealed-seam sack suits at Hanford's C Reactor was the first demonstration of this technology at a DOE facility. The demonstrated suits are all commercially available through contamination control clothing suppliers such as G/O Co.

Technology Limitations/Needs for Future Development

No limitations or needs for further development of the sealed-seam sack suits were identified.

Contacts

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Licensing Information

N/A, distributor is G/O Co (Slidell, LA), (504) 847-0564.

Other

All published Innovative Technology Summary Reports are available at http://em-50.doe.gov. The Technology Management System, also available through the EM-50 Web site, provides information about OST programs, technologies, and problems. The OST Reference # for the Sealed-Seam Sack Suits is 1954.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The DOE's nuclear decommissioning program requirements include decontaminating and decommissioning buildings and structures safely and cost effectively. Worker safety is a primary objective of DOE programs. To increase worker safety during D&D activities, particularly in contaminated areas, protective clothing is provided. The disposable sealed-seam sack suit is a viable alternative to the conventional method of protecting workers with reusable cotton coveralls.

The sealed-seam sack suits are personal protective clothing made from synthetic fabrics. Four different brands (six types) of disposable suits and one brand of reusable cotton suit were demonstrated and assessed. All disposable suits were water-resistant and vapor-permeable, except for one suit that was water-resistant and vapor-impermeable. The suits used for this demonstration are described as follows:

- Comfort Guard-150 - disposable, yellow, non-woven material.
- Frham KoolSuit - disposable, yellow, non-woven, breathable laminate
- Kappler NuFab - disposable, yellow, non-woven material with an internal membrane
- Kappler Pro/Shield 1 and 2 - disposable, white, non-woven laminate point-bonded material
- Kappler Tyvek - disposable, polyethylene-coated Tyvek (impermeable) material.
- Copiah Creek suit (baseline) - washable, white, cotton material.

Some of the material descriptions are based on examinations by the C Reactor Project and LANL because the actual material construction is proprietary. Figures 1 and 2 show the Kappler Pro/Shield 1 and Comfort Guard 150 suits.

Figure 1. Pro/Shield 1.

Figure 2. Comfort Guard 150.

The suits were donned and doffed per instructions provided by site training personnel. The general steps for this process were as follows:

- Check suit for any sign of damage
- Put suit on per instructions provided by site training personnel
- Tape wrist and ankle areas to prevent contamination penetration
- Perform the task
- Remove tape from wrist and ankle
- Remove suit and discard it in designated waste bin
- Perform personal frisking
- Exit the area.

SECTION 3

PERFORMANCE

Demonstration Plan

Site Description

The demonstration was conducted in two parts. A portion of the demonstration was conducted by BHI personnel at DOE's Hanford Site. The Hanford portion involved BHI D&D workers and radiological control technicians (RCT) wearing the sealed-seam sack suits during actual D&D activities at various locations of the C Reactor, both indoors and outside, from October 1996 to August 1997. At the C Reactor area, the D&D workers wore five of the suits during normal daily activity. At the end of each task, the workers were asked a series of specific questions regarding the performance and comfort of the suits. Their responses were recorded by the C Reactor Industrial Safety and Hygiene Officer.

Concurrently, the second part of the demonstration was conducted in Los Alamos against criteria designed by the C Reactor Industrial Safety and Hygiene Officer. LANL Industrial Hygiene and Safety Research and Development Group performed heat stress and temperature measurements in an environmental chamber and conducted two fabric penetration aerosol tests--one test on the fabric when the suit was not being worn and the other tested the suit while it was being worn by a D&D worker. Tests were conducted on all six suits using personnel of varying stature (small, medium, large) in two environmental conditions. The humidity-and temperature-controlled environmental chamber measures 3.1 m^2 (10 ft^2). The tests were conducted at 35°C (95°F) with a relative humidity of 70%, and at 0°C (32°F) with a relative humidity of 50%.

Fabric aerosol penetration assessments were conducted using equipment developed by the LANL Research and Development group. This equipment is capable of testing all types of material equally using an established change in differential pressure (DP) across the material sample. The flow through the fabric sample may vary as the DP is maintained by the equipment. This method allows non-permeable materials to be assessed aside more loosely woven materials. Aerosol penetration was monitored by sample probes that were inserted inside the suits. Heat stress tests were performed simultaneously.

Performance Objectives

The objectives of the demonstration were to evaluate the clothing vis à vis the following factors:

- Degree of protection provided by the protective clothing
- Chemical protection limitations against various hazards and the consequences of exposure
- Donning and doffing procedures
- Effectiveness of various seam sealing methods
- Clothing decontamination procedures
- Compactability of suits after use
- Keeping personnel wearing the suit cooler than baseline
- Cost similar or less than baseline
- Degree of aerosol penetration.

It was desirable to assess specific performance objectives including:

Durability

- Strength of suit material and construction to withstand physical stress of task(s) being performed.
- Ability of the fabric to resist tears, punctures, and abrasions.
- Ability of baseline suit to withstand repeated use after contamination and decontamination.

Flexibility

- Tendency for protective clothing to interfere with workers' ability to perform assigned tasks.

Effectiveness

- Ability of the material to maintain its protective integrity and flexibility under temperature extremes
- Duration of preventing contaminant breakthrough and degradation of the chemical protective qualities.

Compatibility with Other Equipment

- Propensity of clothing to preclude use of other necessary protective equipment.

Technology Demonstration Results

Baseline Technology

The baseline technology used was the washable, reusable Copiah Creek suit, which is constructed of white cotton duct material.

Innovative Technology

Not all suits were tested at both the LANL and BHI locations. Table 1 identifies the number of suits that were laboratory tested by LANL at Los Alamos and field tested at Hanford.

Table 1. Suits tested by LANL and BHI for the demonstration

Type of Suit	Dates	# of Suits Tested at LANL	# of Suits demonstrated at C Reactor
Frham KoolSuit	Jan. 1997	10	40
Kappler Pro/Shield 2	Mar. 1997	10	90
Comfort Guard-150	Oct. 1996 - Mar. 1997	10	4,000
Copiah Creek cotton (baseline)	Oct. 1996 - Jan. 1997	10	500
Kappler NuFab	May - Aug. 1997	10	--
Kappler Tyvek	May - Aug. 1997	10	--
Kappler Pro/Shield 1	Mar. - Aug. 1997	--	3,000

Demonstration Tests and Conditions

The various tests that were conducted on the innovative technology and the baseline technology for this demonstration are described below.

Pre-/Post-Monitoring Checks

- The disposable sealed-seam sack suits were checked for any signs of tears before and after use during the demonstration at C Reactor.
- The fabrics of the sealed-seam sack suits were examined after use during the demonstration at the C Reactor to check for signs of wear or damage.
- Worker's personal protective equipment (PPE) were checked for perspiration breakthrough. The innovative suits showed less breakthrough than the baseline suit.
- Breakthrough could be observed easier and earlier with the innovative suits (this was best observed in Pro/Shield 1).

Heat Stress Environmental Chamber

This test involved monitoring the temperature and heart rate of human subjects as they wore the suits and performed activities in a temperature- and humidity-controlled chamber. The chamber was set for two conditions: 95°F with 75% humidity, and 32°F with 50% humidity.

Both the 95°F and 32°F tests of the Comfort Guard-150 worn by the tallest subject were stopped due to an elevated heart rate. The heart rates for this subject during the 95°F test condition were higher than both the average and maximum heart rates for the corresponding 32°F test condition. These results reflect the subject's physical condition and lack of acclimatization to hot, humid conditions. Most of the subjects, and especially the medium subject, expressed discomfort during the 95°F test. It must also be noted that the medium subject showed a heart rate that was slightly more elevated than the other subjects, possibly due to the subject's relative physical fitness and the fact that the subject is a moderate to heavy smoker.

Ensemble Aerosol Penetration

This test involved evaluating the performance of the suit while it was worn by a human subject to determine the level of barrier to aerosol penetration. Aerosol penetration tests were taken at thigh and torso sections of the suit. Each subject was asked to perform a series of 14 exercises.

The aerosol penetration results listed in Table 2 are an average of the total schedule of 14 exercises for each subject. In conjunction with each test, the body temperatures of the subjects were taken from the front, back, and rectal, and average delta was calculated. The amount of change in temperature is an indicator of the efficiency of the thermal barrier created by the suit material. The suits are open at the neck and contain zippers that do not completely stop the flow of air or aerosol in the suit.

Fabric Aerosol Test

This test evaluated a swatch of fabric from the suit to determine the level of barrier to aerosol penetration.

The Copiah Creek cotton material passed air and aerosol with little to no resistance. The Kappler Tyvek was a complete barrier to both air and aerosol. The Comfort Guard-150 allowed a small amount of air flow but no aerosol penetration, which means it acted as a filter. The Kappler NuFab also acted like a filter, allowing air and a very small amount of aerosol to pass. The Frham KoolSuit material could not hold pressure as the laminate coating separated from the base material.

Table 2 summarizes the demonstration of the sealed-seam sack suits and the baseline cotton suit.

Test Conclusions

Work Environment Tests

The results of interviews conducted with D&D workers and RCTs by the C Reactor Project Industrial Safety and Hygiene Department Officer indicated that a majority of the workers expressed there was no difference between the innovative suits and baseline suit. They further expressed that the innovative suits were as comfortable as the baseline. The workers indicated that taking the innovative suits off was

much easier than the baseline. In addition, the C Reactor radiological control group indicated that during the period of the demonstration they identified two minor skin contamination cases, both of which were associated with the baseline cotton protective clothing. It should be noted that, during this period, most of the protective clothing used was the innovative suits.

Table 2. Summary of sealed-seam sack suits and baseline cotton suit demonstration.

			Conducted Simultaneously	
Test	**Work Environment**	**Fabric Aerosol Penetration**	**Ensemble Aerosol Penetration**	**Heat Stress Environmental Chamber**
Test Media	D&D workers performing actual work activities wearing the suits	Swatch of fabric from the suits	Suit fabric being worn by small-, medium-, and large-stature human subjects	Small-, medium-, and large-stature human subjects in a temperature- and humidity-controlled chamber
Test Parameters	• Comfort • Resistance to tears, abrasions, punctures (for innovative suits) • Durability after repeated laundering (baseline suit) • Body moisture break-through	• Percent aerosol penetration • Resistance to air passage	• Percent aerosol penetration • Resistance to air passage	• Body temperature and heart rate at 35°C with 70% humidity • Body temperature and heart rate at 0°C with 50% humidity
Test Method	• Observation • Interviews	Subject fabric to changes in pressure while applying air and aerosol using specialized equipment	Sample probes inside suits at thigh and torso	Monitor temperature and heart rate of human subjects while performing series of 14 exercises
Primary Test Objective	Determine comfort, ease of use, durability, and body moisture breakthrough in actual work environment	Determine ability of various fabrics to pass air and filter aerosol	Determine ability of various fabrics to pass air and filter aerosol	Test thermal barrier of suit fabrics
Test Results	• No difference in comfort between innovative and baseline suits • Innovative suits were easier to take off • Two skin contaminations resulted while baseline suit was being worn	• Baseline passed air and aerosol with no resistance • Kappler Tyvek provided a complete barrier • Comfort Guard-150 and Kappler NuFab filtered aerosol, passed air • Frham KoolSuit failed to hold pressure	• Penetration ranged from 7% to 73% • Kappler Tyvek allowed large amounts of aerosol to pass (contrary to fabric aerosol penetration test results) • Comfort Guard-150 and Kappler NuFab provided better barrier than the baseline • Kappler Pro/Shield 2 ranked average compared to other materials • Frham KoolSuit compared very well with Comfort Guard-150 and NuFab (contrary to fabric aerosol penetration test results)	• Discomfort during 35°C with 70% humidity test • Delta body temperature observed ranged from 0.06°C to 0.18°C and average heart rate readings ranged from 84 to 133 beat/min

Aerosol Penetration Tests

For the fabric aerosol penetration tests, swatches of the fabric from each of the innovative suits and the cotton baseline suit were tested for their ability to pass air and filter aerosols. The ensemble aerosol penetration tests involved testing the fabric of the suits while they were being worn for performing work tasks. The suits were tested by inserting sample probes in the thigh and torso portion of the suits.

The fabric and ensemble aerosol penetration test results were compared to determine if the fabric test results could be validated under normal working conditions. Ensemble aerosol penetration measurements taken from the thigh and torso ranged from 7% to 73%, indicating that a large amount of the challenge aerosol entered the suits during testing. These results suggest that the materials are breathable, but it cannot be determined how much aerosol passed through the zippers and neck openings of the suits. The left thigh measurement was taken farther away from any of the openings and closures than the torso measurements. If only thigh measurements from the ensemble aerosol penetration test are considered, some similarity to the data recorded for the fabric aerosol tests can be seen.

Similar to the fabric test result, the ensemble aerosol penetration test data indicate that the Kappler NuFab and the Comfort Guard-150 ensembles provide a better barrier than the cotton. The results from testing the Pro/Shield 2 are similar to the fabric aerosol test data, ranking it as average when compared to the other materials and ensembles tested. Ensemble aerosol penetration test results from the Frham KoolSuit and the Kappler Tyvek are unlike the fabric aerosol test data. During the fabric aerosol tests, the Frham KoolSuit provided a very poor barrier to aerosol. However, when the entire ensemble was tested on human subjects, the data showed the KoolSuit to compare very well with the NuFab and Comfort Guard-150 ensembles. Conversely, the Kappler Tyvek, which allowed no penetration during the fabric test, allowed large amounts of aerosol to enter during testing on human subjects. The Tyvek material is stiff and does not lay close to the subjects' body, thus creating openings that allow air and aerosol to more easily flow into the suit.

Successes

- Sealed-seam sack suits were more comfortable than the baseline, cotton overalls.
- Sealed-seam sack suits were found to be easier to don and doff by the workers.
- There were fewer contamination cases with the sealed-seam sack suits than with the cotton overalls.

Shortfalls

- One of the suits, the Frham KoolSuit, provided an aerosol barrier during laboratory testing, but provided a relatively poor barrier on human subjects during actual work activities.

Comparison of Innovative Technology to Baseline

The demonstration consisted of testing six brands of disposable sealed-seam sack suits and one reusable, washable cotton suit as the baseline. Of the six innovative suits, based on the demonstration results for comfort and cost, it was determined that two suits--Comfort Guard-150 and Kappler Pro/Shield 1--warranted further evaluation and comparison to the baseline, including a cost analysis. The cost analysis is presented in Section 5. Table 3 summarizes performance of the two selected innovative suits compared to the baseline.

Meeting Performance Objectives

The objectives mentioned in the demonstration overview section were all met by the sealed-seam sack suits demonstrated.

Table 3. Comparison of innovative and baseline technologies

Activity or Feature	Innovative Technology	Baseline
	Pro/Shield 1 and Comfort Guard-150	Cotton
Donning and doffing suits	Donning the innovative suits is the same as the baseline, but doffing the innovative suits is much easier than the baseline	Donning the suit is the same as the innovative suits
Flexibility	Same as the baseline suit, but easier to manage suit in the field since handling requirements are reduced	Same as the innovative suits
Safety	Very good; better than baseline	Good
Durability	Same as baseline technology	Same as innovative technology
Ease of use	Easy	Easy
Waste generation	One-time use, should be disposed of as waste; much more compact than baseline	Washable, reusable; after life-time should be disposed of as compact waste
Utility requirements	None	Laundry uses hot water and electric power
Training	Same as baseline technology	Same as innovative technology

Variable Conditions Impacting Performance

Because of the variety of functions and facilities, the DOE complex presents a wide range of D&D work conditions. The unique working conditions for an individual job directly affect the manner in which D&D work is performed for an individual job. The innovative and baseline technology estimates presented in this report are based upon a specific set of conditions or work practices found at the Hanford Site. These specific conditions, which could vary at other sites, are presented in the table below. Table 4 is intended to help the technology user identify work conditions that could impact performance at different sites.

Skills/Training

No special training is required for the use of the innovative technology. Because D&D workers are provided with training on personal protective equipment, required training of D&D workers in use of the innovative technology was minimal (approximately 5 minutes of instruction and practical factor on-the-job training).

Operational Concerns

The sealed-seam sack suits are part of personal protective equipment, and usual, site-specific contamination control practices should be implemented when they are used, especially when exiting a highly contaminated area.

Table 4. Summary of variable conditions.

Variable	Sealed-Seam Sack Suits	Baseline Cotton Suit
Scope of Work		
Location of test area	Hanford's C Reactor	LANL's Environmental Chamber
Nature of work	Variety of actual D&D work activities	Series of 14 pre-defined exercises simulating D&D work activities
Work Environment		
Work environment	Actual nuclear facility in various phases of decontamination and decommissioning. Work was conducted both indoors and outside of buildings	Temperature- and humidity-controlled environmental chamber
Level of contamination in the test areas	Contaminated (fixed and loose) areas	Controlled application of pressure and aerosol
Work Performance		
Test methods	Subjective feedback from users via interview of D&D workers and observation of suits during use	Assessment of prescribed tests in controlled environments

Variable Conditions Impacting Performance

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Operational Concerns

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SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

- This technology can be used at DOE and other sites involving work activities where there is possibility of personnel contamination.
- The sealed-seam sack suit can be used both indoors and outside.
- This technology is applicable in any contaminated are where workers need to be protected from dermal exposure to contaminants.
- This technology is well suited for work in higher temperature and contaminated areas where personal protective clothing is required.
- This technology can be used at sites that involve hazardous materials or are contaminated where personnel need to wear protective clothing and perform their tasks in higher temperature areas. Contaminated areas at which remediation or D&D activities are planned (DOE, U.S. Environmental Protection Agency, or U.S. Nuclear Regulatory Commission sites).

Competing Technologies

Other brands of disposable suits and clothing made of reusable, washable fabrics are the technologies that compete with the sealed-seam sack suits. Comfort in most all of the suits assessed was the same, but cost was lower for the selected suits.

Patents/Commercialization/Sponsors

These suits are commercially available though a distributor (i.e., G/O Co [Slidell, LA]).

Technology Status

The demonstration of the sealed-seam sack suits at Hanford's C Reactor was the first demonstration of this technology (set of suits) at a DOE facility. The demonstrated suits are all commercially available through contamination control clothing suppliers such as G/O Co.

SECTION 5

COST

Introduction

As discussed in the previous portions of this report, the performance of seven types of clothing for worker protection was evaluated. Of those seven, two innovative technology suits and one baseline suit were determined to warrant further evaluation, including a cost analysis. The cost analysis presented in this section provides estimates for Comfort Guard-150 and Kappler Pro/Shield 1 and compares them with the cotton suits conventionally worn at the Hanford Site. Using a combination of these technologies, e.g., Comfort Guard-150 during the winter and the Pro/Shield 1 for the spring, summer, and fall, saves approximately 6% over wearing cotton suits year-round. Using a combination of cotton during the winter and Pro/Shield 1 during the spring, summer, and fall saves approximately 17% over wearing only cotton during the year. This cost analysis assumes that there are no differences in worker productivity associated with wearing the cotton baseline technology versus the innovative Comfort Guard-150 and the Pro/Shield 1 (see discussion of worker comfort in Section 3). Consequently, the cost comparison is based on direct costs for purchase, disposal, and laundry (cotton only).

Cost Data

The Comfort Guard-150 and Pro/Shield 1 are available from the distributor at prices indicated in Table 5:

Table 5. Innovative technology costs

PURCHASE	ITEM	COST ($ per case)
Comfort Guard-150	Medium Sized Suits (25/case) XXX Sized Suits (25/case)	113 161
Pro/Shield 1	Case (all sizes with 25/case)	75

The prices shown are for bulk purchases of 60 cases for the Comfort Guard-150 and 270 cases for the Pro/Shield 1. The cost for leggings and hoods are included in the prices shown.

Cost Conclusions

The comparison of cotton suits versus the Comfort Guard-150 and Pro/Shield 1 is based upon the average purchase price and assumes that Comfort Guard-150 and Pro/Shield 1 are worn one time and then disposed, while the cotton suit is laundered and worn several times. Costs per time worn are summarized in Table 6:

Table 6. Cost per use.

Item	Purchase Price	Disposal Cost	Service Life (# of times used)	Purchase + Disposal ÷ Service Life	Laundry Cost Per Unit	Total Cost Per Use
Cotton	$ 38 / suit	2.5 lbs / suit @ $60 / ton = $0.075	50 cycles of wearing and laundry	$0. 76 / use	$1.25 / lb @ 2.5 lbs / suit = $3.125	$3.89
Comfort Guard-150	$ 5.48 / suit	½ lb /suit @ $ 60 / ton = $ 0.015	1	$5.50 / use	$ 0	$5.50
Pro/Shield 1	$3.00 / suit	½ lb / suit @ $60 / ton = $0.015	1	$3.02 / use	$0	$3.02

The laundry costs for the cotton suits include pickup, sorting, laundry, drying, mending, radiological monitoring, folding, delivery, overhead, and fixed costs. Note that if disposal suits replace a substantial number of cloth suits, the cost to launder a cloth suit will increase, because overhead and fixed cost will be higher per cloth suit.

The cotton, Comfort Guard-150, and Pro/Shield 1 were each worn/demonstrated over periods of time that varied from 4 to 6 months between October 1996 through August 1997 at Los Alamos and at the C Reactor. The quantities of suits used for each period varied depending upon the work load and type of work, but a representative quantity is 600 suits per month. Annual cost for the cotton suit baseline is compared with two scenarios for use of the innovative technology. The first scenario assumes that Comfort Guard-150 is used for three months in the winter and the Pro/Shield 1 is used for the remaining nine months of the year. The second scenario assumes that cotton is used for three months in the winter and the Pro/Shield 1 is used for the remaining nine months of the year. The annual costs are summarized in Table 7:

Table 7. Comparison of annual cost

Alternative	Winter Quantity (600/month)	Winter Unit Cost	Spring, Summer & Fall Quantity (600/month)	Spring, Summer, & Fall Unit Cost	Total Annual Cost
Baseline - All Cotton	1800 suits	$ 3.89 per suit	5400 suits	$ 3.89 per suit	$28,008
Scenario 1 - Comfort Guard & Pro/Shield 1	1800 suits	$ 5.50 per suit	5400 suits	$ 3.02 per suit	$26,208
Scenario 2 - Cotton & Pro/Shield 1	1800 suits	$ 3.89 per suit	5400 suits	$ 3.02 per suit	$23,310

Using Comfort Guard-150 and Pro/Shield 1, as described in scenario 1, will save approximately 6% over the year-round usage of the cotton suit baseline. Using cotton during the winter and Pro/Shield 1 during the remainder of the year, as described in scenario 2, saves approximately 17% over the year-round usage of cotton suit baseline.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

- The sealed-seam sack suit is a contamination control and prevention technology for personnel protection from contaminants, and there are no special regulatory permits required for its use.
- This technology can be used in daily operations keeping in mind the requirements of 10CFR, Parts 20, 835, and proposed Part 834 for worker and environment protection from radiological contaminants and Occupational Safety and Health Administration worker safety (29 CFR).
- Although the demonstration took place at a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site, no CERCLA requirements apply to the products demonstrated.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

- Normal radiation protection worker safety instructions used at the facility would apply when used in radiologically controlled areas.
- Users of the technology should implement site contamination control practices. Normal worker safety precautions and practices prescribed by OSHA and the site radiological control department.

Community Safety

- It is not anticipated that implementation of this innovative technology would result in any adverse safety impact on the community.

Environmental Impact

- There is more solid waste to dispose of with disposable suits versus reusable suits.
- Laundering the baseline reusable suits consumes water and produces an effluent stream.

Socioeconomic Impacts and Community Perception

- Use of the innovative disposable suits would adversely impact local laundry businesses.

SECTION 7

LESSONS LEARNED

Implementation Considerations

- No specific implementation consideration is involved, except the work force attitude toward the new technology.
- The sealed-seam sack suits technology can be used for indoor and outdoor D&D activities.
- The sealed-seam sack suit is well suited for work that could potentially cause heat stress.
- Sealed-seam sack suits do produce secondary waste (disposal of the used suits, one time use), but they are a compactable waste if not mixed with noncompactable wastes. Therefore, provisions should be provided to collect this waste separately from other secondary waste generated during D&D activities for the purpose of waste reduction.

Technology Limitations

- No limitations on this technology were observed during this demonstration.

Needs for Future Development

- No limitations on this technology were observed during this demonstration.

Technology Selection Considerations

- The technology is suitable for DOE nuclear facility D&D sites or any other sites where workers would need to be protected from exposure to dermal contamination or where the use of personal protective clothing is required.
- The technology reduces the chance of spreading contamination resulting from body moisture breakthrough.

APPENDIX A

REFERENCES

10 CFR Part 20, "Occupational Radiation Protection," *Code of Federal Regulations*, as amended.

10 CFR Part 834 (Proposed), "Environmental Radiation Protection," *Code of Federal Regulations*, as amended.

10 CFR Part 835, "Occupational Radiation Protection," *Code of Federal Regulations*, as amended.

29 CFR 1910, 1996, "General Industry Occupational Safety and Health Standards," *Code of Federal Regulations,* as amended.

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APPENDIX B

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Description
ALARA	as low as reasonable achievable
BHI	Bechtel Hanford, Inc.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DP	differential pressure
FETC	Federal Energy Technology Center
LANL	Los Alamos National Laboratory
OSHA	Occupational Safety and Health Administration
RCT	radiological control technician
RL	U.S. Department of Energy, Richland Operations Office