EPA
United States
Environmental Protection
Agency

EPA 600/R-11/015 | May 2011 | www.epa.gov/ord

River Technologies LLC 3-Way Decontamination System for Radiological Decontamination

TECHNOLOGY EVALUATION REPORT

Office of Research and Development
National Homeland Security Research Center

EPA 600-R-11-015
May 2011

Technology Evaluation Report

River Technologies LLC 3-Way Decontamination System for Radiological Decontamination

United States Environmental Protection Agency
Cincinnati, OH 45268

Disclaimer

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development's National Homeland Security Research Center, funded and managed this technology evaluation through a Blanket Purchase Agreement under General Services Administration contract number GS23F0011L-3 with Battelle. This report has been peer and administratively reviewed and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use of a specific product.

Questions concerning this document or its application should be addressed to:

John Drake
National Homeland Security Research Center
Office of Research and Development
U.S. Environmental Protection Agency
26 West Martin Luther King Dr.
Cincinnati, OH 45268
513-569-7164
drake.john@epa.gov

Foreword

The Environmental Protection Agency (EPA) holds responsibilities associated with homeland security events: EPA is the primary federal agency responsible for decontamination following a chemical, biological, and/or radiological (CBR) attack. The National Homeland Security Research Center (NHSRC) was established to conduct research and deliver scientific products that improve the capability of the Agency to carry out these responsibilities.

An important goal of NHSRC's research is to develop and deliver information on decontamination methods and technologies to clean up CBR contamination. When directing such a recovery operation, EPA and other stakeholders must identify and implement decontamination technologies that are appropriate for the given situation. The NHSRC has created the Technology Testing and Evaluation Program (TTEP) in an effort to provide reliable information regarding the performance of homeland security related technologies. TTEP provides independent, quality assured performance information that is useful to decision makers in purchasing or applying the tested technologies. TTEP provides potential users with unbiased, third-party information that can supplement vendor-provided information. Stakeholder involvement ensures that user needs and perspectives are incorporated into the test design so that useful performance information is produced for each of the tested technologies. The technology categories of interest include detection and monitoring, water treatment, air purification, decontamination, and computer modeling tools for use by those responsible for protecting buildings, drinking water supplies and infrastructure, and for decontaminating structures and the outdoor environment. Additionally, environmental persistence information is also important for containment and decontamination decisions.

NHSRC is pleased to make this publication available to assist the response community to prepare for and recover from disasters involving CBR contamination. This research is intended to move EPA one step closer to achieving its homeland security goals and its overall mission of protecting human health and the environment while providing sustainable solutions to our environmental problems.

Jonathan Herrmann, Director
National Homeland Security Research Center

Acknowledgments

Contributions of the following individuals and organizations to the development of this document are gratefully acknowledged.

United States Environmental Protection Agency (EPA)

John Drake
Emily Snyder
Sang Don Lee
Lukas Oudejans
David Musick
Kathy Hall
Eletha Brady-Roberts
Jim Mitchell

University of Tennessee

Howard Hall

United States Department of Energy's Idaho National Laboratories

Battelle Memorial Institute

Contents

Foreword iii
Acknowledgments iv
Abbreviations/Acronyms vii
Executive Summary viii
1.0 Introduction 1
2.0 Technology Description 3
3.0 Experimental Details 4
3.1 Experiment Preparation 4
3.1.1 Concrete Coupons 4
3.1.2 Coupon Contamination 4
3.1.3 Measurement of Activity on Coupon Surface 5
3.1.4 Surface Construction Using Test Stand 6
3.2 Evaluation Procedures 6
4.0 Quality Assurance/Quality Control 8
4.1 Intrinsic Germanium Detector 8
4.2 Audits 9
4.2.1 Performance Evaluation Audit 9
4.2.2 Technical Systems Audit 10
4.2.3 Data Quality Audit 10
4.3 QA/QC Reporting 10
5.0 Evaluation Results 11
5.1 Decontamination Efficacy 11
5.2 Deployment and Operational Factors 12
6.0 Performance Summary 15
6.1 Decontamination Efficacy 15
6.2 Deployment and Operational Factors 15
7.0 References 16

Figures

Figure 2-1. 3WDS rotating spray tool (left). 3WDS vacuum canister and waste collection drum (right). 3
Figure 3-1. Demonstration of contaminant application technique....5
Figure 3-2. Containment tent: outer view (left) and inner view with test stand containing contaminated coupons (right). 6
Figure 3-3. Operator applying 3WDS to concrete coupon. 7
Figure 5-1. Water running onto other coupons....12

Tables

Table 3-1. Characteristics of Portland Cement Clinker Used to Make Concrete Coupons 4
Table 4-1. Calibration Results – Difference from Th-228 Calibration Energies 8
Table 4-2. NIST-Traceable Eu-152 Activity Standard Check 9
Table 5-1. Decontamination Efficacy Results....12
Table 5-2. Operational Factors Gathered from the Evaluation 14

Abbreviations/Acronyms

3WDS	River Technologies, LLC 3-Way Decontamination System
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
BQ	Becquerel
Cs	cesium
cfm	cubic feet per minute
cm	centimeters
cm^2	square centimeters
DARPA	Defense Advanced Research Projects Agency
DF	decontamination factor
DHS	U.S. Department of Homeland Security
DOD	Department of Defense
EPA	U.S. Environmental Protection Agency
Eu	europium
Ft	feet
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
keV	kilo electron volts
mg	milligram
mL	milliliter
L	liter
m	meter
m^2	square meters
µCi	microCuries
NHSRC	National Homeland Security Research Center
NIST	National Institute of Standards and Technology
ORD	Office of Research and Development
%R	percent removal
PE	performance evaluation
psi	pounds per square inch
QA	quality assurance
QC	quality control
QMP	quality management plan
RDD	radiological dispersion device
RH	relative humidity
RML	Radiological Measurement Laboratory
RSD	relative standard deviation
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program
Th	thorium
V	volt

Executive Summary

The U.S. Environmental Protection Agency's (EPA's) National Homeland Security Research Center (NHSRC) Technology Testing and Evaluation Program (TTEP) is helping to protect human health and the environment from adverse impacts resulting from acts of terror by carrying out performance tests on homeland security technologies. Under TTEP, Battelle evaluated the performance of the River Technologies, LLC 3-Way Decontamination System (hereafter referred to as the 3WDS), and its ability to remove radioactive Cs-137 from the surface of unpainted concrete.

Experimental Procedures. The 3WDS is designed to clean floors, walls, and surfaces contaminated with loose or fixed radioactive debris by using a high pressure/hot water sprayer and an air-powered vacuum recovery system. The 3WDS consists of a pressure washer spray tool equipped with rotating spray nozzles enclosed by a vacuum shroud. Eight 15 centimeter (cm) × 15 cm unpainted concrete coupons were contaminated with approximately 1 microCurie (µCi) of Cs-137 per coupon and allowed to age for seven days. The amount of contamination deposited on each coupon was measured using gamma spectroscopy. The eight contaminated coupons were placed in a test stand (along with one uncontaminated blank coupon) that was designed to hold nine concrete coupons in a vertical orientation to simulate the wall of a building. Each coupon was treated using the 3WDS, and the decontamination efficacy was determined by calculating both a decontamination factor (DF) and percent removal (%R). Important deployment and operational factors were also documented and reported.

Results. The decontamination efficacy attained by the 3WDS was evaluated for each concrete coupon used during the evaluation. When the decontamination efficacy metrics (DF and %R) of the eight contaminated coupons were averaged together, the average %R for the 3WDS was 36% ± 4% and the average DF was 1.58 ± 0.09. Hypothesis testing was performed to determine if there were significant differences between the %R values determined for the coupons in each row (top, middle, and bottom) of the test stand. No differences were found.

The rate at which the 3WDS could be used to decontaminate a vertical surface was approximately 5.4 square meters (m^2) per hour. The 3WDS caused no visible surface destruction of the coupons. Approximately 40 liters (L) of secondary liquid waste was generated during application. The texture of the concrete surface is not likely to be important to the efficacy of the 3WDS and similar water blasting radiological decontamination technologies. The high pressure water should access most concrete surfaces, regardless of the irregularities. The 3WDS was used with a gas-powered, diesel-heated high pressure hot water washer. In addition, the vacuum recovery system required an air compressor to provide at least 250 cubic feet per minute (cfm) of air flow at a pressure of 120 pounds per square inch (psi). A large diesel powered air compressor was used during this evaluation to power the 3WDS vacuum. With two sources of power required the locations at which the 3WDS can be used could be limited.

A very limited evaluation of cross-contamination was performed. During an actual decontamination of a vertical surface, the higher elevation surfaces would likely be decontaminated first, possibly exposing the lower elevation surfaces to secondary contamination. To simulate an actual scenario, one uncontaminated coupon was placed in the bottom row of the test stand and decontaminated using the 3WDS in the same way as the other coupons. Following decontamination, the uncontaminated coupon exhibited a very small but measurable activity (0.0019 µCi compared with approximately 0.7 µCi on the coupons that had been decontaminated), suggesting that minimal cross contamination had occurred in the process of decontaminating the other coupons and this coupon using the 3WDS. In addition, the 3WDS created a significant amount of mist around the spray tool. This mist caused the operator's outer layer of protective gear to become very wet. The possibility of contaminating the operator with secondary waste would likely be a safety concern in an actual decontamination operation.

1.0 Introduction

The U.S. Environmental Protection Agency's (EPA) National Homeland Security Research Center (NHSRC) is helping to protect human health and the environment from adverse effects resulting from acts of terror. NHSRC is emphasizing decontamination and consequence management, water infrastructure protection, and threat and consequence assessment. In doing so, NHRSC is working to develop tools and information that will improve the ability of operational personnel to detect the intentional introduction of chemical, biological, or radiological contaminants on or into buildings or water systems, to contain or mitigate these contaminants, to decontaminate affected buildings and/or water systems, and to dispose of contaminated materials resulting from clean-ups.

NHSRC's Technology Testing and Evaluation Program (TTEP) works in partnership with recognized testing organizations; stakeholder groups consisting of buyers, vendor organizations, and permitters; and through the participation of individual technology developers in carrying out performance tests on homeland security technologies. The program evaluates the performance of homeland security technologies by developing evaluation plans that are responsive to the needs of stakeholders, conducting tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and high quality are generated and that the results are defensible. TTEP provides high-quality information that is useful to decision makers in purchasing or applying the evaluated technologies and in planning clean-up operations. TTEP provides potential users with unbiased, third-party information that can supplement vendor-provided information. Stakeholder involvement ensures that user needs and perspectives are incorporated into the evaluation design so that useful performance information is produced for each of the evaluated technologies.

Under TTEP, Battelle evaluated the performance of the River Technologies (Forest, VA), LLC 3-Way Decontamination System (hereafter referred to as the 3WDS) in removing radioactive isotope Cs-137 from concrete. Battelle followed a peer-reviewed test/QA plan that was developed according to the requirements of the quality management plan (QMP) for TTEP. The evaluation generated the following performance information for the 3WDS:

> Decontamination efficacy, defined as the extent of radionuclide removal following use of the 3WDS, and the possibility of cross-contamination.
> Deployment and operational data, including rate of surface area decontamination, applicability to irregular surfaces, skilled labor requirement, utility requirements, portability, secondary waste management, and technology cost.

This evaluation took place from August 11, 2009 until October 13, 2009. All of the experimental work took place in a radiological contamination area at the U.S. Department of Energy's Idaho National Laboratory (INL). This report describes the quantitative results and qualitative observations gathered during this evaluation of the 3WDS. Battelle and EPA were responsible for QA oversight. The Battelle QA Manager conducted a technical systems audit (TSA) during the evaluation as well as a data quality audit of the evaluation data.

2.0 Technology Description

The following description of the 3WDS is based on information provided by the vendor and was not verified during this evaluation.

The 3WDS consists of a pressure washer spray tool equipped with rotating spray nozzles enclosed by a vacuum shroud. The spray tool is attached to a gas-powered, diesel-heated high pressure hot water washer (Mi-T-M, Peosta, IA; Model HSP-3504-3), capable of providing pressures of up to 3,500 pounds per square inch (psi) and water at 180 ºF. During this evaluation the unit was attached to a compressed air powered vacuum (Nederman, Helsingborg, Sweden; Model NE52), which requires approximately 250 cubic feet per minute (cfm) of air at approximately 120 psi. A diesel-powered air compressor (LeROI, Sidney, OH; Model 260) was used to provide the compressed air to operate the vacuum necessary for recovery of the water. The air compressor was available at the test location and the pressure washer was rented for the duration of testing. Figure 2-1 shows photographs of the 3WDS spray tool and vacuum used during the evaluation. The metal surrounding the rotating spray nozzles serves as a vacuum shroud to collect the sprayed water.

Figure 2-1. 3WDS rotating spray tool (left). 3WDS vacuum canister and waste collection drum (right).

3.0 Experimental Details

3.1 Experiment Preparation

3.1.1 Concrete Coupons

The concrete coupons were prepared from a single batch of concrete made from Type II Portland cement.[1] The ready-mix company (Burns Brothers Redi-Mix, Idaho Falls, ID) that supplied the concrete for this evaluation provided the data which describe the cement clinker used in the concrete mix. For Type II Portland cement, the American Society for Testing and Materials (ASTM) Standard C 150-7[1] specifies that tricalcium aluminate account for less than 8% of the overall cement clinker (by weight). The cement clinker used for the concrete coupons was 4.5% tricalcium aluminate (Table 3-1). For Type I Portland cement the tricalcium aluminate content should be less than 15%. Because Type I and II Portland cements differ only in tricalcium aluminate content, the cement used during this evaluation meets the specifications for both Type I and II Portland cements.

Table 3-1. Characteristics of Portland Cement Clinker Used to Make Concrete Coupons

Cement Constituent	Percent of Mixture
Tricalcium Silicate	57.6
Dicalcium Silicate	21.1
Tricalcium Aluminate	4.5
Tetracalcium Aluminoferrite	8.7
Minor Constituents	8.1

The wet concrete was poured into 0.9 meter (m) square plywood forms with the exposed surface “floated” to allow the smaller aggregate and cement paste to float to the top, and the concrete was then cured for 21 days. Following curing, the squares were cut to the desired size with a laser-guided rock saw. For this evaluation, the “floated” surface of the concrete coupons was used. The coupons were approximately 4 centimeters (cm) thick, 15 cm × 15 cm square, and had a surface finish that was consistent across all the coupons. The concrete was representative of exterior concrete commonly found in urban environments in the United States as shown by INL under a previous project sponsored by the U.S. Department of Defense (DOD), Defense Advanced Research Projects Agency (DARPA) and U.S. Department of Homeland Security (DHS).[2]

3.1.2 Coupon Contamination

Eight coupons were contaminated by spiking individually with 2.5 milliliters (mL) of aqueous solution that contained 0.26 milligrams (mg)/liter (L) Cs-137 as a solution of cesium chloride, corresponding to an activity level of approximately 1 microCurie (µCi) over the 225 square centimeter (cm^2) surface. Application of the Cs in an aqueous solution was justified because even if Cs were dispersed in a particle form following a radiological dispersion device (RDD) or “dirty bomb” event, morning dew or rainfall would likely occur before the surfaces could be decontaminated. In addition, from an experimental standpoint, it is much easier to apply liquids, rather than particles, homogeneously across the surface of the concrete coupons. The liquid spike was delivered to each coupon using an aerosolization technique developed by INL under a DARPA/DHS project[2]) and described in detail in the test/QA plan. The coupons were then allowed to age for seven days.

The aerosol delivery device was constructed of two syringes. The plunger and needle were removed from the first syringe and discarded. Then, a compressed air line was attached to the rear of the syringe. The second syringe contained the contaminant solution and was equipped with a 27 gauge needle, which penetrated through the plastic housing near the tip of the first syringe. Compressed air flowing at a rate of approximately 1 - 2 L per minute created a turbulent flow through the first syringe. When the contaminant solution in the second syringe was introduced, the solution became nebulized by the turbulent air flow. A fine aerosol was ejected from the tip of the first syringe, creating a controlled and uniform spray of fine liquid droplets onto the coupon surface. The contaminant spray was applied all the way to the edges of the coupon, which were taped (after having previously been sealed with polyester resin) to ensure that the contaminant was applied only to the surfaces of the coupons. The photographs in Figure 3-1 show this procedure being performed using a nonradioactive, nonhazardous aqueous dye to demonstrate that the 2.5 mL of contaminant solution is effectively distributed across the surface of the coupon.

Figure 3-1. Demonstration of contaminant application technique.

3.1.3 Measurement of Activity on Coupon Surface

Gamma radiation from the surface of each concrete coupon was measured to quantify contamination levels both before and after evaluation of the 3WDS. These measurements were made using an intrinsic, high purity germanium detector (Canberra LEGe Model GL 2825R/S, Meriden, CT). After being placed into the detector, each coupon was measured until the average activity level of Cs-137 from the surface stabilized to a relative standard deviation of less than 2%. Gamma-ray spectra acquired from Cs-137 contaminated coupons were analyzed using INL Radiological Measurement Laboratory (RML) data acquisition and spectral analysis programs. Radionuclide activities on coupons were calculated based on efficiency, emission probability, and half-life values. Decay corrections were made based on the date and the duration of the counting period. Full RML gamma counting QA/quality control (QC), as described in the test/QA plan, was employed and certified results were provided.

3.1.4 Surface Construction Using Test Stand

To evaluate the decontamination technologies on vertical surfaces (simulating walls), a stainless steel test stand was fabricated that held three rows of three concrete coupons. The test stand, approximately 9 feet (ft) × 9 ft, was erected within a containment tent. The concrete coupons were placed into holders so their surfaces extended just beyond the surface of the stainless steel face of the test stand. Eight of the nine coupons placed in the test stand were contaminated with Cs-137, which has a half-life of 30 years. One uncontaminated coupon was placed in the bottom row of the test stand and decontaminated using the 3WDS in the same way as the other coupons. This coupon was placed there to observe possible secondary contamination caused by the decontamination higher on the wall. Figure 3-2 shows the containment tent and the test stand loaded with the concrete coupons.

Figure 3-2. Containment tent: outer view (left) and inner view with test stand containing contaminated coupons (right).

3.2 Evaluation Procedures

The containment tent consisted of two rooms. One room contained the test stand to hold the contaminated coupons; the other room (the shorter part of the tent as shown in Figure 3-2) held the 3WDS vacuum and collection drum. The vacuum hose extending from the collection drum connected to the vacuum shroud on the spray tool through a small opening in the tent wall between the two rooms. The power washer and air compressor were located outside the containment tent. The high pressure water hose connected to the spray tool through a small opening in the outer tent wall, and traveled through the smaller room and into the test stand room through a small opening in the tent wall between the two rooms. Each of the tent openings was taped closed around the hoses. Figure 3-3 shows the metal tube providing the high pressure water through the top of the spray tool and the larger diameter vacuum hose connecting to the vacuum shroud (which surrounds the spray tool) as the operator applies the 3WDS to a concrete coupon.

The nine concrete coupons in the test stand were pressure washed with the 3WDS starting with the top row and working from left to right, then proceeding to the middle and bottom rows. The coupons were sprayed in this manner to simulate an approach that would likely be taken in an actual decontamination event, where higher wall surfaces would be decontaminated first because of the possibility of secondary contamination lower on the wall.

The flow of hot, pressurized water was initiated by hand triggering the spray tool; the vacuum flow was continuous (controlled by a valve near the vacuum canister). Upon triggering, there was approximately a two second delay before the water flowed at full strength and caused the nozzles to rotate. Each coupon was then sprayed for approximately 15 seconds, moving the tool back and forth to ensure that the entire surface of the coupon had been covered. The trigger was released between coupons to stop the flow of water. This application technique would correspond to a rate of 0.1 square meters (m^2) per minute. The temperature and relative humidity (RH) were recorded before (17.5 °C, 32% RH) and after (18.6 °C, 32% RH) the approximately one hour test. These conditions did not vary significantly in the room where the evaluation was performed.

Figure 3-3. Operator applying 3WDS to concrete coupon.

4.0 Quality Assurance/Quality Control

QA/QC procedures were performed in accordance with the program QMP and the test/QA plan for this evaluation.

4.1 Intrinsic Germanium Detector

The germanium detector was calibrated once each week. The calibration was performed in accordance with standardized procedures from the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (IEEE).[3] In brief, detector energy was calibrated using thorium (Th)-228 daughter gamma rays at 238.6, 583.2, 860.6, 1620.7, and 2614.5 kilo electron volts (keV). This calibration was performed three times throughout the evaluation and documented by the RML. Table 4-1 gives the difference between the known energy levels and those measured following calibration. The energies were compared to the previous 30 calibrations to confirm that the results were within three standard deviations of the previous calibration results. The calibrations are shown for the detector used during this evaluation. All the calibrations fell within this requirement.

Table 4-1. Calibration Results – Difference from Th-228 Calibration Energies

	Calibration Energy Levels (keV)				
Date	**Energy 1 238.632**	**Energy 2 583.191**	**Energy 3 860.564**	**Energy 4 1620.735**	**Energy 5 2614.533**
8-25-2009	-0.005	0.014	-0.031	-0.199	0.031
9-21-2009	-0.003	0.009	-0.040	-0.125	0.015
10-13-2009	-0.003	0.008	-0.011	-0.180	0.020

Gamma ray counting was continued on each coupon until the activity level of Cs-137 on the surface had a relative standard deviation RSD of less than 2%. This RSD occurred within the initial 1 hour of counting for all the coupons measured during this evaluation. The final activity assigned to each coupon was a compilation of information obtained from all components of the electronic assemblage that comprise the "gamma counter," including the raw data and the spectral analysis described in Section 3.1.3. Final spectra and all data that comprise the spectra were sent to a data analyst who independently confirmed the "activity" number arrived at by the spectroscopist. When both the spectroscopist and an expert data analyst independently arrived at the same value, then the data were considered certified. This process defines the full gamma counting QA process for certified results.

The background activity of the concrete coupons was determined by analyzing nine arbitrarily selected coupons from the stock of concrete coupons used for this evaluation. The ambient activity level of these coupons was measured for at least two hours. No activity was detected above the minimum detectable level of 2×10^{-4} µCi on these coupons. Because the background activity was not detectable (and the detectable level was more than 2,500 times lower than the post-decontamination activity levels), no background subtraction was required.

Throughout the evaluation, a second measurement was taken on 10 coupons in order to provide duplicate measurements to evaluate the repeatability of the instrument. Half of the duplicate measurements were performed after contamination prior to application of the decontamination technology and half were performed after decontamination. Five of the duplicate pairs showed no difference in activity levels between the two measurements; the other five duplicate pairs had a difference of 2% between the two measurements, within the acceptable difference of 5%.

4.2 Audits

4.2.1 Performance Evaluation Audit

RML performed regular checks of the accuracy of the Th-228 daughter calibration standards (during the time when the detector was in use) by measuring the activity of a National Institute of Standards and Technology (NIST)-traceable europium (Eu)-152 standard (in units of Becquerel, BQ) and comparing this activity to the accepted NIST value. Results within 7% of the NIST value are considered to be within acceptable limits. The Eu-152 activity comparison is a routine QC activity performed by INL, but for the purposes of this evaluation this activity comparison serves as the performance evaluation (PE) audit, an audit that confirms the accuracy of the calibration standards used for the instrumentation critical to the results of an evaluation. Table 4-2 gives the results of each of the audits applicable to the duration of evaluation. All of the measurements during this evaluation were made during three separate weeks. Therefore, there are three sets of results and all results are within the acceptable difference of 7%.

Table 4-2. NIST-Traceable Eu-152 Activity Standard Check

Date	NIST Activity (BQ)	INL RML Result (BQ)	Relative Percent Difference
8-18-2009	124,600	122,400	2%
9-10-2009	124,600	122,600	2%
10-12-2009	124,600	122,300	2%

4.2.2 Technical Systems Audit

A TSA was conducted during testing at INL to ensure that the evaluation was performed in accordance with the test/QA plan and the TTEP QMP. As part of the audit, the actual evaluation procedures were compared with those specified in the test/QA plan, and the data acquisition and handling procedures were reviewed. No significant adverse findings were noted in this audit. The records concerning the TSA are stored indefinitely with the Battelle QA Manager.

4.2.3 Data Quality Audit

The Battelle QA Manager verified all of the raw data acquired during the evaluation and transcribed into spreadsheets for use in the final report. The data were traced from the initial raw data collection, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results.

4.3 QA/QC Reporting

Each assessment and audit was documented in accordance with the test/QA plan and the QMP. The Battelle QA Manager prepared the draft assessment report and sent it to the Test Coordinator and Battelle TTEP Program Manager for review and approval. The Battelle QA Manager then sent the final assessment report to the EPA QA Manager and Battelle staff.

5.0 Evaluation Results

5.1 Decontamination Efficacy

The decontamination efficacy of the 3WDS was measured for each contaminated coupon in terms of percent removal (%R) and decontamination factor (DF). Both of these measurements provide a means of representing the extent of decontamination accomplished by a technology. The %R gives the extent as a percent relative to the activity and the DF is the ratio of the initial activity to the final activity or the factor by which the activity was decreased. These terms are defined by the following equations:

$$\%R = (1 - A_f/A_o) \times 100\% \text{ and } DF = A_o/A_f$$

where A_o is the radiological activity from the surface of the coupon before application of the 3WDS and A_f is radiological activity from the surface of the coupon after treatment. While the DFs are reported, the narrative describing the results focuses on the %R.

Table 5-1 gives the %R and DF for the 3WDS. All coupons were oriented vertically. The target activity for each of the contaminated coupons (pre-decontamination) was within the acceptable range of 1 µCi ± 0.5 µCi. The overall average (plus or minus one standard deviation) of the contaminated coupons was 1.13 µCi ± 0.03 µCi, a variability of 3%. The post-decontamination coupon activities were less than the pre-decontamination activities showing an overall reduction in activity. The %R (calculated as described above) averaged 36% ± 4% and the DF averaged 1.58 ± 0.09. Overall, the %R ranged from 31% to 43% and the DF ranged from 1.46 to 1.76.

Paired t-tests were performed at a 95% confidence interval to determine whether location (top, middle, or bottom) on the test stand affected the decontamination efficacy. No significant difference between any of the rows was determined. The bottom middle coupon was not contaminated to test the possibility of cross-contamination. Activity of the uncontaminated coupon was measured after the 3WDS had been applied to all nine coupons. During application of the 3WDS to the coupons located higher on the test stand, droplets of water that had been sprayed onto the coupons (but not collected by the vacuum) ran down the test stand onto the coupons below as shown in Figure 5-1. Following the application of the 3WDS to all nine coupons, including the uncontaminated coupon, the uncontaminated coupon exhibited a very small but measurable activity (0.0019 µCi compared with 1 µCi on the contaminated coupons), suggesting that some cross contamination had occurred during the application of the 3WDS.

Table 5-1. Decontamination Efficacy Results

Coupon Location in Test Stand	Pre-Decon Activity µCi / Coupon	Post-Decon Activity µCi / Coupon	%R	DF
Top left	1.14	0.781	31	1.46
Top middle	1.18	0.769	35	1.53
Top right	1.15	0.730	37	1.58
Center left	1.09	0.619	43	1.76
Center middle	1.12	0.699	38	1.60
Center right	1.11	0.734	34	1.51
Bottom left	1.17	0.757	35	1.55
Bottom right	1.10	0.678	38	1.62
Average	**1.13**	**0.72**	**36**	**1.58**
Std. Dev	**0.03**	**0.05**	**4**	**0.09**

5.2 Deployment and Operational Factors

A number of operational factors were documented by the 3WDS operator. One of the factors was damage to the surface of the concrete coupons. The 3WDS used pressurized hot water to remove radiological contamination from the surface of the concrete coupons. The water pressures and spray nozzles used did not cause any visible surface removal of concrete. The hot, high pressure water spray combined with the vacuum to clean the surface of the concrete coupons of all loose particles and dirt, but did not cause visible surface damage.

Another important factor to consider is the secondary waste management of a decontamination technology and the personal protection of the technology operators. During this evaluation, the radiological control technicians required the operators to wear full anti-contamination personal protective equipment that included a full face respirator with supplied air. The 3WDS created a significant amount of mist around the spray tool that caused water to run down the test stand and caused the operator’s outer layer of protective gear to become very wet. The possibility of contaminating the operators with secondary waste or the ground surrounding the surface being contaminated with liquid radiological waste may be a major concern in an actual decontamination event. These concerns were also present during this evaluation, but the radiological control technicians who oversaw the evaluation determined that no measureable cross-contamination occurred due to the water from the 3WDS.

Figure 5-1. Water running onto other coupons.

Table 5-2 summarizes qualitative and quantitative practical information gained by the operator during the evaluation of the 3WDS. All of the operational information was gathered during use of 3WDS on the concrete coupons inserted into the test stand. Some of the information given in Table 5-2 could differ if the 3WDS were applied to a larger surface or surfaces made up of different types of concrete.

Table 5-2. Operational Factors Gathered from the Evaluation

Parameter	Description/Information
Decontamination rate	Technology Preparation: Upon initial receipt, it took 1.5 days to get the components assembled and the spray tool to function properly. Application: Approximately 15 seconds per concrete coupon corresponds to an application rate of 5.4 m^2/hour; less or more time per coupon may result in different levels of radiological decontamination.
Applicability to irregular surfaces	Irregular surfaces should not be a problem for the 3WDS as the high pressure water should be able to access most concrete surfaces, regardless of the roughness.
Skilled labor requirement	Adequate training would likely require approximately one hour. In addition to the assembly and operation of the 3WDS, topics would need to include safety precautions unique to pressurized water spray and 3WDS troubleshooting. The 3WDS spray tool alone is not heavy, but the operator experienced a significant level of exertion as he completed the evaluation. The weight of the 3WDS, in combination with the additional weight and awkwardness of the attached water and vacuum hoses, increased the level of effort required to use the 3WDS. Depending on what row of the test stand is being used, the operator was required to bend over, stand on the floor, or stand on a ladder. Each of these situations required a significant amount of exertion. These factors will exclude some people from operating the 3WDS. However, most people who are used to performing physical labor should not have any problem operating the 3WDS.
Utilities required	250 cfm compressed air at 120 psi and hot, high pressure water are the two requirements for operation.
Portability	The limiting factors of portability for the 3WDS will include the availability of 250 cfm compressed air.
Amount of spent media	Following blasting of 9 coupons, approximately 40 L of dispensed water was collected in the collection drum. Over the course of the evaluation, an estimated 4 L of water was not collected by the vacuum and ran down the test stand and sprayed onto the operator.
Secondary waste management	An estimated 90% of the water was collected by the vacuum. However, during testing there was a visible mist that extended approximately two feet surrounding the spray tool. As mentioned in the text, drops of water flowed down over the surface of the test stand during application of the 3WDS to coupons higher on the test stand. The mist that extended from the spray tool caused the outer layer of the operator's protective equipment to become very wet. This was a concern from the standpoint of protecting the operator from radiological contamination. Small pools of water collected at the base of the test stand. These pools of water were collected using the vacuum as well as absorbent rags. The radiological control technicians that oversaw the evaluation determined that no measureable contamination occurred due to the 3WDS water.
Surface damage	Pressurized water and vacuum collection removed loose particles from surface of concrete coupon, but did not visibly damage the surface.
Cost	The 3WDS costs $24,500 for the vacuum, pressure washer, and discharge pump situated on a portable stand with wheels. The hand cleaning tool with the rotating water jet would be an additional approximately $3,500 - $5,000.

6.0 Performance Summary

This section presents Battelle's findings from the evaluation of the 3WDS for each performance parameter evaluated.

6.1 Decontamination Efficacy

The decontamination efficacy (in terms of %R) attained by the 3WDS was evaluated for each concrete coupon used during the evaluation. When the decontamination efficacy metrics (DF and %R) of the eight contaminated coupons were averaged together, the average %R for the 3WDS was 36% ± 4% and the average DF was 1.58 ± 0.09. Hypothesis testing was performed to determine if there were significant differences between the %R values determined for the coupons in each row (top, middle, and bottom) of the test stand. No differences were found.

6.2 Deployment and Operational Factors

The rate at which the 3WDS could be used to decontaminate a vertical surface was approximately 5.4 m^2 per hour. The 3WDS caused no visible surface destruction of the coupons. Approximately 40 L of secondary liquid waste was generated during application. The texture of the concrete surface is not likely to be important to the efficacy of the 3WDS and similar water blasting radiological decontamination technologies. The high pressure water should access most concrete surfaces, regardless of the irregularities. The 3WDS was used with a gas-powered, diesel-heated high pressure hot water washer. In addition, the vacuum recovery system required an air compressor to provide at least 250 cfm of air flow at a pressure of 120 psi. A large diesel powered air compressor was used during this evaluation to power the 3WDS vacuum. These pieces of equipment were the only two sources of power required and could limit the locations at which the 3WDS can be used.

A very limited evaluation of cross-contamination was performed. During an actual decontamination of a vertical surface, the higher elevation surfaces would likely be decontaminated first, possibly exposing the lower elevation surface to secondary contamination. To simulate an actual scenario, one uncontaminated coupon was placed in the bottom row of the test stand and decontaminated using the 3WDS in the same way as the other coupons. Following decontamination, the uncontaminated coupon exhibited a small but measurable activity (0.0019 µCi compared with approximately 0.7 µCi on the coupons that had been decontaminated), suggesting that minimal cross contamination had occurred in the process of decontaminating the other coupons and this coupon using the 3WDS. In addition, the 3WDS created a significant amount of mist around the spray tool. This mist caused the operator's outer layer of protective gear to become very wet. The possibility of contaminating the operators with secondary waste would likely be a safety concern in an actual decontamination operation.

7.0 References

1. ASTM Standard C 150-07, “Standard Specification for Portland Cement,” ASTM International, West Conshohocken, PA, www.astm.org, 2007.
2. Radionuclide Detection and Decontamination Program. Broad Agency Announcement 03-013, U.S. Department of Defense (DOD) Defense Advanced Research Projects Agency (DARPA) and the U.S. Department of Homeland Security, classified program.
3. Calibration and Use of Germanium Spectrometers for the Measurement of Gamma Emission Rates of Radionuclides. American National Standards Institute. ANSI N42.14-1999. IEEE New York, NY (Rev. 2004).

SC
IEN
CE

United States
Environmental Protection
Agency

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Office of Research and Development (8101R)
Washington, DC 20460

Official Business
Penalty for Private Use
$300