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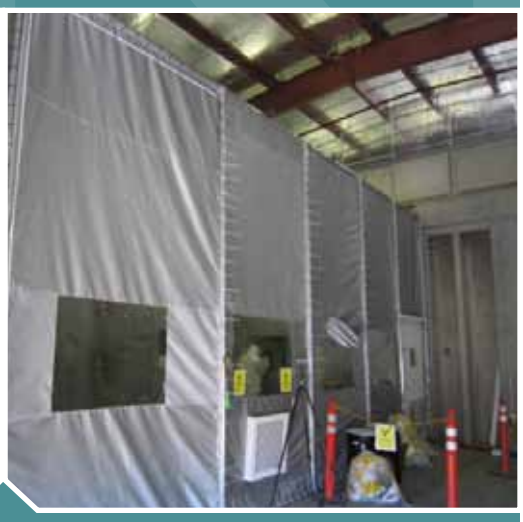
United States
Environmental Protection
Agency

Technology Evaluation Report

Environment Canada's Universal Decontamination Formulation



Office of Research and Development
National Homeland Security Research Center

EPA 600-R-13-048
May 2013

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Environment Canada's Universal Decontamination Formulation

National Homeland Security Research Center
Office of Research and Development
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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 under Contract No. EP-C-10-001 with Battelle. This report has been peer and administratively reviewed and has been approved for publication as an EPA document. It does not necessarily reflect the views of the EPA. Mention of trade names or commercial products does not constitute endorsement or recommendation for use of a specific product.

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FOREWORD

The U.S. 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 EPA's Homeland Security Research Program (HSRP) 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 the HSRP's research is to develop and deliver information on decontamination methods and technologies to clean up CBR contamination. When supporting or directing such a recovery operation, EPA and other stakeholders must identify and implement decontamination technologies that are appropriate for the given situation. The EPA's National Homeland Security Research Center (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. Through TTEP, the HSRP provides independent quality assured performance information that is useful to decision makers in purchasing or applying the tested technologies. Potential users are provided 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.

The HSRP 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 G. Herrmann
National Program Director
Homeland Security Research Program

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Abbreviations/Acronyms

ANSI	American National Standards Institute
ASTM	American Society of Testing and Materials, International
Bq	Becquerel(s)
°C	degree(s) Celsius
CASCAD™	Canadian Aqueous System for Chemical/Biological Agent Decontamination
cm	centimeter(s)
CBR	chemical, biological, and radiological
CBRNE	Chemical, Biological, Radiological-Nuclear and Explosives
Cs	cesium
DARPA	Defense Advanced Research Projects Agency
DF	decontamination factor
DHS	U.S. Department of Homeland Security
DI	deionized
DoD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
Eu	europium
HSRP	Homeland Security Research Program
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
keV	kilo electron volt(s)
mL	milliliter(s)
L	liter(s)
Lpm	liters per minute
m	meter(s)
m^2	square meter(s)
µCi	microCurie(s)
nCi	nanoCurie(s)
NHSRC	National Homeland Security Research Center
NIST	National Institute of Standards and Technology
%R	percent removal
PE	performance evaluation
PPE	personal protective equipment
psi	pound(s) per square inch
QA	quality assurance
QC	quality control
QMP	quality management plan
R&D	research and development
RDD	Radiological Dispersion Device
RML	Radiological Measurement Laboratory
RSD	relative standard deviation
SD	standard deviation

SDF	Allen-Vanguard's Surface Decontamination Foam
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program
Th	thorium
UDF	Universal Decontamination Formulation
Vac	volts alternating current

Executive Summary

The U.S. Environmental Protection Agency's (EPA) Homeland Security Research Program (HSRP) 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. Through its Technology Testing and Evaluation Program (TTEP), the National Homeland Security Research Center (NHSRC) evaluates the performance of technologies for their ability to decontaminate surfaces contaminated with radionuclides such as might result from terrorist use of a radiological dispersion device (RDD). This report is one of several that document the results of a recently completed series of decontamination technology performance evaluations, which can be accessed through NHSRC's Science Inventory [www.epa.gov/nhsrc/pubs.html accessed 28 Jan 2013]. NHSRC evaluated the performance of Environment Canada's Universal Decontamination Formulation (UDF) for its ability to remove radioactive cesium (Cs)-137 from the surface of anodized aluminum and unpainted concrete. This formulation was developed to decontaminate surfaces from a broad range of chemical, biological, and radiological agents simultaneously. The UDF formulation was developed by incorporating radionuclide-sequestering agents into an existing commercially available chemical and biological decontamination foam produced by Allen-Vanguard, Corp. The coupons, which measured 15 centimeters (cm) × 15 cm, were contaminated using an aqueous solution containing Cs-137 approximately two weeks prior to the test. The contaminated coupons were measured to determine an initial contamination level and were then placed in a vertical test stand. Following the manufacturer's recommended procedure, the foam was applied to the coupons in the test stand. The foam was allowed to remain on the coupons for 30 minutes, followed by removal with a standard wet/dry vacuum, rinse with water, and removal of the water rinse with the vacuum. These steps were repeated once, followed by application of a liquid reagent with a handheld sprayer as a final treatment following the foam application/removal. Following this application procedure, the residual activity on the coupons was measured and compared with the activity of similar coupons decontaminated using deionized water as a control. Important deployment and operational factors were also documented and reported.

Results included in this report consist primarily of (1) the decontamination efficacy of UDF, and (2) an evaluation of parameters affecting deployment of the product in a field scenario. A detailed discussion of the observed performance can be found in Section 5 of this report.

Decontamination Efficacy: The decontamination efficacy (in terms of percent removal, %R) attained by the UDF was evaluated following contamination of the coupons with approximately one microCurie (μCi) of Cs-137, measured by gamma spectroscopy. For the anodized aluminum surfaces, the %R was determined to be 92 ± 8.9% for the UDF and 59 ± 10% for the water control. For the concrete coupons, the %R was determined to be 62 ± 8.9% for UDF, and 6.1 ± 1.0% for the water control. A limited evaluation of

cross contamination (spread of contamination to previously uncontaminated areas) was performed, and the results confirmed that minimal cross contamination did occur.

Deployment and Operational Factors: The UDF was applied as a foam using a foamer provided by Allen-Vanguard. The foamer was suitable for use with a backpack attachment (not used during this evaluation) also available from Allen-Vanguard. The test stand containing the coupons used during this evaluation totaled nine square meters (m^2) in area. Each foam application required approximately one minute followed by a 30 minute residence time and subsequent vacuum/rinse as described above. This two-step application/removal cycle was performed twice. The UDF decontamination rate was 4.4 m^2 per hour, and the amount of waste generation was approximately 8 liters (L) of foam/water rinse for each complete application. UDF seems well suited for rough or jagged surfaces, as the foam can reach most areas easily. However, vacuum removal could become difficult on rough surfaces. The surface finish of neither the aluminum nor the concrete was visibly affected by decontamination with UDF.

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1.0 Introduction

The U.S. Environmental Protection Agency's (EPA's) Homeland Security Research Program (HSRP) is helping to protect human health and the environment from adverse effects resulting from intentional acts of terror. With an emphasis on decontamination and consequence management, water infrastructure protection, and threat and consequence assessment, HSRP is working to develop tools and information that will help detect the intentional introduction of chemical, biological, or radiological (CBR) contaminants in buildings or water systems, the containment of these contaminants, the decontamination of buildings and/or water systems, and the disposal of material resulting from cleanups.

The National Homeland Security Research Center (NHSRC), through its Technology Testing and Evaluation Program (TTEP), works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the participation of individual technology developers in carrying out performance tests on homeland security technologies. The program evaluates the performance of innovative 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 results are defensible. High-quality information that is useful to decision makers in purchasing or applying the evaluated technologies is provided. Potential users are provided 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.

The performance of Environment Canada's Universal Decontamination Formulation (UDF), a modification of Allen Vanguard's chemical and biological Surface Decontamination foam (SDF), was evaluated for decontamination of radioactive cesium-137 (Cs-137) from unpainted concrete and anodized aluminum. This evaluation was conducted according to a peer-reviewed Quality Assurance Project Plan (QAPP) entitled, "Evaluation of the Performance of Surface Decontamination Foam on Urban Substrates", Version 3.0, dated January 18, 2011, that was developed according to the requirements of the TTEP Quality Management Plan (QMP) Version 3, January 2008. These documents are available upon request from NHSRC. The following performance characteristics of UDF were evaluated:

- Decontamination efficacy, defined as the extent of radionuclide removal following application of UDF to aluminum and concrete coupons. Another quantitative parameter

evaluated was the potential for cross contamination of adjacent uncontaminated surfaces due to the decontamination procedure.

- Deployment and operational characteristics including rate of surface area decontamination, applicability to irregular surfaces, skilled labor requirements, utilities requirements, extent of portability, shelf life of media, secondary waste management including the estimated amount and characteristics of the spent media, and cost of using UDF.

This evaluation took place during April 2011, August 2011, and February 2012 at the U.S. Department of Energy's Idaho National Laboratory (INL). The results generated in April 2011 included all of the results pertaining to the aluminum coupons. The results generated in August 2011 and February 2012 were intended to clarify the concrete coupon results generated in April as some of the concrete coupons had been prepared using an approach not described in the QAPP, and the decontamination efficiency results were affected. The April and August 2011 concrete results are presented in Appendices A and B while the April 2011 anodized aluminum and February 2012 concrete results are presented in the main body of this report.

2.0 Technology Description

The following description of UDF is based on information provided by the vendor. The information provided below was not verified during this evaluation.

The UDF was developed to enhance the radiological decontamination performance of Allen-Vanguard's existing commercial product called SDF. SDF is an aqueous foam decontaminant which is a derivative product of the Canadian Aqueous System for Chemical/Biological Agent decontamination (CASCAD™). SDF was originally developed primarily as a decontaminant for chemical and biological response and was not intended for radiological decontamination. The development of UDF was funded by the Chemical, Biological, Radiological-Nuclear and Explosives (CBRNE) Research and Technology Initiative, Defence R&D Canada. NHSRC was included in the development plan for the purpose of radiological efficacy determination and also contributed project funding for this purpose.

In comparison to SDF, UDF contains radionuclide-sequestering agents. However, the UDF retains the chemical and the biological decontamination capability of SDF. The original SDF formulation was modified by incorporating two additional reagents into the SDF formulation. Reagent A is included in the mixture prepared in the foamer, while Reagent B is applied separately to the surfaces after application and removal of the modified foam and is then rinsed off with deionized (DI) water. The reagents, surfactant, foamer, and drill mixer are all sold separately.

3.0 Experimental Details

3.1 Experimental Preparation

3.1.1 Concrete and Anodized Aluminum Coupons

Concrete coupons were prepared in a single batch of concrete made from Type II Portland cement. The ready-mix company (Burns Brothers Redi-Mix, Idaho Falls, ID) from which the concrete for this evaluation was obtained provided the data shown in Table 3-1 describing the cement clinker used in the concrete mix. The ASTM C150[1] requirement for Type II Portland cement is that the tricalcium aluminate content be less than 8% of the overall cement clinker. As shown in Table 3-1, the cement clinker used for the concrete coupons was 4.5% tricalcium aluminate. Because the only difference between Type I and II Portland cements is the maximum allowable tricalcium aluminum content, and the maximum for Type I is 15%, the cement used during this evaluation meets the specifications for both Type I and II Portland cements.

Table 3-1. Concrete Characterization

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

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

The anodized aluminum coupons (Work-Savers Industries Anodized Aluminum, Metal Supermarkets, Ottawa, Canada) were approximately 15 cm × 15 cm with a thickness of 0.6 cm. These coupons were glued to a concrete substrate resulting in a coupon thickness of approximately 4.6 cm (similar to the concrete coupons) so they could be placed in the test stand and be counted by the gamma counter in a fashion identical to the concrete coupons.

3.1.2 Coupon Contamination

Table 3-2 describes the number of coupons used in this evaluation. In April 2011, 16 concrete and 16 aluminum coupons were used, including water controls. Following that part of the evaluation, incorrect preparation of a number of the concrete coupons was discovered. A portion of the April 2011 testing was therefore repeated in August 2011 and then again in February 2012 using only concrete coupons that had been prepared properly. The decontamination efficacy results for the April and August concrete decontamination tests are shown in Appendices A and B while the rest of the results are shown in Section 5.

All of these coupons were contaminated with 2.5 milliliters (mL) of an unbuffered slightly acidic aqueous solution containing 0.4 µCi/mL Cs-137, which corresponds to an activity level of approximately 1 ± 0.5 µCi per coupon. In the case of an actual urban RDD event, dry contaminated particles would be expected to settle over a wide area of a city. Such an event would increase the likelihood that the Cs-137 would no longer be bound to the particles and that a chemical decontamination technology for decontaminating concrete surfaces would be preferable to a physical removal approach. Application of the Cs-137 in an aqueous solution was justified because even if Cs-137 were to be dispersed in dry particle form following an RDD event, morning dew or rainfall would likely occur before the surfaces could be decontaminated, and, from an experimental standpoint, the ability to apply liquids homogeneously across the surface of the concrete coupons greatly exceeds the ability to apply dry particles. The liquid spike was delivered to each coupon using an aerosolization technique developed by INL under the DARPA/DHS project[2].

Table 3-2. Number of Coupons of Each Surface

Decontamination Technology	Number of Coupons Decontaminated			
	April 2011 (concrete)	April 2011 (aluminum)	August 2011 (concrete)	February 2012 (concrete)
UDF	8	8	4	4
Water control	8	8	6	4

The aerosol delivery device was constructed of two syringes. The plunger and needle were removed from the first syringe and discarded. A compressed air line was then attached to the larger open end of this syringe. The second syringe containing the contaminant solution 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 liters per minute (Lpm) created a turbulent flow through the first syringe. When the radioactive 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 masked with tape (after having previously been sealed with polyester resin) to ensure that the contaminant was applied only to the working surfaces of the coupons. The photographs in Figure 3-1 show this procedure being performed using a nonradioactive

nonhazardous aqueous dye to demonstrate that 2.5 mL of contaminant solution is effectively distributed across the surface of the coupon.

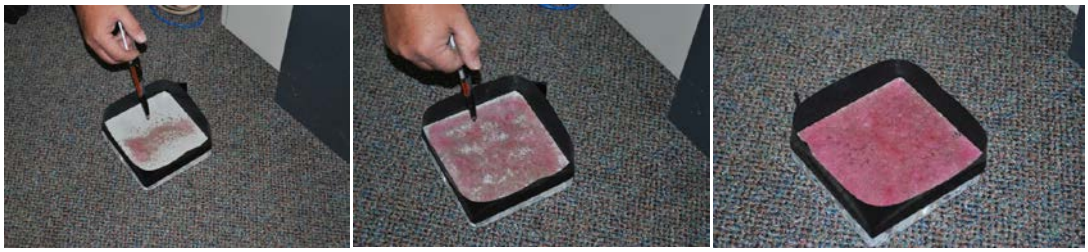


Figure 3-1. Demonstration of contaminant application technique.

3.1.3 Measurement of Activity on Coupon Surface

Within 1-2 weeks of coupon contamination, gamma radiation from the surface of each contaminated coupon was measured to quantify contamination levels both before and after use of SDF, UDF, or water (control). As described in the QAPP, these measurements were made using an intrinsic high purity germanium detector (Canberra LEGe Model GL 2825R/S, Meriden, CT). After being placed in the detector, each coupon was measured until the average activity level of Cs-137 from the surface stabilized to a relative standard deviation (RSD) of less than 2%. Gamma-ray spectra acquired from Cs-137-contaminated coupons were analyzed using the INL Radiological Measurement Laboratory (RML) data acquisition and spectral analysis programs. Radionuclide activities on each of the 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 QAPP, 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 that held three rows of three concrete coupons was used. As shown in Figure 3-2, the test stand was located in a containment tent and was approximately 2.7 m × 2.7 m. The 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 with one uncontaminated

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

(blank) coupon placed in the bottom row of the test stand and decontaminated in the same way as the other coupons. This coupon, referred to as the cross contamination blank, was placed on the test stand to observe possible cross contamination caused by the decontamination process being conducted higher on the wall.

3.2 Evaluation of UDF

The UDF was applied to all of the coupons in the same way. Nine coupons in the test stand (eight contaminated and one cross contamination blank) were decontaminated at one time. The application of UDF was performed using a foamer (Concealed Backpack Foamer, Allen-Vanguard, Ottawa, ON, Canada) following instructions provided by Allen-Vanguard. The application included loading the foamer with liquid foam (constituents given in the instructions), pressurization of the foamer to 2,500 pounds per square inch (psi) with compressed carbon dioxide and application of the foam to the surface coupons so that the coupons were completely covered. For the purposes of this test, the foamer was not used with the backpack because the sprayer hose was threaded into the containment tent with the foamer remaining on the outside. The foam was allowed to reside on the surface for 30 minutes and then was removed using a vacuum (6.5 horsepower, ShopVac® QSP® Quiet Deluxe®, Williamsport, PA) mounted on top of a 65 gallon vacuum collection reservoir (1065-YE Poly Over Pak® 65, Enpac, Eastlake, OH) containing a defoaming reagent to diminish the volume of the collected foam. The defoaming reagent was recirculated from the collection reservoir into the vacuum wand so that the foam would not clog the vacuum hose. The final step in the application process involved rinsing the surface of each coupon thoroughly with DI water using a handheld sprayer (Model 1125D Wood and Masonry Sprayer, Root-Lowell Flo Master®, Lowell, MI) followed by vacuuming. This procedure was repeated once, for a total of two iterations. Figure 3-3 shows the foamer, the foam application, and vacuum removal.

The UDF included three commercial Allen-Vanguard reagents (GPA2100, GPB2100, and GCE 2000, Allen-Vanguard, Ottawa, ON, Canada) and an additional reagent (referred to by Environment Canada as Reagent A). This additional reagent, Reagent A, was added to the liquid foam mixture during both foam applications. Following the two iterations of foam application, rinse, and removal, another reagent (referred to by Environment Canada as Reagent B) was applied to the surfaces using the handheld sprayer. This reagent had the consistency of water with a light yellow color. After application using the handheld sprayer, the Reagent B was left on the surfaces for 30 minutes followed by a final rinse with DI water and vacuuming.

Figure 3-3. Foamer, foam application, and vacuum removal.

As discussed above, the testing was performed during parts of three separate months over the course of approximately one year. Table 3-3 gives the number of days between coupon contamination and decontamination, the temperature (or range) in degrees Celsius (°C) and the percent relative humidity measured during each month's testing.

Table 3-3. Details of Each Testing Time Period

Month	Days Between Coupon Contamination and Decontamination	Temperature During Decontamination (°C)	Relative Humidity During Decontamination (%)
April 2011	12-14	13.9-20.0	16-22
August 2011	8-9	26.6	20
February 2012	14-15	16.1	20-31

4.0 Quality Assurance/Quality Control

QA/QC procedures were performed in accordance with the QMP and the QAPP for this evaluation, including a planned deviation described in a formal QAPP deviation dated August 12, 2011, and a QAPP amendment dated January 20, 2012.

4.1 Intrinsic Germanium Detector

The germanium detector was calibrated weekly during each time period of the overall project. 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] 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). Table 4-1 presents the calibration results across the duration of the project. In each row are shown the difference between the known energy levels and the energy levels measured following calibration (rolling average across the six most recent calibrations). Each row represents a six-week rolling average of calibration results. The energies were compared to the previous 30 calibrations to confirm that the results were within three standard deviations of the previous calibration results. All the calibrations fell within this requirement.

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

Testing Month	Date Range	Calibration Energy Levels in keV				
		Energy 1 238.632	Energy 2 583.191	Energy 3 860.564	Energy 4 1620.735	Energy 5 2614.511
April 2011	3-22-11 to 4-26-11	-0.001	0.004	-0.055	0.051	-0.002
	4-26-11 to 5-31-11	-0.003	0.012	-0.037	-0.145	0.021
August 2011	7-12-11 to 8-15-11	-0.003	0.010	-0.026	-0.170	0.021
	8-23-11 to 9-20-11	-0.002	0.006	-0.019	-0.095	0.010
February 2012	12-31-10 to 2-1-11	-0.002	0.007	-0.019	-0.143	0.013
	1-31-12 to 3-6-12	-0.003	0.007	0.008	-0.189	0.017
	2-7-12 to 3-13-12	-0.006	0.018	-0.038	-0.335	0.032

Gamma ray counting was continued for each coupon until the activity level of Cs-137 on the surface had an RSD of less than 2%. This RSD was achieved during the first 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 the data analyst independently arrived at the same value, the data were considered certified. This process defines the full gamma counting QA process for certified results.

The background activity of 13 laboratory blank coupons (four aluminum and nine concrete) was determined by analyzing arbitrarily selected coupons from the stock of aluminum and concrete coupons used for this evaluation. The ambient activity level of these coupons was measured for one hour. No activity was detected above the minimum detectable level of 0.3 nanoCuries (nCi) on these coupons.

Throughout the evaluation, a second measurement was taken on 15 coupons to provide duplicate measurements to evaluate the repeatability of the instrument. One of the duplicate measurements was performed after contamination prior to application of the UDF, and one measurement was performed after decontamination. All 15 of the duplicate pairs showed a difference in activity levels of 3% or less, within the acceptable range of 0-5%.

4.2 Audits

4.2.1 Performance Evaluation Audit

RML performs monthly checks of the accuracy of the Th-228 daughter calibration standards by measuring the activity of a National Institute of Standards and Technology (NIST)-traceable europium (Eu)-152 standard (in units of Becquerels, Bq) and comparing to the accepted NIST value. Table 4-2 shows the activity of each of three different Eu-152 energies (122, 779, 1,408 kEV and the average) compared with the NIST values. Results within 7% of the NIST value are considered to be within acceptable limits as per the INL RML QC requirements. The Eu-152 activity comparison is a routine QC activity performed by INL, but for the purposes of this evaluation, serves as the performance evaluation (PE) audit. A PE audit 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 these audits of the detector that was used during this evaluation. All results are within the acceptable difference of 7%.

4.2.2 Technical Systems Audit

Multiple Technical Systems Audits (TSAs) were conducted during testing to ensure that the evaluation was performed in accordance with the QAPP and the TTEP QMP. As part of the audit, the actual evaluation procedures were compared with those specified in the QAPP. In addition, the data acquisition and handling procedures were reviewed. No significant adverse findings were noted in this audit. The records concerning the TSAs are stored indefinitely with the QA Manager.

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

Date	Eu-152 (keV)	NIST Activity (Bq)	INL RML Result (Bq)	Absolute Difference
January 2011	Average	124,600	124,700	0.08%
	122	124,600	122,800	1.4%
	779	124,600	122,600	1.6%
	1408	124,600	125,100	0.4%
April 2011	Average	124,600	121,600	2.4%
	122	124,600	119,100	4.4%
	779	124,600	119,000	4.5%
	1408	124,600	123,200	1.1%
August 2011	Average	124,600	123,500	0.9%
	122	124,600	119,100	4.4%
	779	124,600	118,700	4.7%
	1408	124,600	123,200	1.1%
February 2012	Average	124,600	121,500	-2.5%
	122	124,600	119,500	-4.1%
	779	124,600	118,100	-5.2%
	1408	124,600	122,800	-1.4%

4.2.3 Data Quality Audit

At least 10% of the data acquired during the evaluation were audited. The QA Manager traced the data from the initial acquisition through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked. No significant findings were noted.

4.3 QA/QC Reporting

Each assessment and audit was documented in accordance with the QAPP and the QMP.

There was one deviation from the QAPP during this evaluation. This deviation involved the improper preparation of coupons (use of wire brush instead of soft bristle brush – see Appendix A). In response to this deviation, additional experiments were performed in August 2011 to replace the results from the improperly prepared coupons (April 2011). In addition to the deviation, one QAPP amendment was used to include the decontamination experiments performed in February 2012.

5.0 Evaluation Results and Performance Summary

5.1 Decontamination Efficacy

The decontamination efficacy was determined for each contaminated coupon in terms of %R and decontamination factor (DF) as 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 decontamination and A_f is radiological activity from the surface of the coupon after decontamination. While the DF values are reported in the following data tables, the narrative describing the results will focus on percent removed (%R).

5.1.1 Anodized Aluminum Coupons

Table 5-1 presents the decontamination efficacy, expressed as both %R and DF, for UDF, and the water control when used on anodized aluminum coupons. The target activity for each of the contaminated coupons (pre-decontamination) was between 0.5 μCi and 1.5 μCi. The overall average (plus or minus one standard deviation) of the contaminated coupons was 1.0 ± 0.05 μCi, a variability of 5%. The post-decontamination coupon activities were significantly less than the pre-decontamination activities with average %R of 92 ± 8.9%. The use of deionized water as a control applied to the anodized aluminum surface coupons resulted in a %R of 59 ± 10%. The process used for application of the deionized water was the same as that used for application of the UDF, including vacuuming and rinsing.

Table 5-1. Decontamination Efficacy Results on Anodized Aluminum Coupons

Technology		Pre-Decontamination Activity µCi/Coupon	Post-Decontamination Activity µCi/Coupon	%R	DF
UDF		0.94	0.174	81%	5.4
		0.95	0.239	75%	4.0
		0.99	0.027	97%	37
		1.04	0.041	96%	25
		1.14	0.030	97%	38
		0.99	0.028	97%	26
		0.96	0.035	96%	16
		1.04	0.030	97%	35
	Avg	1.01	0.075	92%	23
	SD*	0.07	0.083	8.9%	14
Water Control		0.95	0.46	52%	2.1
		1.01	0.24	77%	4.3
		1.07	0.42	61%	2.5
		1.03	0.51	50%	2.0
		0.99	0.48	52%	2.1
		1.05	0.50	52%	2.1
		0.96	0.27	72%	3.6
		1.03	0.42	59%	2.5
	Avg	1.01	0.412	59%	2.6
	SD	0.04	0.104	10%	0.84

* SD = Standard Deviation.

5.1.2 Concrete Coupons from February 2012

The decontamination testing conducted in February 2012 was performed approximately two weeks after coupon contamination with radioactive cesium. Other than only very slight differences in temperature and relative humidity, all other variables were nearly identical to the previous testing that had been performed. The concrete coupons were from the same batch and had been prepared properly with the nylon brush, and the UDF was applied identically to the way it had been applied in August and April 2011, and the same technicians performed the evaluation.

Table 5-2 gives the %R and DF for the UDF and the water control. The target activity for each of the contaminated coupons (pre-decontamination) was between 0.5 µCi and 1.5 µCi. The overall average (plus or minus one standard deviation) of the contaminated coupons was 0.97 ± 0.05 µCi, a variability of 5%.

The post-decontamination coupon activities were significantly less than the pre-decontamination activities with an average %R of 62 ± 8.9%. The water control applied to the concrete coupons resulted in a %R of 6.1 ± 1.0%. These results were compared with the April %R results using the properly prepared coupons. The average removal for the one properly prepared April concrete coupon was 76% (see Appendix A). The results obtained during the August 2011 tests were determined to be suspect, which led to the decision to repeat the concrete tests in February 2012. A complete discussion of the August results is included in Appendix B.

Table 5-2. Decontamination Efficacy Results on Concrete Coupons in February 2012

Technology		Pre-Decontamination Activity µCi/Coupon	Post-Decontamination Activity µCi/Coupon	%R	DF
UDF		0.97	0.50	48%	1.9
		0.92	0.32	65%	2.9
		1.04	0.33	68%	3.2
		0.98	0.35	64%	2.8
	Avg	0.98	0.38	62%	2.7
	SD*	0.05	0.08	8.9%	0.52
Water Control		0.98	0.93	5.1%	1.1
		1.05	0.99	5.7%	1.1
		0.97	0.91	6.2%	1.1
		0.95	0.88	7.4%	1.1
	Avg	0.99	0.93	6.1%	1.1
	SD	0.04	0.05	1.0%	0.01

* SD = Standard Deviation.

5.1.3 Cross Contamination Blanks

As described in Section 3.2, cross contamination blanks were included in the test stand during each portion of the evaluation to evaluate the potential for cross contamination due to application of UDF on wall locations above the placement of the uncontaminated coupon. After decontamination, the activity of the cross contamination blanks was found to be not detectable (detection limit of approximately 0.0002 µCi) for the anodized aluminum coupons and from 0.0066 µCi to 0.015 µCi for the UDF concrete coupons, and from 0.0011 µCi to 0.0018 µCi for water on concrete. In all cases, the activity levels on the cross contamination blanks were less than 7% of the average post-decontamination activity of that same set of coupons. This result suggests that cross contamination resulting from the application of UDF and the water controls on coupons located above the cross contamination blank was detectable in most cases, but minimal with respect to the contamination levels on the other coupons.

5.2 Deployment and Operational Factors

A number of operational factors were documented by the technician who performed the testing over the past year. The application procedure was described in Section 3.2 and included use of a foamer provided by Allen-Vanguard. Foam application to the test stand containing all nine coupons required approximately one minute. This step was followed by a dwell time of 30 minutes. The foam was then vacuumed and an agricultural mist sprayer was used to rinse the surfaces with water which required approximately ten minutes. The surface was vacuumed again after the water rinse taking approximately three minutes. This process was repeated once. The surfaces were then rinsed with Reagent B and allowed to sit for 30 minutes before completing the decontamination process with a final water rinse and vacuum. In total, the entire procedure required approximately 2 hours. The UDF caused no visible damage to the surface of any of the coupons.

Throughout the evaluation, technicians were required to use full anti-contamination personal protective equipment (PPE) because the work was performed in a radiological tent using Cs-137. Whenever radioactive contaminated material is handled, anti-contamination PPE will be required and any waste (e.g., from vacuuming) will likely be considered low level radioactive waste and will need to be deposed of accordingly. The level of PPE required was not driven by the use of UDF (which is not hazardous), but by the use of Cs-137.

All of the operational information gathered during this evaluation was gathered during use of UDF on relatively small concrete coupons inserted into a test stand to make a large, relatively smooth surface. Some of the information given in Table 5-4 could therefore differ if UDF were applied to a larger or significantly different surface type or mixtures of surfaces.

Table 5-3. Operational Factors

Parameter	Description/Information
Decontamination rate	**Foam preparation:** Combine SDF components (GPA, GPB and GCE-2000) in foamer and mix with drill until dissolved (5-10 minutes); add surfactant just before foam application to coupons. Reagent B is added to the coupons at the end of the application procedure. **Application time:** Approximately one minute for foam application to nine coupons (0.2 m^2 total) in the test stand; 30 minute wait, vacuum removal (5 minutes for nine coupons), water rinse (3 minutes), vacuum removal of water (3 minutes), repeat once. Apply reagent B for 2 minutes. Aside from the waiting time (which is independent of surface area), overall decontamination rate is 0.5 m^2/hour.
Applicability to irregular surfaces	Application to more irregular surfaces than the surfaces encountered during this evaluation would not seem to be much of a problem as the foam can reach most types of surfaces. However, irregular surfaces may pose a problem for vacuum removal.
Skilled labor requirement	After a brief training session to explain the procedures, no special skills would be required to perform both the application and removal procedures successfully.
Utilities requirement	Compressed carbon dioxide was required to operate the foamer. A vacuum cleaner was used to remove the foam and water rinses, which required 120 volts AC (Vac) power.
Extent of portability	Portability may be limited by the requirement for vacuum removal and by extreme cold temperatures because UDF is water-based. The foamer is designed for use with a backpack (not used during this testing). Fully charged, the backpack foamer would weigh approximately 24 kilograms. Compressed carbon dioxide would be required for recharging foamer when it runs empty.
Shelf life of reagents	Once mixed, the reagents should be used within 24 hours. The chemical components should not be used past the expiration date on their label.
Secondary waste management	Foam was collected in the vacuum collection reservoir containing a defoaming reagent to reduce the volume of the collected foam; the defoaming reagent was recirculated from the collection reservoir into the vacuum wand so the foam would not clog the vacuum hose. For each complete application of UDF to the nine coupons (0.2 m^2 total), approximately 5 L of foam and 3 L of rinse water were used resulting in a liquid waste generation of approximately 40 L/m^2.
Surface damage	No visible surface damage.
Cost	Material cost is approximately \$12.00/m^2 if used in a way similar to this evaluation. Labor costs were not calculated.

6.0 References

1. ASTM Standard C 150-07, 2007, "Standard Specification for Portland Cement," ASTM International, West Conshohocken, PA, www.astm.org [accessed 10/2/2012].
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.
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).

Appendix A April 2011 Concrete Results

April 2011 Concrete Results

The table below gives the %R and DF for UDF and the water control when used on concrete coupons. The target activity for each of the contaminated coupons (pre-decontamination) was again between 0.5 µCi and 1.5 µCi. The overall average (plus or minus one standard deviation) of the contaminated concrete coupons was 0.99 ± 0.04 µCi, a variability of 4%. The UDF %R results revealed that one coupon had a 76 %R while all the others (shaded in the table) ranged from 7.4 to 19 %R (14 ± 4%).

Decontamination Efficacy Results for Concrete Coupons in April 2011

Technology	Pre-Decontamination Activity µCi/Coupon	Post-Decontamination Activity µCi/Coupon	%R	DF
UDF	1.00	0.87	13%	1.1
	0.95	0.88	7.4%	1.1
	0.95	0.78	18%	1.2
	0.90	0.81	10%	1.1
	0.92	0.75	19%	1.2
	0.96	0.81	16%	1.2
	0.98	0.84	14%	1.2
	1.01	0.25	76%	4.1
Water Control	1.08	1.05	2.8%	1.0
	1.08	1.07	0.9%	1.0
	1.02	1.01	1.0%	1.0
	1.02	1.01	1.0%	1.0
	1.01	1.00	1.0%	1.0
	0.97	0.94	3.1%	1.0
	1.00	1.0	0.0%	0.0
	0.98	0.96	2.0%	1.0

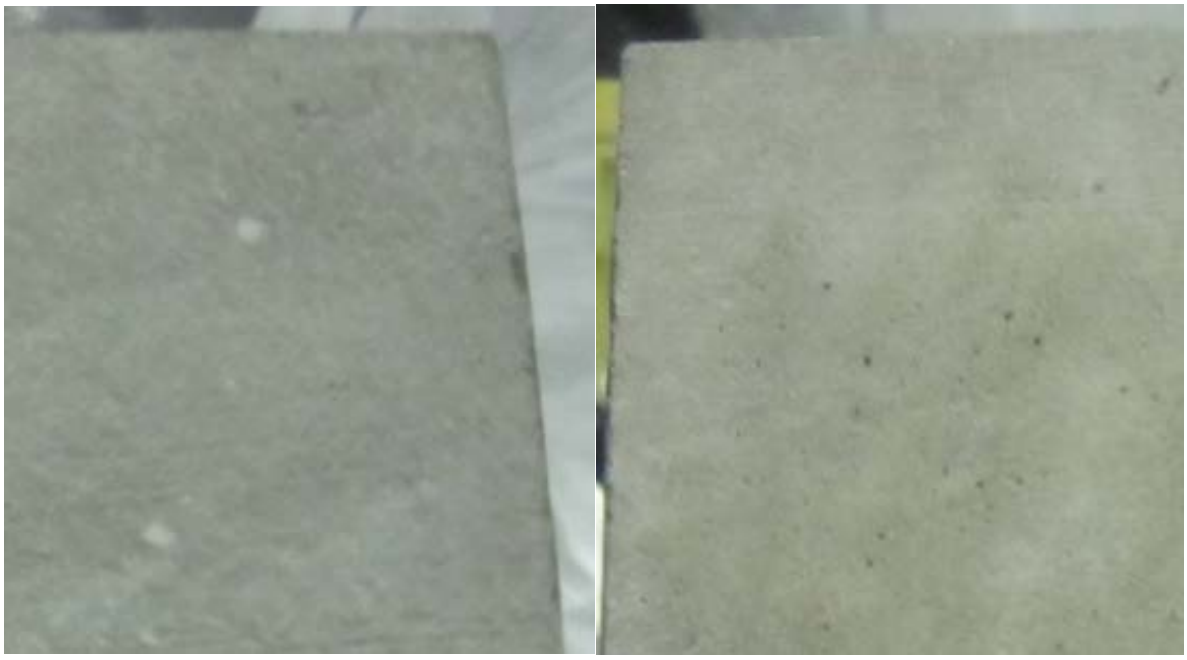
Shading – Improperly prepared wire-brushed coupons

These rather low decontamination efficacies were unexpected and were not consistent with previous evaluations of similar technologies. In response to these unexpected results, a review of all the steps of the technology evaluation was performed. This review revealed that 15 of the 16 concrete coupons had been brushed with a wire brush during the initial cleaning of the coupons. This procedure deviated from the QAPP, which required cleaning the coupons with a nylon brush.

The figure below shows a close up photograph of one coupon that was prepared with a nylon brush (left) and one that was prepared with a wire brush (right). Close inspection of these surfaces reveals that wire brushing apparently removes some portion of the outer surface of the concrete coupons. This removal of the surface is most obvious in small pits in the surface of the concrete. On the nylon-brushed coupon, the small pits are filled with white residue left over from the concrete drying process. On the wire-brushed coupons, the small pits are no longer filled and show up as small dark holes in the surface. These are the only areas that indicate a visible difference but, presumably, if the wire brushing caused removal of the white residue in

the small pits, the brushing also may have removed some amount of the rest of the surface as well (even if it was not visible in these photographs). The wire-brushed coupons exhibited much lower %Rs than the properly prepared coupon. This decreased removal might be expected given that the wire brushing seems to have lessened the integrity of the outer surface of the concrete, thus increasing the porosity of the surface of the coupon, making it more difficult to remove contamination. A decision was made to prepare additional coupons properly and repeat the affected tests. An evaluation of the effect of various methods of surface preparation on decontamination efficacy was not an objective of this study, therefore no additional surface characterization was performed to study this issue further. However, the following variables and their effect on decontamination performance were suggested and may provide areas for future research:

- Aged vs newly exposed surface characteristics
- Reactivity of concrete surfaces as a function of exposure to elements
- Presence of foreign particles (e.g. iron from wire brushing) on the concrete surface.



Concrete coupon prepared with nylon brush (left) and wire brush (right).

Appendix B August 2011 Concrete Results

August 2011 Concrete Results

To complete the experimental plan initiated, but not fully accomplished, in April (because of the wire brushing of the concrete coupons), additional decontamination testing was performed in August 2011. This testing included four Cs-137-contaminated concrete coupons decontaminated with UDF and six decontaminated with water only. The table below gives the %R and DF for UDF and the water control when using concrete coupons. The target activity for each of the contaminated coupons (pre-decontamination) was again between 0.5 µCi and 1.5 µCi. The overall average (plus or minus one standard deviation) of the contaminated coupons was 1.03 ± 0.04 µCi, a variability of 4%. For UDF, the post-decontamination coupon activities were significantly less than the pre-decontamination activities with an average %R of 20 ± 9.1%. The water control applied to the concrete surface coupons resulted in a %R of 1.2 ± 0.4%. These results differ from what was expected based on the results from the properly prepared April 2011 coupons and previous experiments with decontamination technologies. The results are particularly perplexing given the special attention to using properly prepared coupons and following the identical procedures that were followed in April and in the previous experiments (published and available at www.epa.gov/nhsrc/pubs.html) [accessed 28 Jan 2013]. Despite all of this, the results were not similar to the results with the properly prepared coupons in April and were not consistent with results that the vendor had observed during internal testing performed with non-radiological cesium prior to this technology evaluation. In fact, the water control results from this August testing also differ markedly from previous experiments which further indicated the probability of some pervasive abnormality surrounding the August tests. Because of these unexpected and inconsistent results, another round of decontamination testing was planned and conducted in February 2012 (as discussed in the main sections of this report).

Decontamination Efficacy Results on Concrete Coupons in August 2011

Technology		Pre-Decontamination Activity µCi/Coupon	Post-Decontamination Activity µCi/Coupon	%R	DF
UDF		1.00	0.73	27%	1.4
		1.01	0.74	27%	1.4
		0.98	0.79	19%	1.2
		1.05	0.97	7.6%	1.1
	Avg	1.01	0.81	20%	1.26
	SD	0.03	0.11	9.1%	0.14
Water Control		1.07	1.06	0.9%	1.0
		0.98	0.95	3.1%	1.0
		1.04	1.03	1.0%	1.0
		1.12	1.11	0.9%	1.0
		0.97	0.96	1.0%	1.0
		1.09	1.07	1.8%	1.0
	Avg	1.06	1.04	1.2%	1.0
	SD	0.07	0.06	0.4%	0.0

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