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Technology Evaluation Report

Radiation Decontamination Solutions, LLC "Quick Decon" Solutions for Radiological Decontamination

Office of Research and Development
National Homeland Security Research Center

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Radiation Decontamination Solutions, LLC "Quick Decon" Solutions for Radiological Decontamination

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Disclaimer

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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. Through TTEP, NHSRC 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 G. Herrmann, Director
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Abbreviations/Acronyms

ANSI	American National Standards Institute
ASTM	ASTM International
BQ	Becquerel
CBRNIAC	Chemical, Biological, Radiological and Nuclear Defense Information Analysis Center
°C	degrees Celsius
CC	cross-contamination
Cs	Cesium
cm	centimeter
cm^2	square centimeter
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
°F	degrees Fahrenheit
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
keV	kilo electron volts
mL	milliliter(s)
L	liter
m	meter
m^2	square meter
µCi	microCurie
NHSRC	National Homeland Security Research Center
NIST	National Institute of Standards and Technology
ORD	Office of Research and Development
PE	performance evaluation
PPE	personal protective equipment
%R	percent removal
QA	quality assurance
QC	quality control
QDS	Quick Decon Solutions
QDS-A	Actinide Mass Effect solution
QDS-H	Halogen Mass Effect solution
QDS-TM	Transition Metal Mass Effect solution
QMP	quality management plan
RDS	Radiation Decontamination Solutions, LLC
RH	relative humidity
RDD	radiological dispersion device
RML	Radiological Measurement Laboratory
RSD	relative standard deviation

Th	Thorium
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program

Executive Summary

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 impacts resulting from acts of terror by carrying out performance tests on homeland security technologies. Through it's Technology Testing and Evaluation Program (TTEP), NHSRC evaluated the Radiation Decontamination Solutions (RDS) Quick Decon Solutions (QDS) technology applied as a liquid and as a foam for the ability to remove radioactive cesium (Cs)-137 from the surface of unpainted concrete.

Experimental Procedures. The liquid and foam applications of the QDS technology is performed using a two-step chemical decontamination process. This process involves the sequential application and removal of two decontamination solutions, Halogen Mass Effects (QDS-H) and Transition Metal Mass Effects (QDS-TM), to surfaces being decontaminated. RDS recommended this two-step chemical decontamination process be repeated six times. Eight 15 centimeter (cm) × 15 cm unpainted concrete coupons were contaminated with approximately 1 microCurie (µCi) of Cs-137 per coupon. 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. Four coupons were decontaminated with a liquid application of QDSs and four with the foam application. 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 (in terms of %R) attained for liquid and foam applications of the QDS was evaluated for each concrete coupon used during the evaluation. When the decontamination efficacy metrics (%R and DF) of the four contaminated coupons for each were averaged together, the average %R for liquid QDS was 53% ± 7% and the average DF was 2.1 ± 0.31. The average %R for foam QDS was 51% ± 8% and the average DF was 2.1 ± 0.43.

Both the liquid and foam applications of the QDS were performed using commercially available plastic spray and foaming bottles scaled for use for the coupons used during this evaluation. For the liquid application, the concrete coupons were thoroughly wetted with the first solution (QDS-H) with 3-4 sprays. After a 5-10 second wait, the solution was wiped off the surface of the concrete with a Rad-wipe. This process was repeated with the second solution (QDS-TM). This two-step cycle was repeated six times before a final water rinse and wipe dry. During testing, semi-quantitative measurement of activity was performed using a radiation dose rate survey meter (RO-20, Eberline-Thermo Scientific, San Diego, CA) following each application cycle of QDS liquid and foam (on only one coupon only). The results indicated that no additional decrease in activity occurred following the second application of the liquid and the third application of the foam.

The Rad-wipe waste generated through use of the QDS was estimated to be approximately 5 liters (L)/ square meter (m^2). As used for this evaluation, no utilities were required. Scaled up applications in remote locations may require additional equipment such as firetruck mounted or other large scale sprayer equipment to provide means for sprayer or foamer application and larger scale removal techniques. Minimal training would be required for technicians using the QDS, and the surface of the concrete was not visibly damaged during use of the liquid or foam application of the QDS.

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 cleanups.

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. Through TTEP, NHSRC provides high-quality information that is useful to decision makers in purchasing or applying the evaluated technologies, and in planning cleanup operations. The evaluations generated through TTEP provide 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.

Through TTEP, NHSRC evaluated the performance of liquid and foam application of the Quick Decon Solutions (QDS) from Radiation Decontamination Solutions (RDS) (Oldsmar, FL), in removing radioactive isotope cesium (Cs)-137 from concrete. A peer-reviewed test/QA plan was followed, entitled "The Performance of Selected Radiological Decontamination Processes on Urban Substrates", Version 1.0, Amendment 1 dated July 14, 2010. This document will be referred to as the test/QA plan and was developed according to the requirements of the Quality Management Plan (QMP) for the Technology Testing and Evaluation Program, Version 3.0 dated January 2008. The evaluation generated the following performance information:

- Decontamination efficacy, defined as the extent of radionuclide removal following use of the QDS, and the possibility of cross-contamination (CC)

- Deployment and operational factors, including the approximate rate of surface area decontamination, applicability to irregular surfaces, skilled labor requirement, utility requirements, portability, secondary waste management, and technology cost.

The evaluation of the QDS took place October 28, 2010, with the pre-evaluation activity measurements occurring in September 2010 and the post-evaluation activity measurements occurring in early November 2010. 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 the evaluation of the QDS. The contractor and EPA were responsible for QA oversight. A technical systems audit (TSA) was conducted during the evaluation as well as a data quality audit of the evaluation data.

2.0 Technology Description

This technology evaluation report provides results on the performance of QDS liquid and foam under controlled conditions. The following description of the QDS is based on information provided by the vendor and was not verified during this evaluation.

The QDSs, applied either as a liquid or a foam, functions by way of a “mass effect" influence. The solutions are designed to draw the radioactive material from the contaminated surfaces (porous, nonporous, sensitive surfaces such as human skin), suspend the radionuclide in solution where it can easily be wiped up (rinse followed by vacuuming or effluent collection are alternate approaches) and removed as low level radioactive waste. Each QDS is specially prepared to address a specific chemical group (i.e., they are ion-specific): The Halogen Mass Effect solution (QDS-H) is for decontamination of halogen-containing (iodine, fluorine, and chlorine) contaminants; the Transition Metal Mass Effect solution (QDS-TM) is for decontamination of contaminants containing transition metals such as cesium, cobalt, strontium, and thallium; and the Actinide Mass Effect solution (QDS-A) is for decontamination of actinides. In situations with unknown contaminants, all three solutions would be recommended in the above sequence. The application method is the spray on and wipe off of each solution (repeated until adequate removal is attained). The solutions are water-based and environmentally friendly. The product can be foamed and concentrated for adaptability to existing shower systems and municipal fire foaming equipment. Figure 2-1 shows the contents of the RDS Emergency RadDecon Kit which includes the QDSs in spray bottles, wipes (the same wipes used during this evaluation) plastic gloves, instructions for use, and disposal bags. RDS has the QDS available in bulk solutions or concentrates. More information is available at www.raddecon.com.

Figure 2-1. RDS Eme**rgency RadDecon Kit containing all three QDS**.

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. 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 ASTM International (ASTM) Standard C 150-7[1] specifies that tricalcium aluminate accounts 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. The apparent porosity of the concrete from the prepared coupons ranged from 15-30%.

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 concrete was representative of exterior concrete commonly found in urban environments in the United States as shown by INL under a previous project entitled, "Radionuclide Detection and Decontamination Program. Broad Agency Announcement 03-013" sponsored by the U.S. Department of Defense (DOD), Defense Advanced Research Projects Agency (DARPA) and U.S. Department of Homeland Security (DHS). 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.

3.1.2 Coupon Contamination

Eight coupons were contaminated by spiking individually with 2.5 milliliters (mL) of aqueous solution that contained 0.4 microCurie (µCi)/mL Cs-137 as a solution of cesium chloride, which corresponded to an activity level of approximately 1 µCi over the 225 square centimeters (cm^2) surface. Application of the Cs-137 in an aqueous solution was justified because even if Cs-137 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).

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 liter (L) per minute created a turbulent flow through the first syringe. When the contaminant solution in the second syringe was introduced, the contaminant 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 QDS. 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 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 that held three rows of three concrete coupons was used. The test stand, approximately 2.7 m × 2.7 m, 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 (position 8) and decontaminated in the same way as the other coupons. This coupon, referred to as the CC blank, was placed there to observe possible CC 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 with numbered coupon positions (right).

3.2 Evaluation Procedures

The eight concrete coupons in the test stand which had been contaminated approximately one month before were decontaminated using liquid and foam applications of the QDS. The liquid QDS was applied to the coupons in positions 1, 2, 4, 7, and 8 (blank coupon) and simultaneously foam QDS was used on the coupons in positions 3, 5, 6, and 9. Both the liquid and foam applications of the QDSs were applied starting with the higher wall surfaces because of the possibility of secondary contamination lower on the wall. Both solutions were applied to the coupons because RDS testing had indicated increased efficacy for decontaminating Cs-137 using this combination. In the case of an unknown contaminant, all three QDS solutions would be used.

The liquid and foam applications of the QDS were made using plastic spray and foaming bottles (32 oz. Heavy Duty Spray Bottle, Rubbermaid Professional, Atlanta, GA and Equate Foaming Hand Soap bottle [cleaned], Wal-Mart, Bentonville, AR). Regardless of whether liquid or foam applicators were used, the application included two solutions, QDS-H and QDS-TM, and the same procedure was used. First, QDS-H was applied to the surface with the spray or foaming bottles. The spray was applied to the whole surface while the foam was applied and then spread over the entire surface of each coupon with a plastic trowel. After a 5-10 second wait, the liquid or foam was removed by wiping with a RDS provided Rad-wipe (BH 92910, 8 inch × 9 inch BIO-SCREEN® BIO-HAZARD WIPES, Current Technologies, Crawfordsville, IN). Then, the same procedure was performed again using the QDS-TM. This two-step application was repeated five additional times. Altogether, the liquid application and removal took between one and three minutes per concrete coupon and the foam application took between three and five minutes.

The overall decontamination method for QDS spray and foam included:

1. Apply spray or foam QDS-H solution
2. Wait 5 - 10 seconds
3. Remove spray or foam QDS-H solution with Rad-wipe
4. Apply spray or foam QDS-TM solution
5. Wait 5 - 10 seconds
6. Remove QDS-TM with Rad-wipe
7. Repeat steps 1 - 6 five additional times
8. Rinse with water (with spray bottle) and remove with Rad-wipe.

The temperature and relative humidity (RH) were recorded at the start and finish. The temperature and relative humidity was 21 °C (70 °F) and 20% at the start and 19 °C (66 °F) and 16% at the finish. According to the vendor, these conditions were acceptable for use of the QDSs.

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 weekly during 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).[2] 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). Table 4-1 gives the calibration results across the duration of the project. Each row gives the difference between the known energy levels and those measured following calibration (rolling average across the six most recent calibrations). Pre-contamination measurements were performed in late September and the post-contamination results were measured in late November. Each row represents a six week rolling average of calibration results. In addition, 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 from Th-228 Calibration Energies

	Calibration Energy Levels (keV)				
Date Range (2010)	**Energy 1 238.632**	**Energy 2 583.191**	**Energy 3 860.564**	**Energy 4 1620.735**	**Energy 5 2614.533**
9-27 to 11-2	-0.003	0.010	-0.039	-0.121	0.017
10-5 to 11-8	-0.003	0.011	-0.029	-0.206	0.023
10-12 to 11-16	-0.004	0.015	-0.040	-0.245	0.031
10-19 to 11-24	-0.005	0.014	-0.001	-0.320	0.043

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 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 comprises 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 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 four 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 five coupons in order to provide duplicate measurements to evaluate the repeatability of the instrument. Three of the duplicate measurements were performed after contamination prior to application of the decontamination technology and two were performed after decontamination. All five of the duplicate pairs showed difference in activity levels of 2% or less, 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 it to the accepted NIST value. Results within 7% of the NIST value are considered (according to RML internal quality control procedures) 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 serves as the performance evaluation (PE) audit. This audit confirms the accuracy of the calibration of the germanium detector instrumentation critical to the results of the evaluation. Table 4-2 gives the results of each of the audits applicable to the duration of the evaluation including the pre-decontamination measurements performed in late September. All results are below 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
9-15-2010	124,600	122,000	2%
10-13-2010	124,600	123,100	1%
11-10-2010	124,600	121,600	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. 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 Contractor QA Manager.

4.2.3 Data Quality Audit

At least 10% of the raw data acquired during the evaluation and transcribed into spreadsheets for use in the final report was verified by the QA manager. 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. Draft assessment reports were prepared and sent to the Test Coordinator and Program Manager for review and approval. Final assessment reports were then sent to the EPA QA Manager and contractor staff.

5.0 Evaluation Results

5.1 Decontamination Efficacy

The decontamination efficacy of the QDSs was measured for each contaminated coupon in terms of percent removal (%R) and decontamination factor (DF). Both of these 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:

$$\%R = (1 - A_f/A_o) \times 100\%$$

$$DF = A_o/A_f$$

where, A_o is the radiological activity from the surface of the coupon before application of QDS 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.

Tables 5-1 and 5-2 give the %R and DF for the liquid and foam applications of the QDS, respectively. 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 1.10 µCi ± 0.028 µCi and 1.0 µCi ± 0.11 µCi for the coupons used for liquid and foam QDS, respectively. The post-decontamination coupon activities were less than the pre-decontamination activities showing an overall reduction in activity for both QDS applications. For the liquid QDS application, the %R averaged 53% ± 7% and the DF averaged 2.1 ± 0.31. Overall, the %R ranged from 43% to 59% and the DF ranged from 1.8 to 2.5. For the foam QDS application, the %R averaged 51 ± 8% and the DF averaged 2.1 ± 0.43. Overall, the %R ranged from 46% to 63% and the DF ranged from 1.9 to 2.7. Each set of four coupons had one coupon (liquid-bottom left, foam-top right) that appeared to be a slight outlier compared to the other three coupons. There was no explanation for these results. A t-test was performed on the two data sets in order to determine the likelihood of generating the observed %R data if the data sets were not different. Based on this test, the liquid QDS and the foam QDS were not considered to be significantly different from one another, with a 95% confidence interval.

Table 5-1. Decontamination Efficacy Results for the Liquid QDS

Coupon Location in Test Stand	Pre-Decon Activity (µCi / Coupon)	Post-Decon Activity (µCi / Coupon)	%R	DF
Top left	1.09	0.44	59%	2.5
Top middle	1.12	0.55	51%	2.0
Center left	1.07	0.46	57%	2.3
Bottom left	1.13	0.64	43%	1.8
Average	**1.10**	**0.52**	**53%**	**2.1**
Std. Dev	**0.028**	**0.09**	**7%**	**0.31**

Table 5-2. Decontamination Efficacy Results for the Foam QDS

Coupon Location in Test Stand	Pre-Decon Activity (µCi / Coupon)	Post-Decon Activity (µCi / Coupon)	%R	DF
Top right	1.10	0.40	63%	2.7
Center middle	1.11	0.57	49%	2.0
Center right	0.98	0.53	46%	1.9
Bottom right	0.88	0.47	46%	1.9
Average	**1.0**	**0.49**	**51%**	**2.1**
Std. Dev	**0.11**	**0.07**	**8%**	**0.43**

As described above in Section 3.1, the CC blank was included in the test stand to evaluate the potential for CC due to application of the liquid and foam QDS on wall locations above the placement of the uncontaminated coupon. In the case of this evaluation, foam QDS was applied to the contaminated coupon in the center middle position. Liquid QDS was then applied to the CC blank using the same method as for the other coupons. After decontamination, the activity of the CC blank was found to be 0.00082 µCi. This value was two times greater than the minimum detectable level, but more than 500 times less than the post-decontamination activities of the contaminated coupons. Therefore, this detectable result suggested that cross-contamination resulting from the application/ removal of the QDS on coupons located above the CC blank is possible, but that the extent of CC observed here was minimal.

5.2 Deployment and Operational Factors

A number of operational factors were documented by the technician who performed the testing with the QDS. One of the factors was the degree of difficulty in application. The application of the liquid and foam QDS was described in Section 3.2 and included use of plastic spray and foaming bottles. Application of the liquid QDS to each coupon took approximately 5 - 10 seconds while application of the foam QDS took slightly longer (approximately 20 – 30 seconds) because of the need to spread the foam across the coupon. After a 5 - 10 second wait, the liquid or foam (depending on the coupon) was removed from the coupons with a Rad-wipe in less than 10 seconds. This very simple procedure was repeated five additional times with water rinse and wipe removal as the final step. While the procedure was very straightforward, the technician who performed the testing noted that the repetition of spraying and wiping on the same coupon became somewhat cumbersome. During testing, semi-quantitative measurement of activity was performed using a radiation dose rate survey meter (RO-20, Eberline-Thermo Scientific, San Diego, CA) following each application cycle of QDS liquid and foam (on only one coupon only). The results indicated that no additional decrease in activity occurred following the second application of the liquid and the third application of the foam.

The elapsed time for the coupons decontaminated with both liquid QDS ranged from one to three minutes and from three to six minutes for both foam QDS applications. These application and removal times are applicable only to the experimental scenario including these rather small concrete coupons. According to RDS, if the QDS were applied to larger surfaces, larger application and removal tools such as larger sprayers or foamers (e.g., firetruck mounted, robotic, or aircraft deicing spraying equipment) and large scale rinsing or vacuum removal system (in lieu of Rad-wipes) could be used. Neither the liquid nor foam QDS caused any visible damage to the surface of the coupons. Figure 5-1 shows a photograph of the plastic bottles used for application and the QDS-TM (yellow) foams on a concrete coupon. The QDS-H was similar, but white in color. The personal protective equipment (PPE) used by the technician in the picture was required because the work was performed in a radiological contamination area using Cs-137 on the concrete coupon surfaces. Whenever radioactive contaminated material is handled, anti-contamination PPE will be required and any waste will be considered low level radioactive waste (and will need to be disposed of accordingly). The required PPE was not driven by the use of the QD solutions (which are not hazardous), rather the interaction with surfaces contaminated with Cs-137.

Figure 5-1. QDS foam application (left) and concrete coupons containing QDS-TM (right).

Table 5-3 summarizes qualitative and quantitative practical information gained by the operator during the evaluation of the QDS. All of the operational information was gathered during use of the QDS on the concrete coupons inserted into the test stand. Some of the information given in Table 5-3 could differ if the liquid and foam QDS were applied to a larger surface or to a surface that was smoother or more rough and jagged than the concrete coupons used during this evaluation.

Table 5-3. Operational Factors Gathered from the Evaluation

Parameter	Description/Information
Decontamination rate	Technology Preparation: No preparation was required as the QDS-H and QDS-TM solutions are provided ready to use. Application: Liquid was applied in 5-10 seconds with 2-4 squeezes of the spray bottle. Foam took 20-30 seconds because it was smoothed across the surface of the coupon with a plastic trowel. Liquid and foam then removed by wiping. Requires six iterations of above described application with QDS-H and QDS-TM. Required 3-6 minutes for each 225 cm^2 concrete coupon corresponding to a decontamination rate of 0.225 to 0.45 m^2/hr. Estimated volumes used for all the concrete coupons included 470 mL of QDS-H, 300 mL of QDS-TM as liquids and 150 mL of each solution as a foam. Overall that corresponding to 3 L/m^2 for QDS-H and 2 L/m^2 for QDS-TM.
Applicability to irregular surfaces	Application to irregular surfaces would not seem to be problematic as the QDS are sprayed or spread into hard to reach locations.
Skilled labor requirement	Adequate training would likely include a few minutes of orientation so the technician is familiar with the application technique. Larger surfaces may required more complex equipment such as spray or foam application.
Utilities requirement	As evaluated here, no utilities were required.
Extent of portability	At a scale similar to that used for this evaluation, there would not be any limitation to portability. However, for larger scale applications, limiting factors would include the ability to apply the QDS at an adequate scale and remove with an approach more efficient than hand wiping. RDS indicated that use with higher volume application tools such as fire truck mounted, robotic, or aircraft deicing equipment would be feasible.
Secondary waste management	1 L of liquid was applied to the concrete coupons used during this evaluation. That volume corresponds to a waste generation rate of approximately 5 L/m^2 and 2000-3000 cm^3 of Rad-wipe waste. Because Cs-137 was used for this testing, all waste (liquid and Rad-wipes) was disposed of as low level radioactive waste.
Surface damage	Concrete surfaces appeared undamaged.
Cost (material only)	The material cost was approximately \$50 per liter for each QDS which corresponds to \$250/m^2 if used in a similar way as used during this evaluation. Labor costs were not calculated.

6.0 Performance Summary

This section presents the findings from the evaluation of the liquid and foam applications of the QDS for each performance parameter evaluated.

6.1 Decontamination Efficacy

The decontamination efficacy (in terms of %R) attained for liquid and foam applications of the QDS was evaluated for each concrete coupon used during the evaluation. When the decontamination efficacy metrics (%R and DF) of the eight contaminated coupons were averaged together, the average %R for liquid QDS was 53% ± 7% and the average DF was 2.1 ± 0.31. The average %R for foam QDS was 51% ± 8% and the average DF was 2.1 ± 0.43.

6.2 Deployment and Operational Factors

Both the liquid and foam applications of the QDS were performed using a plastic spray and foaming bottles. For the liquid application, the concrete coupons were thoroughly wetted with the first QDS (QDS-H) with 3 - 4 sprays. After a 5 - 10 second wait, the solution was wiped off the surface of the concrete with a Rad-wipe. This process was repeated with the second solution (QDS-TM). This two-step process was repeated six times before a final water rinse and wipe dry. For each 225 cm^2 concrete coupon, the liquid application took 1-3 minutes and for the foam application, 3 - 6 minutes.

The waste generated through use of the QDS was estimated to be approximately 5 L/m^2. As used for this evaluation, no utilities were required. Scaled up applications in remote locations may require additional equipment such as a fire truck mounted or other large scale sprayer equipment to provide means for spray or foam application and larger scale removal techniques. Minimal training would be required for technicians using the QDS, and the surface of the concrete was not visibly damaged during use of the liquid or foam application of the QDS. The material cost was approximately $50 per liter for each QDS which corresponds to $250/$m^2$ if used in a similar way as used during this evaluation. Labor and waste management costs would be dependent on the particular physical characteristics of the area being decontaminated and so were not calculated.

It should be noted that the test results indicated that no additional decrease in activity occurred following the second application of the liquid and the third application of the foam.

7.0 References

1. ASTM Standard C 150-07, "Standard Specification for Portland Cement." ASTM International, West Conshohocken, PA, www.astm.org, 2007.

2. 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).

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