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Technology Evaluation Report

Decontamination of Concrete with Aged and Recent Cesium Contamination

Office of Research and Development
National Homeland Security Research Center

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National Homeland Security Research Center
Office of Research and Development
U.S. Environmental Protection Agency
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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. 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 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
National Program Director
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Contents

Tables

Figures

Abbreviations/Acronyms

ANSI	American National Standards Institute
ASG	Argonne SuperGel
Bq	Becquerel
ºC	degrees Celsius
CASCAD™	Canadian Aqueous System for Chemical/Biological Agent Decontamination
cm	centimeters
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
EAI	Environmental Alternatives, Inc.
EPA	U.S. Environmental Protection Agency
Eu	europium
G	gram(s)
hr	hour(s)
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
keV	kilo electron volt(s)
mL	milliliter(s)
L	liter(s)
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
RML	Radiological Measurement Laboratory
RRII	Rad-Release II
RSD	relative 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

Executive Summary

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 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) evaluated the performance of a number of chemical-based radiological decontamination technologies for removal of cesium from concrete. The objective of this evaluation was to quantify the effect of residence time of radiological contamination, such as would result from an urban "dirty bomb", on concrete relative to decontamination efficacy of various decontamination technologies. The technologies chosen for the evaluation were selected from among the best-performing chemical-based technologies tested to date under TTEP. The four technologies chosen include:

- Allen-Vanguard's Surface Decontamination Foam (SDF™);
- a modified formulation of SDF developed by Environment Canada called Universal Decontamination Formulation (UDF);
- Environmental Alternatives, Inc.'s Rad-Release II (RRII); and
- Argonne SuperGel (ASG).

These technologies were evaluated for their ability to remove radioactive cesium (Cs)-137 from the surface of unpainted concrete that had been recently contaminated (within approximately two weeks) compared to their ability to remove radioactive cesium from concrete that had been similarly contaminated approximately one year prior to decontamination.

SDF and UDF are both applied as a foam, removed with a vacuum, and the surface is rinsed with water. RRII is applied as a liquid with spray bottles and removed with a water rinse and vacuum. ASG is applied as a gel and removed with a vacuum. Prior to the application of each technology, unpainted concrete coupons contaminated with Cs-137 were placed in a vertical test stand designed to hold nine coupons. Following manufacturer's recommendations, the technologies were applied to the surface of the test stand where the coupons were located. Following application of the decontamination technologies, the residual activity on the coupons was measured and compared with that of similar control coupons decontaminated using deionized water as a control. Important deployment and operational factors were also documented and reported.

A summary of the evaluation results for SDF, UDF, RRII, and ASG is presented below while a 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) achieved by SDF, UDF, RRII, and ASG was evaluated following contamination of the coupons with approximately one microCurie (μCi) Cs-137, measured by gamma

spectroscopy. For the concrete coupons contaminated within two weeks of the decontamination evaluation, the %Rs were determined to be 51 ± 3.9 for SDF, 62 ± 8.9 for UDF, 74 ± 7.3 for RRII, 75 ± 4.4 for ASG, and 6.1 ± 1.0 for the water control. The %Rs for the coupons that had been contaminated approximately one year prior to decontamination were 29 ± 10 for SDF, 37 ± 10 for UDF, 50 ± 17 for RRII, 46 ± 5.7 for ASG, and 4.0 ± 0.4 for the water control. Therefore, across all the decontamination technologies, the aged coupons exhibited less effective decontamination. A very limited evaluation of cross contamination was performed (not specific to age of concrete), and the results confirmed that cross contamination did occur to a minimal extent.

Deployment and Operational Factors: The test stand containing the coupons used during this evaluation totaled nine square meters (m^2). Each technology was applied according to the procedure recommended by the manufacturer. Each application of SDF and UDF foam took approximately one minute followed by a 30 minute wait and rinse. This two-step application followed by removal was performed twice. Use of RRII also included an initial application, a 30 minute dwell time, and rinse and vacuum removal. These steps were performed once for RRII Formula 1 and once for RRII Formula 2. ASG required a one-step application that included vacuum removal after a 90 minute wait period. All four decontamination technologies seem well suited for rough or jagged surfaces as the foam, spray, and gel can reach most areas easily. However, the vacuum removal step could become difficult on rough surfaces. The surface finish of the concrete was not visibly affected by decontamination with any of the four decontamination technologies.

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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 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 contaminants into buildings or water systems, the containment of these contaminants, the decontamination of buildings and/or water systems, and the disposal of material resulting from clean-ups.

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 of 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 is provided that is useful to decision makers in purchasing or applying the evaluated 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 evaluation design so that useful performance information is produced for each of the evaluated technologies.

Four separate technologies were evaluated for decontamination of radioactive isotope cesium-137 (Cs-137) from unpainted concrete:

- Allen-Vanguard Surface Decontamination Foam™ (SDF);
- SDF with an additional reagent (and decontamination step) referred to as Universal Decontamination Formulation (UDF);
- Environmental Alternatives, Inc.'s Rad-Release II™ (RRII); and
- Argonne SuperGel™ (ASG).

This evaluation was conducted according to a peer-reviewed test/QA plan 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. The following performance characteristics of SDF, UDF, RRII, and ASG were evaluated:

- Decontamination efficacy defined as the extent of radionuclide removal following application of the four decontamination technologies to concrete coupons upon which Cs-137 had been applied both in January 2012 (approximately two weeks prior to decontamination) and January 2011 (one year prior to decontamination) to determine if significant differences in decontamination efficacy resulted. Another quantitative parameter evaluated was the possibility of cross contamination onto uncontaminated surfaces due to the decontamination procedure.

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

This technology evaluation took place during February 2012 at the U.S. Department of Energy's Idaho National Laboratory (INL).

2.0 Technology Description

This report provides results for the evaluation of SDF, UDF, RRII, and ASG. Following is a description of each technology, based on information provided by the vendor. The information provided below was not verified during this evaluation.

2.1 Allen-Vanguard SDF and UDF

Allen-Vanguard's SDF is an aqueous foam decontaminant which is a derivative product of the Canadian Aqueous System for Chemical/Biological Agent Decontamination (CASCAD™). The SDF foam is generated by dissolving 485 grams (g) GPA2100 and 110 g GPB2100 (both reagents from Allen-Vanguard, Ottawa, ON, Canada) in deionized (DI) water. SDF was not designed for radiological decontamination but rather as a decontaminant for chemical and biological agents, which also has blast mitigation applications.

To expand its application to radiological decontamination, a project entitled "Universal Surface Decontamination Formulation" (CRTI-06-0169TA) was initiated and funded by Chemical, Biological, Radiological, Nuclear and Explosives (CBRNE) Research and Technology Initiative, Defence R&D Canada. The original SDF formulation was modified by incorporating two additional reagents into the SDF formulation. Reagent A is included into the mixture prepared in the foamer, while Reagent B is applied separately to the surfaces after application and removal of the modified foam and then is rinsed off with de-ionized (DI) water. The reagents, surfactant, foamer, and drill mixer are all sold separately. The reagents and backpack foamer can be purchased from Allen-Vanguard. The UDF is designed to decontaminate surfaces exposed to radionuclides while retaining its existing chemical and biological decontamination characteristics.

2.2 Environmental Alternatives, Inc. Rad-Release II

The Rad-Release II (RRII) decontamination technology is a chemical process that involves the sequential topical application of two solutions (applied in the order directed by Environmental Alternatives, Inc. (EAI)). RRII extracts radionuclides, including transuranics, from nearly all substrates. This process was developed to be used in sequence to synergistically remove the contaminants via the migration pathways, pores and capillaries of the contaminated material.

To maximize the efficacy of the extraction process, the chemistry and application are tailored to the specific substrate, targeted contaminant(s), and surface interferences. The RRII Formula 1 contains salts to promote ion exchange and surfactants to remove dirt, oil, grease, and other surface interferences. Broad-target and target-specific chelating agents are blended into the solution to sequester and encapsulate the contaminants, keeping them in suspension until they are

removed by the subsequent rinse. RRII Formula 2 is designed as a caustic solution containing salts to promote ion exchange, ionic and nonionic surfactants, and additional sequestering agents, also utilized to encapsulate the contaminants and keep them in suspension until they are removed by the subsequent rinse.

RRII is applied in low volume, as either an atomized spray or foam. Foam deployment of the solution is most appropriate for large scale applications while the spray application (as used during this evaluation) is beneficial for smaller applications and applications where waste minimization is a critical factor. Several options are available to facilitate the removal step. For small surfaces removal could be accomplished by vacuuming or by simple wiping with absorbent laboratory wipes or rags. For wider areas one could use a clay overlay technique to wick out the RRII and contamination over time, removing the clay at a later date. Another technique suitable for larger surface areas could be to spray absorbent polymer over the chemically treated surface to leach or wick out the contaminant-laden solutions, binding them in the polymer, which could subsequently be peeled off. The sequence of application, dwell, rinse, and removal of the decontamination solution constitutes a single iteration. This procedure may be repeated, as needed, until the desired residual contaminant levels are achieved. More information is available at www.eai-inc.com [accessed 9-12-12].

2.3 Argonne SuperGel

Argonne SuperGel (ASG) is a system of super absorbing polymers containing solid sequestering agents dissolved in a nonhazardous ionic wash solution. The resulting hydrogel is applied to the contaminated surface and provides exchangeable ions to the substrate to promote the desorption of radioactive cesium and other radionuclides. The solid sequestering agent provides strong sorption of the target radionuclides within the gel. After removing the radionuclide-loaded hydrogel by conventional wet vacuum, the contaminated hydrogel can be dehydrated or incinerated to minimize waste volume without loss of volatilized contaminants. The goals of this approach are:

- *In situ* dissolution of bound contaminants without dissolving or corroding contaminated structural components.
- Controlled extraction of water and dissolved radionuclides from the surface and pore/microcrack structures into a super-absorbing hydrogel.
- Rapid stabilization of the solubilized radionuclides with high-affinity and high-specificity sequestering agents immobilized in the hydrogel layer.
- Low toxicity reagents and low volume of radioactive waste.

The superabsorbing polymers consist of an anionic mixture of polyacrylamide and polyacrylate in both linear and cross-linked form. The solid sequestering agent is mixed into the dry polymer (10% by mass). The ionic wash solution is composed of a single component salt at 1 mole/liter (L) concentration (no strong acid or base is used). The reconstituted hydrogel (19-20 grams of ionic wash solution per gram of dry polymer mix) can be applied by hand for small areas or sprayed on for larger applications. The hydrogel is allowed to react with the contaminated surface for at least 60-90 minutes to maximize the ionic exchange of radionuclides and diffusion/absorption into the hydrogel. The hydrogel is designed to adhere to vertical surfaces

without slipping and maintain hydration in direct sunlight for more than an hour. Because no component of the hydrogel is hazardous, there are no special precautions required to deal with hazardous materials. The hydrogel is also compliant with disposal as low-level radioactive waste.

Conventional wet-vacuum technology is sufficient to remove the hydrogel from the contaminated surface. For small-scale applications, the head of a standard wet vacuum is adequate, while for larger scale applications, a squeegee attachment is recommended.

3.0 Experimental Details

3.1 Experimental Preparation

3.1.1 Concrete Coupons

Concrete coupons were prepared from a single batch of concrete made out of 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. This data describes the cement clinker used in the concrete mix. The ASTM C150[1] requires that the tricalcium aluminate content be less than 8% of the overall cement clinker for Type II Portland cement. 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 aluminate 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 centimeters [cm] deep) with the surface exposed. The surface was then "floated" to get the smaller aggregate and cement paste to float to the top (the surface used for this evaluation) and 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. In addition, the concrete was representative of exterior concrete commonly found in urban environments in the United States as shown by INL under a U.S. Department of Defense, Defense Advanced Research Projects Agency (DARPA) and U.S. Department of Homeland Security (DHS) project[2]. Prior to contaminant application, the surface of each coupon was examined for obvious cracks or abnormalities and, if none were found, the coupon surfaces were cleaned with a soft nylon brush and ASTM International Type I water and allowed to air dry on a laboratory bench for at least five days.

3.1.2 Coupon Contamination

Table 3-2 describes the number of coupons used in this evaluation. To observe the effect of contaminant aging on decontamination efficacy, 20 coupons were contaminated approximately two weeks prior to decontamination, and 20 coupons had been contaminated approximately one year prior to decontamination.

All of these coupons were contaminated with 2.5 milliliters (mL) of unbuffered slightly acidic aqueous solution containing 0.4 µCi/mL Cs-137 which corresponds to an activity level of approximately 1 µCi per coupon (± 0.5 µCi). In the case of an actual urban Radiological Dispersion Device (RDD) event dry contaminated particles are expected to settle over a wide area of a city. Application of the Cs-137 in an aqueous solution was justified because even if Cs-137 were to be dispersed in a dry particle form, 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 that for the ability to apply dry particles homogenously. The aqueous contaminant was delivered to each coupon using an aerosolization technique developed by INL under the DARPA/DHS project[2].

Table 3-2. Number of Coupons Decontaminated

Decontamination Technology	Number of Coupons Decontaminated	
	Contaminated in January 2011	Contaminated in January 2012
SDF	4	4
UDF	4	4
RRII	4	4
ASG	4	4
Water control	4	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 rear 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 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 masked with tape (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 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 approximately one week of coupon contamination, gamma radiation from the surface of each contaminated coupon was measured to quantify contamination levels both before and after decontamination 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 activity on each of the coupons was 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. 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 (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 wall to observe possible cross contamination caused by the decontamination process being conducted.

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

3.2 Decontamination Technology Procedures

3.2.1 SDF and UDF

Using the procedure recommended by the manufacturer, SDF and UDF were applied to 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 SDF and UDF was performed using a foamer (Concealed Backpack Foamer, Allen-Vanguard, Ottawa, ON, Canada) following instructions provided by Allen-Vanguard. For both SDF and UDF, 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 equipped with the backpack because the sprayer hose was threaded into the radiological tent with the foamer remaining on the outside. The foam was allowed to reside on the surface for 30 minutes and then 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 deionized water using a handheld sprayer (Model 1125D Wood and Masonry Sprayer, Root-Lowell Flo Master®, Lowell, MI) and followed by vacuuming. For SDF and UDF, this procedure was repeated once, for a total of two iterations. Figure 3-3 shows the backback foamer, the foam application, and vacuum removal.

There were two differences between the SDF and UDF procedures. For UDF, an additional reagent (referred to by Allen-Vanguard as Reagent A) was added to the liquid foam mixture during both foam applications. Also, for UDF, one additional step was included. Following the two iterations of foam application, rinse, and removal, another reagent (referred to by Allen-Vanguard 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 surface for 30 minutes, followed by a final rinse with DI water and vacuuming. Altogether, decontamination of the coupons with SDF took approximately

Figure 3-3. Backpack foamer, foam application, and vacuum removal.

84 minutes to complete. Of this, 24 minutes were spent applying the technology, rinsing, and

vacuuming, with 60 minutes of dwell time. Decontamination of the coupons with UDF took a approximately 122 minutes including the added steps required for Reagent B, with 90 minutes total dwell time. The area treated in both cases was 0.2 m^2.

3.2.2 EAI RRII

The application of RRII onto the nine coupons in the test stand was performed according to the procedure recommended by the manufacturer using plastic spray bottles (32 oz. Heavy Duty Spray Bottle, Rubbermaid Professional, Atlanta, GA) as directed by EAI. The concrete coupons were thoroughly wetted with RRII Formula 1 with 3 - 4 sprays. The solution was then worked into the surface of the coupon by scrubbing the entire surface of the coupon once with a scouring pad (Heavy Duty Scouring Pad, 3M Scotch-Brite, St. Paul, MN). During this evaluation, the initial application of RRII Formula 1 took only 10-15 seconds for each coupon. The next step was a 30-minute dwell time for the RRII Formula 1 to reside on the surfaces of the concrete coupons. The coupon surfaces were kept damp with 1-2 sprays of additional RRII Formula 1 approximately every five minutes. The additional 1-2 sprays of the RRII Formula 1 were performed to simulate foam collapse, i.e. the reintroduction of fresh solutions to the contaminated matrix, as would be observed when RRII was deployed as a foam for larger scale real-world applications. After the 30 minute dwell time, the coupon surfaces were thoroughly wetted with a 10% nitric acid rinse solution (in deionized water) using another spray bottle. The surface was then vacuumed a final time (12 gallon, 4.5 horsepower, QSP® Quiet Deluxe, Shop-Vac Corporation, Williamsport, VA) which took approximately 25 seconds per coupon. The above procedure was then repeated for RRII Formula 2. Altogether the RRII procedure took approximately 73 minutes to complete. Of this, 13 minutes were spent applying the technology, rinsing, and vacuuming, with 60 minutes total dwell time. The area treated was 0.2 m^2. Figure 3-4 shows the rinse and vacuuming step of the Rad-Release procedure.

Figure 3-4. Rinsing and vacuuming RRII from concrete coupon

3.2.3 Argonne ASG

The ASG was prepared by mixing two dry powders with water as directed by Argonne. The mixture was then stirred with a drill equipped with a mixing tool until the mixture was homogeneous. The ASG was applied to the nine concrete coupons using a four-inch paint brush and a spackling knife to smooth the ASG across the surface. The specifications of the paint brush/spackling knife were not critical as a perfectly smooth application was not required. The application of the ASG took approximately 30 seconds per coupon. The ASG was allowed to stay on the surface for 90 minutes, and was then removed with a wet vacuum (12 gallon, 4.5 horsepower, QSP® Quiet Deluxe, Shop-Vac Corporation, Williamsport, VA) which required approximately 25 seconds per concrete coupon. Altogether, decontamination of the coupons with ASG took approximately 99 minutes to complete. Of this, 9 minutes were spent applying the technology, rinsing, and

vacuuming, with 90 minutes total dwell time. The area treated was 0.2 m^2. Figure 3-5 shows the application and vacuum removal steps for the ASG.

3.2.4 Water as Control

For all four of the decontamination technology evaluations deionized water was used as a decontamination method to provide a baseline against which to compare the commercial technologies. The water was sprayed onto the coupons using a hand-held spray bottle. Once the coupons were thoroughly wetted, the water was allowed to reside on the coupons for 30 minutes, after which the coupons were vacuumed, rinsed again, and vacuumed again. This process was completed two times in order to be comparable to the processes used for the commercial products.

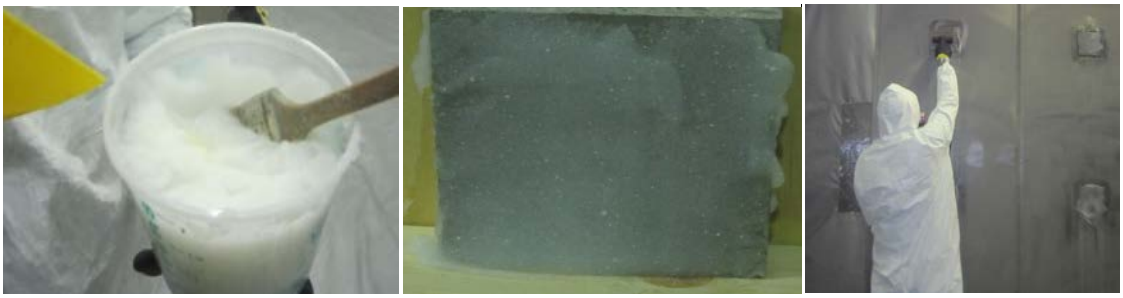

Figure 3-5. ASG before application, as applied to coupon, and during vacuum removal.

3.3 Decontamination Conditions

The decontamination technology testing was performed over the course of three days. Table 3-3 presents the number of days between coupon contamination and decontamination, the temperature (or range) in degrees Celsius (°C) and the percent relative humidity measured during the evaluation.

Table 3-3. Details of Each Testing Time Period

Technology	Time Between Coupon Contamination and Decontamination	Temperature During Decontamination (°C)	Relative Humidity During Decontamination (%)
SDF/UDF	1 year or 12-14 days	18.3-18.8	29-31
RRII		17.8	16
ASG		18.9	31

4.0 Quality Assurance/Quality Control

QA/QC procedures were performed in accordance with the QMP and the test/QA plan for this evaluation. In addition, this evaluation followed a test/QA plan amendment dated January 20, 2012.

4.1 Intrinsic Germanium Detector

The germanium detector was calibrated weekly during the evaluation. 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). Table 4-1 presents the calibration results across the duration of the project. In each row are shown the differences between the known energy levels and those measured following calibration (rolling average across the six most recent calibrations). Each row represents a six week rolling average of calibration results. These 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

Measurement 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
January 2011	12-31-10 to 2-1-11	-0.002	0.007	-0.019	-0.143	0.013
January 2012	1-31-12 to 3-6-12	-0.003	0.007	0.008	-0.189	0.017
March 2012	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 discussed 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 five laboratory blank coupons was determined by analyzing arbitrarily selected coupons from the stock of 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 four coupons in order to provide duplicate measurements to evaluate the repeatability of the instrument. Two of the duplicate measurements were performed after contamination prior to application of the decontamination technologies and two were performed after decontamination. All four of the duplicate pairs showed differences in activity level of 2% or less, within the acceptable difference of 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 (NIST)-traceable europium (Eu)-152 standard (in units of Becquerel, Bq) and comparing 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 served 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 these audits for the detector that was used during this evaluation. All results were within the acceptable difference of 7%.

4.2.2 Technical Systems Audit

A TSA was conducted during testing 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. In addition, 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 QA Manager.

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

Date	Eu-152 (keV)	NIST Activity (Bq)	INL RML Result (Bq)	Difference
January 2011	Average	124,600	124,700	1.0%
	122	124,600	122,800	1.4%
	779	124,600	122,600	1.6%
	1408	124,600	125,100	1.0%
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 test/QA plan and the QMP.

There was one amendment to the January 18, 2011 version of the test/QA plan to include the decontamination experiments performed as described in this report.

5.0 Evaluation Results and Performance Summary

5.1 Decontamination Efficacy

The decontamination efficacy was determined for each contaminated coupon in terms of percent removal (%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 application of the decontamination technologies and A_f is radiological activity from the surface of the coupon after removal. While the DFs are reported in the following data tables, the narrative describing the results will focus on the %R.

The decontamination testing described in this report included concrete coupons that had been contaminated at two different times. The first group of coupons had been contaminated approximately two weeks before decontamination testing, and the second group of coupons had been contaminated approximately one year before the decontamination testing. Other than the time elapsed since contamination, all other variables were consistent with the previous EPA testing that had been performed in 2010 with the same technologies[4,5].

5.1.1 SDF and UDF Results

Table 5-1 presents the decontamination efficacy, expressed as both %R and DF, for SDF, UDF, and the water control on coupons contaminated two weeks and one year prior to decontamination testing. The target activity for each of the 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 1.01 ± 0.07 µCi, a variability of 7%.

The decontamination efficacies of SDF and UDF in terms of %R for two-week-old contamination were 51 ± 3.9% and 62 ± 8.9%, respectively. The water control applied to these coupons resulted in a %R of 6.1 ± 1.0%. The decontamination efficacy of SDF and UDF were statistically the same while the water control was significantly less than both SDF and UDF.

Table 5-1. SDF and UDF Decontamination Efficacy Results

Technology		Pre-Decontamination Activity (µCi/Coupon)	Post-Decontamination Activity (µCi/Coupon)	%R	DF
SDF		0.93	0.48	48%	1.9
		0.98	0.42	57%	2.3
		0.89	0.44	51%	2.0
		1.01	0.51	50%	2.0
	Avg	0.95	0.46	51%	2.1
	SD	0.05	0.04	3.9%	0.2
SDF (aged)		1.07	0.76	29%	1.4
		0.87	0.51	41%	1.7
		1.07	0.76	29%	1.4
		1.08	0.89	18%	1.2
	Avg	1.02	0.73	29%	1.4
	SD	0.10	0.16	10%	0.2
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%	0.5
UDF (aged)		1.10	0.79	28%	1.4
		1.05	0.51	51%	2.1
		1.08	0.70	35%	1.5
		1.17	0.76	35%	1.5
	Avg	1.10	0.69	37%	1.6
	SD	0.05	0.13	10%	0.3
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
Water Control (aged)		1.03	0.99	3.9%	1.0
		1.08	1.03	4.6%	1.0
		1.08	1.04	3.7%	1.0
		1.08	1.04	3.7%	1.0
	Avg	1.07	1.03	4.0%	1.0
	SD	0.03	0.02	0.4%	0.01

The decontamination efficacies in terms of %R of SDF and UDF applied to the one year coupons averaged 29 ± 10% and 37 ± 10%, respectively. The water control applied to these coupons resulted in a %R of 4.0 ± 0.4%. The %Rs of SDF and UDF were statistically the same while the %Rs for the water control were significantly less than both SDF and UDF. On average, SDF was 43% less effective and UDF 38% less effective on the coupons contaminated one year ago than on the coupons contaminated two weeks before decontamination. The water control was 33% less effective on the year old contaminated coupons than on the coupons contaminated for just two weeks. These results suggest that the increased time since contamination does in fact make the Cs-137 more difficult to remove and the degree of removal difficulty is similar (33-43%) regardless of decontamination method. This result may be due to the Cs-137 moving deeper into the porous matrix of the concrete, making it less available for removal.

5.1.2 RRII Results

Table 5-2 presents the decontamination efficacy, expressed as both %R and DF, for RRII and the water control when using coupons contaminated two weeks and one year prior to decontamination testing. As with the previous test, the target pre-decontamination activity was between 0.5 µCi and 1.5 µCi. The overall average (plus or minus one standard deviation) of the contaminated coupons was 0.98 ± 0.09 µCi, a variability of 9%.

The decontamination efficacy of RRII in terms of %R for two week old contamination was 74 ± 7.3%. The water control applied to these coupons resulted in a %R of 6.1 ± 1.0%. The decontamination efficacy of RRII applied to the one year coupons averaged 50 ± 17%. One of the four results (%R=25%) appeared to be a possible outlier. However, Dixon's Q-test for outliers was performed and the value was determined not to be an outlier. However, something about the surface of that coupon or about the application of RRII to that particular coupon may have caused this result that stands out from the others. If this data point had been removed, the average %R would have been 58 ± 5.8%. The water control applied to these coupons resulted in a %R of 4.0 ± 0.4%. On average, RRII was 32% less effective on the coupons contaminated one year ago than on the coupons contaminated two weeks before decontamination. The water control was 33% less effective on the year old coupons than on the coupons contaminated for just two weeks. As in the case of the SDF and UDF, these results suggest that the increased time since contamination does in fact make the Cs-137 more difficult for RRII to remove.

Table 5-2. RRII Decontamination Efficacy Results

Technology		Pre-Decontamination Activity (µCi/Coupon)	Post-Decontamination Activity (µCi/Coupon)	%R	DF
RRII		1.01	0.19	81%	5.3
		0.90	0.32	64%	2.8
		1.03	0.22	78%	4.6
		1.00	0.27	73%	3.7
	Avg	0.99	0.25	74%	4.1
	SD	0.06	0.06	7.3%	1.1
RRII (aged)		1.06	0.79	25%	1.3
		0.81	0.32	60%	2.5
		0.96	0.37	61%	2.6
		1.06	0.52	51%	2.0
	Avg	0.97	0.50	50%	2.1
	SD	0.12	0.21	17%	0.6
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
Water Control (aged)		1.03	0.99	3.9%	1.0
		1.08	1.03	4.6%	1.0
		1.08	1.04	3.7%	1.0
		1.08	1.04	3.7%	1.0
	Avg	1.07	1.03	4.0%	1.0
	SD	0.03	0.02	0.4%	0.01

5.1.3 ASG Results

Table 5-3 presents the decontamination efficacy, expressed as both %R and DF, for ASG and the water control when using coupons contaminated two weeks and one year prior to decontamination testing. The target pre-decontamination activity was between 0.5 µCi and 1.5 µCi. The overall average (plus or minus one standard deviation) of the contaminated coupons was 1.03 ± 0.07 µCi, a variability of 7%.

The decontamination efficacy of ASG in terms of %R for two-week-old contamination was 75 ± 4.4%. The water control applied to these coupons resulted in a %R of 6.1 ± 1.0%. The decontamination efficacy of RRII applied to the one year coupons averaged 46 ± 5.7%. The water control applied to these coupons resulted in a %R of 4.0 ± 0.4%. On average, ASG was 39% less effective on the coupons contaminated one year ago than on the coupons contaminated

two weeks before decontamination. The water control was 33% less effective on the year old contaminated coupons than on the coupons contaminated for just two weeks. As with SDF, UDF, and RRII, these results suggest that the increased time since contamination does in fact make the Cs-137 more difficult for ASG to remove.

Table 5-3. ASG Decontamination Efficacy Results

Technology		Pre-Decontamination Activity (µCi/Coupon)	Post-Decontamination Activity (µCi/Coupon)	%R	DF
ASG		0.94	0.21	77%	4.4
		1.00	0.27	73%	3.7
		1.01	0.30	70%	3.4
		0.99	0.20	80%	5.0
	Avg	0.99	0.25	75%	4.1
	SD	0.03	0.05	4.4%	0.8
ASG (aged)		0.98	0.47	52%	2.1
		1.18	0.65	45%	1.8
		1.06	0.56	47%	1.9
		1.07	0.66	38%	1.6
	Avg	1.07	0.59	46%	1.9
	SD	0.08	0.09	5.7%	0.2
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
Water Control (aged)		1.03	0.99	3.9%	1.0
		1.08	1.03	4.6%	1.0
		1.08	1.04	3.7%	1.0
		1.08	1.04	3.7%	1.0
	Avg	1.07	1.03	4.0%	1.0
	SD	0.03	0.02	0.4%	0.01

5.1.4 Cross Contamination Blanks

As described in Section 3.2, cross contamination blanks were included in the test stand to evaluate the potential for cross contamination due to application of the decontamination technologies on wall locations above the blank. After decontamination, the activities of the cross contamination blanks were found to be 0.015 µCi for the SDF and UDF tests, 0.008 µCi for RRII, 0.0006 µCi for ASG, and 0.001 µCi for water. In all cases, the activity levels on the cross contamination blanks were minimal, but still detectable, though less than 4% of the average post-decontamination activity of that same set of coupons.

5.2 Deployment and Operational Factors

Throughout the evaluation, technicians were required to use full anti-contamination personal protective equipment (PPE) because the work was performed in a radiological enclosure using Cs-137. Similarly, in an operational setting, whenever radiological material is handled, anti-contamination PPE is required and all waste (e.g., from removal of the decontamination technology foams and reagents) will be considered at a minimum as low level radioactive waste and will need to be disposed of accordingly. The requirement for this level of PPE during the course of the evaluation was driven by the presence of the Cs-137, not by the nature of the decontamination technologies, which are not hazardous.

5.2.1 SDF and UDF

A number of operational factors were documented by the technician who performed the testing with SDF and UDF. The application procedure for SDF and UDF was described in Section 3.2 and included the use of a backpack foamer provided by Allen-Vanguard. Foam application to the test stand containing all nine coupons took 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. Vacuuming and rinsing took approximately ten minutes. The surface was vacuumed again after the water rinse taking approximately three minutes. In total, one application took approximately 45 minutes. This process was repeated for a total of two iterations. For UDF only, the surfaces were then rinsed with Reagent B and allowed to sit for 30 minutes before completion with a final water rinse and vacuum. Neither SDF nor UDF caused any visible damage to the surface of the coupons. Table 5-4 provides some additional detail about the operational factors for SDF and UDF as observed using this experimental setup/test stand with relatively small concrete coupons.

Table 5-4. Operational Factors of SDF and UDF

Parameter	Description/Information
Decontamination rate	**Foam preparation:** combine reagents (two for SDF and three for UDF) in foamer and mix with drill until dissolved (5-10 minutes); add surfactant just prior to foam application to coupons; for UDF, Reagent B is added to the coupons at the end of the application procedure. **Application time:** SDF: Approximately one minute for foam application to the test stand (containing nine concrete coupons with a total surface area of 0.2 m^2); 30 minute dwell time, vacuum removal (5 minutes for nine coupons), water rinse (3 minutes), vacuum removal of water (3 minutes), repeat once. Aside from the waiting time (which is independent of surface area), overall decontamination rate (for the 0.2 m^2 of concrete only) of 0.5 m^2/hour. UDF: Same foam application as SDF plus application of Reagent B (2 minutes) after the SDF procedure; 30 minute wait, water rinse (3 minutes), vacuum removal (3 minutes). Aside from the wait time, overall decontamination rate (for the 0.2 m^2 of concrete only) of 0.4 m^2/hour.
Applicability to irregular surfaces	Application of the foam to more irregular surfaces than what was encountered during this evaluation would not seem to be a problem as the foam can reach most types of surfaces. Irregular surfaces may pose a problem for vacuum removal.
Skilled labor requirement	After a brief training session to explain the procedures, most operators could perform both the application and removal procedures successfully.
Utilities requirement	Compressed carbon dioxide was required to operate the backpack foamer and a commercial/industrial vacuum cleaner was required to remove the foam and the water rinsates.
Extent of portability	Portability would seem to be limited by (1) access for vacuum removal and (2) by extreme cold temperatures (since SDF and UDF are water-based); Limiting factors would include the ability to apply the technology at scale applicable to an urban contamination (area of city blocks or square miles).
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 agent to reduce the volume of the collected foam; the defoaming agent was recirculated from the collection reservoir into the vacuum wand so the foam would not clog the vacuum hose. For each complete application of SDF and UDF to the nine concrete coupons (0.2 m^2), 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	Not visible to the eye.
Cost	Material cost is approximately \$8.25/m^2 for SDF and \$12.00/m^2 if used in a similar way as used during this evaluation. Labor costs were not calculated.

5.2.2 RRII

A number of operational factors were documented by the technician who performed the testing with RRII. The application of RRII was described in Section 3.2 and included use of a plastic spray bottle. Application of the RRII solutions to each coupon took 10-15 seconds in addition to the recommended dwell time of 30 minutes for each solution. For RRII, there were two formulas that were applied using the identical procedure, which included a 30-minute dwell time for each. The total elapsed time for the nine coupons decontaminated with Rad-Release II was approximately 70 minutes. These application and removal times are applicable only to the

experimental scenario involving these rather small concrete coupons. According to the manufacturer, if RRII was applied to larger surfaces, larger application tools such as larger sprayers or foamers would likely be used which would impact the application rate. In addition, larger vacuum heads would be used for removal. RRII did not cause any visible damage to the surface of the coupons. The RRII coupons did not dry completely overnight. Table 5-5 provides some additional detail about the operational factors for RRII as observed using this experimental setup/test stand with relatively small concrete coupons.

Table 5-5. Operational Factors of RRII

Parameter	Description/Information
Decontamination rate	Technology Preparation: RRII is provided ready to use. The solutions (Formula 1 and Formula 2) were transferred into spray bottles and applied. Application: The factor limiting decontamination rate is the surface area that can be covered before the 30 minute dwell time expires. Larger surfaces would likely utilize larger capacity sprayers or foamers. During this experiment, the initial application to the concrete coupons took only seconds and then the coupons were kept damp (to simulate the ongoing presence of a foam as might be the case during a large-scale application) with intermittent reapplication during the dwell time. Rinsing and vacuuming took approximately 25 seconds per coupon. In all, the application and removal took 10 minutes in addition to the 60 minutes of waiting time. Not including the wait times (which are independent of the surface area), this corresponds to a decontamination rate of approximately 1 m^2/hr for RRII. Estimated volumes used for 0.2 m^2 of concrete surface included 180 mL RRII Formula 1, 240 mL RRII Formula 2, and 330 mL of the rinse solution.
Applicability to irregular surfaces	Application to irregular surfaces would not seem to be problematic. RRII is easily sprayed into hard to reach locations. Irregular surfaces may pose a problem for vacuum removal.
Skilled labor requirement	Adequate training would likely include a few minutes of orientation so the technician is familiar with the application technique including dwell times and requirement of keeping the surface wet. Larger surfaces may require more complex equipment such as spray or foam application.
Utilities requirement	Electricity for the wet vacuum. Larger surfaces may require more complex equipment such as spray or foam application requiring additional utilities.
Extent of portability	At a scale similar to that used for this evaluation, vacuum removal would be the only portability factor. However, for larger scale applications, limiting factors would include the ability to apply the RRII at scale applicable to an urban contamination (area of city blocks or square miles) and then rinse and remove with a vacuum. Portable electrical generation or vacuum capability may be required.
Shelf life of reagents	Formula 1 and 2 are stable at room temperature for up to six months.
Secondary waste management	A volume of 750 mL of liquid was applied to the concrete coupons used during this evaluation. That volume corresponds to a waste generation rate of approximately 3.8 L/m^2 depending on how much of the solutions absorb to the surfaces.
Surface damage	Concrete surfaces appeared undamaged.
Cost	RRII solutions are not sold as a stand-alone product, but are available only as a decontamination service for which the cost varies greatly from project to project. Typical project costs are in the approximate range of \$33-\$55/m^2.

5.2.3 ASG

A number of operational factors were documented by the technician who performed the testing with the ASG. Once fully mixed, the ASG had the look of cooked oatmeal but was very "slippery" and tended to slide off any plastic tools used to apply the ASG onto the coupons. This is why a paint brush was used to apply the ASG to the coupons. However, once on the concrete, the ASG adhered rather well. Altogether, the application of the ASG took approximately 30 seconds per coupon and removal with a wet vacuum took approximately 25 seconds per concrete coupon. The ASG caused no visible damage to the surface of the coupons. Table 5-6 provides some additional detail about the operational factors for ASG as observed using this experimental setup/test stand with relatively small concrete coupons.

Table 5-6. Operational Factors of ASG

Parameter	Description/Information
Decontamination rate	Technology Preparation: A time of 15 minutes was required to measure and mix powder with water. Application: ASG was applied with a paint brush to each concrete coupon in approximately 30 seconds (2.4 m^2/ hr). After a 90 minute dwell time, the ASG was removed with a wet vacuum and the surface was wiped with a paper towel at a rate of approximately 25 seconds per coupon (3.2 m^2/hr). Aside from the wait time (independent of the surface area), the application and removal rate was approximately 1.5 m^2/hr for hand application and corresponding removal. Estimated volumes used across all the 0.2 m^2 of concrete coupons included 0.5-1.0 L of ASG. Overall that volume corresponds to a loading of 2.5-5 L/m^2.
Applicability to irregular surfaces	Application to irregular surfaces may be problematic as the ASG could slide off jagged edges and be hard to apply to hard-to-reach locations. Irregular surfaces may pose a problem for vacuum removal.
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 require more complex equipment such as sprayer application.
Utilities requirement	Electricity for the wet vacuum. Larger surfaces may require more complex equipment such as spray or foam application requiring additional utilities.
Extent of portability	At a scale similar to that used for this evaluation, the only limitation on portability would be the ability to provide vacuum removal in remote locations. However, for larger scale applications, limiting factors would include the ability to apply the ASG at scale applicable to an urban contamination (area of city blocks or square miles).
Shelf life of reagents	The ASG is able to be used for several days after mixing as long as the ASG is kept moist, as it will dry out if left exposed to air for several days.
Secondary waste management	0.5-1.0 L of ASG was applied to the concrete coupons used during this evaluation. That volume corresponds to a waste generation rate of approximately 2.5 -5 L/m^2. The ASG was collected entirely by the wet vacuum. Because Cs-137 was used for this testing, all waste (in vacuum and paper towels) was disposed of as low level radioactive waste.
Surface damage	Concrete surfaces appeared undamaged.
Cost	Material cost is approximately $0.30/L for the ASG (depending on source material costs). This cost corresponds to approximately $2/$m^2$ if used in a similar way as used during this evaluation. Labor costs were not calculated.

6.0 References

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