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Technology Evaluation Report

Decontamination of Concrete and Granite Contaminated with Cobalt-60 and Strontium-85

Office of Research and Development
National Homeland Security Research Center

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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 through Contract No. EP-C-10-001 with Battelle. This report has been peer and administratively reviewed and has been approved for publication as an EPA document. 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 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.

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
National Homeland Security Research Center

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Abbreviations/Acronyms

ANSI	American National Standards Institute
ASG	Argonne SuperGel
Bq	Bequerel
°C	degrees Celsius
cm	centimeters
Co	cobalt
DARPA	Defense Advanced Research Projects Agency
DF	decontamination factor
DHS	U.S. Department of Homeland Security
EAI	Environmental Alternatives, Inc.
EPA	U.S. Environmental Protection Agency
Eu	europium
g	gram
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
keV	kilo electron volts
mL	milliliter
L	liter
m	meter
m^2	square meters
µCi	microCuries
nCi	nanoCuries
NHSRC	National Homeland Security Research Center
NIST	National Institute of Standards and Technology
%R	percent removal
PE	performance evaluation
PPE	personal protective equipment
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
QMP	quality management plan
RDD	radiological dispersion device
RML	Radiological Measurement Laboratory
RRII	Rad-Release II
RSD	relative standard deviation
Sr	strontium
TTEP	Technology Testing and Evaluation Program
Th	thorium

Executive Summary

The U.S. Environmental Protection Agency's (EPA's) 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 its Technology Testing and Evaluation Program (TTEP), NHSRC recently evaluated the performance of Environmental Alternatives, Inc.'s Rad-Release II (RRII), and Argonne National Laboratory's SuperGel (ASG) intended specifically for decontamination of radiological contamination. The objective of evaluating these technologies was to test their ability to remove radioactive cobalt (Co)-60 and strontium (Sr)-85 from the surface of unpainted concrete and split face granite.

RRII was applied as a liquid with spray bottles and removed with a water rinse and vacuum. ASG was applied as a gel and removed with a vacuum. Prior to the application of each decontamination technology, 15 centimeter (cm) × 15 cm unpainted concrete and split face granite coupons were contaminated with liquid aerosols of Co-60 and Sr-85 and placed in a vertical test stand. Following manufacturer's recommendations, the decontamination technologies were applied to all the coupons on the test stand. Thereafter, the residual activity on the contaminated coupons was measured. Important deployment and operational factors were also documented and reported.

A summary of the evaluation results for 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) attained by RRII and ASG was evaluated following contamination of the coupons with approximately one microCurie (µCi) Co-60 and Sr-85, measured by gamma spectroscopy. For the concrete coupons, the %Rs for Co-60 were determined to be 79% ± 6.0% for RRII and 62% ± 5.2% for ASG and for Sr-85, 70% ± 6.1% for RRII and 40% ± 7.1% for ASG. For the granite coupons, the %Rs for Co-60 were determined to be 64% ± 10% for RRII and 48% ± 14% for ASG and for Sr-85, 44% ± 4.4% for RRII, 32% ± 2.2% for ASG. Therefore, across all the decontamination technologies, on average, the Co-60 was more effectively decontaminated than the Sr-85 and the concrete was more effectively decontaminated than the granite.

Deployment and Operational Factors: Use of RRII included a two-step spray application to each surface material coupon and rinse and removal that involved two 30 minute waiting periods. ASG was a one step application that included vacuum removal after a 90 minute wait period. Both decontamination technologies seem well suited for rough or jagged surfaces as the spray and gel can reach most areas easily, however, the vacuum removal step could become difficult on rough surfaces. Neither the surface finish of the concrete or the granite coupons were visibly affected by either of the decontamination technologies.

1.0 Introduction

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

NHSRC, through its Technology Testing and Evaluation Program (TTEP), works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the participation of individual technology developers in carrying out performance tests on homeland security technologies. The program evaluates the performance of innovative homeland security technologies by developing evaluation plans that are responsive to the needs of stakeholders, conducting tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and high quality are generated and that results are defensible. NHSRC, through TTEP (for example), provides high-quality information 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.

Through TTEP, NHSRC evaluated the decontamination efficacy (results in this report) of two separate technologies: 1) Environmental Alternatives, Inc.'s Rad-Release II (RRII), and 2) Argonne National Laboratory's SuperGel (ASG) in decontamination of radioactive cobalt-60 (Co-60) and strontium-85 (Sr-85) from unpainted concrete and granite. This evaluation was conducted according to a quality assurance project plan (QAPP) entitled, "Evaluation of Chemical Technologies for Decontamination of Cobalt, Strontium, and Americium from Porous Surfaces", Version 1.0 dated May 8, 2012 (available upon request) that was developed according to the requirements of the TTEP Quality Management Plan (QMP) Version 3, January 2008. The following performance characteristics of RRII and ASG were evaluated:

- Decontamination efficacy was defined as the extent of radionuclide removal following application of the decontamination technology to concrete and granite coupons to which

Co-60 and Sr-85 had been applied. Another quantitative parameter evaluated was the extent 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 requirement, utilities 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 July 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 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 Environmental Alternatives, Inc. Rad-Release II

The RRII decontamination technology is a chemical process that involves the sequential topical application of two solutions (applied in the order directed by 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. 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 volumes, as either an atomized spray or foam (active ingredients do not change). According to the manufacturer, 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 including vacuuming, simple wiping with absorbent laboratory wipes or rags for small surfaces, use of a clay overlay technique to wick out RRII and contamination over time and then removing the clay at a later date, or use of an absorbent polymer that is sprayed over the chemically treated surface to leach or wick out the contaminant laden solutions and bind them. 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.

2.2 Argonne SuperGel

The 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 a contaminated surface and provides exchangeable ions to the substrate to promote the desorption of radionuclides. The solid sequestering agent provides strong sorption of the target radionuclides within the gel. After removing the radionuclide-laden hydrogel by conventional wet vacuum, the contaminated hydrogel can be dehydrated or incinerated to minimize waste volume without loss of volatilized contaminants. To summarize, ASG provides for:

- *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; and
- Low toxicity reagents and low volume radioactive waste.

The superabsorbing polymers consist of an anionic mixture of polyacrylamide and polyacrylate in both linear and cross-linked form. The solid sequestering agents are 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 gram 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.

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

The granite coupons were provided by INL and were approximately 16 cm × 16 cm and 4 cm thick. These coupons consisted of a Milford Pink Granite (Fletcher Granite Co., Westford, Massachusetts) that is pinkish gray with areas of black and white. The surface finish of the granite coupons was a split face granite, a rugged, uneven finish produced by splitting granite with shims, wedges, or hydraulics. This type of granite has been used in the U.S. National Archives Building, the Smithsonian, and the United States Department of the Interior Building in Washington, DC. Figure 3-1 shows the surface finish of both the concrete and granite coupons.

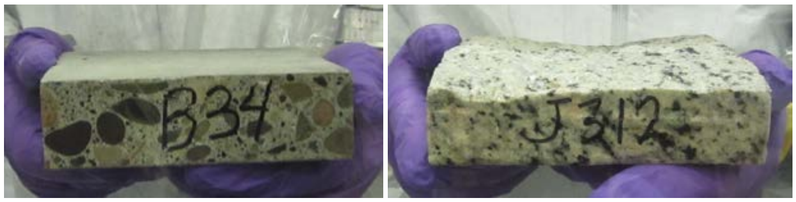

Figure 3-1. Surface finish of concrete and granite coupons.

3.1.2 Coupon Contamination

Table 3-2 describes the number of coupons used in this technology evaluation. Regardless of surface type, all of these coupons were contaminated with 2.5 milliliters (mL) of unbuffered, slightly acidic aqueous solution containing approximately 0.4 microCurie (µCi)/mL Co-60 or Sr-85 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 radionuclides in an aqueous solution was justified because even if Co-60 and Sr-85 were to be dispersed in a dry particle form following an RDD event, morning dew or rainfall would likely occur before the surfaces could be decontaminated. In addition, from an experimental standpoint, the ability to apply liquids homogeneously across the surface of the concrete coupons greatly exceeds that capability for dry particles. The aqueous contamination was delivered to each coupon using an aerosolization technique developed by INL under the DARPA/DHS project[2]. Coupons were contaminated approximately two weeks before use.

Table 3-2. Number of Coupons included in Technology Evaluation

	Coupons			
Surface Material	**Decon by RRII**	**Decon by ASG**	**Cross-contamination Blanks**	**Laboratory Blanks**
Concrete	4	4	2	5
Granite	4	4	-	5

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 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 masked with tape (after having previously been sealed with polyester resin) to ensure that the contaminant was applied only to the working surfaces of the coupons. The photographs in Figure 3-2 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 3-2. Demonstration of contaminant application technique.

3.1.3 Measurement of Activity on Coupon Surface

Gamma radiation from the surface of each contaminated coupon was measured to quantify contamination levels both before and after application of the two decontamination technologies using an intrinsic high purity germanium detector (Canberra LEGe Model GL 2825R/S, Meriden, CT). After each coupon was placed in front of the detector face, gamma ray spectra were collected until the average activity level of Co-60 and Sr-85 from the surface stabilized to a relative standard deviation (RSD) of less than 2%. Gamma-ray spectra acquired from contaminated coupons were analyzed using INL Radiological Measurement Laboratory (RML) data acquisition and spectral analysis programs. Radionuclide activities on each of the coupons were calculated based on efficiency, emission probability, and half-life values. Decay corrections were made based on the date and the duration of the counting period. Full RML gamma counting QA/quality control (QC), as described in the test/QA plan, was employed and certified results were provided. The minimum detectable level of each radionuclide was 0.3 nanoCuries (nCi) for Co-60 and 0.2 nCi for Sr-85 on these coupons.

 

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

3.1.4 Surface Construction Using Test Stand

To evaluate the decontamination technologies on vertical surfaces (simulating walls), a stainless steel test stand (2.7 m × 2.7 m) designed to hold three rows of coupons was used. The granite coupons were slightly too big to fit into the openings in the test stand so a second smaller test stand was used only for the granite coupons. As shown in Figure 3-3, both test stands were located in 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 and the granite coupons were placed in a row next to one another on the smaller test stand. Nine coupons (four concrete, four granite, and one concrete blank) were decontaminated together. The four concrete coupons placed in the top two rows of the middle and left of the large test stand (see Figure 3-3) were contaminated and the one concrete coupon in the bottom row was an uncontaminated blank concrete coupon. This blank coupon was placed there to observe the extent of cross contamination caused by the decontamination higher on the wall or transfer of contaminants due to use of decontamination equipment higher on the wall.

3.2 Decontamination Technology Procedures

3.2.1 EAI RRII

The application of RRII onto the nine coupons was performed using plastic spray bottles (32 oz. Heavy Duty Spray Bottle, Rubbermaid Professional, Atlanta, GA) according to the manufacturer's recommended procedures. The coupons were thoroughly wetted with RRII

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

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 RRII Formula 1 to reside on the surfaces of the 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 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 about 25 seconds per coupon. The above procedure was then repeated for RRII Formula 2. Altogether, the RRII procedure took 68 and 73 minutes to complete for the two sets of nine coupons. Figure 3-4 shows the rinse and vacuuming step of the RRII procedure.

3.2.2 ASG

The ASG was prepared by mixing two dry powders with water according to the manufacturer's recommended procedures. 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 coupons using a four-inch paint brush 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. Altogether, the application of the ASG required approximately 20 seconds per coupon, ASG was allowed to stay on the surface for 90 minutes, and then was removed with a wet vacuum (12 gallon, 4.5 horsepower, QSP® Quiet Deluxe, Shop-Vac Corporation, Williamsport, VA) which required approximately 20 seconds per coupon. Figure 3-5 shows the application and vacuum removal steps for ASG.

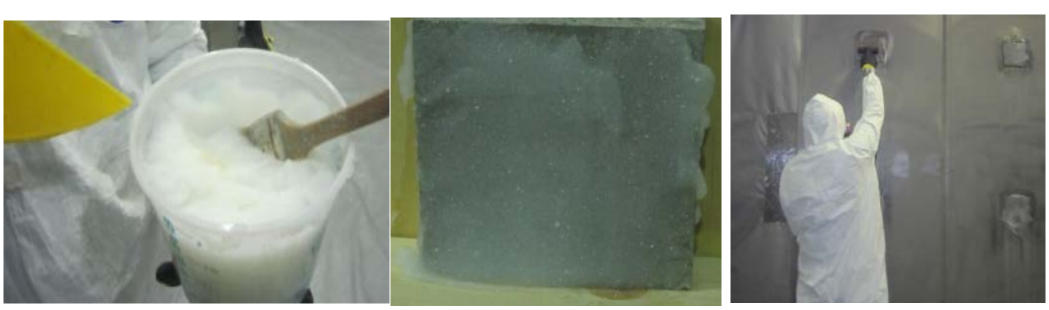

Figure 3-5. ASG before application, as applied to coupon, and during vacuum removal.

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 (%)
RRII	Co-60	13 days	25.6	40
ASG				
RRII	Sr-85	13 days	21.7	36
ASG				

4.0 Quality Assurance/Quality Control

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

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 difference 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
July 2012	7-3-12 to 7-24-12	-0.002	0.007	-0.028	-0.110	0.011
August 2012	7-9-12 to 8-14-12	-0.004	0.012	-0.034	-0.159	0.016

Gamma ray counting was continued for each coupon until the activity level of Co-60 and Sr-85 on the surface had a RSD of less than 2%. This RSD was achieved during the first hour of counting for all the coupons measured during this evaluation. The final activity assigned to each coupon was a compilation of information obtained from all components of the electronic assemblage that comprise the gamma counter, including the raw data and the spectral analysis described in Section 3.1.3. Final spectra and all data that comprise the spectra were sent to a data analyst who independently confirmed the "activity" number arrived at by the spectroscopist. When both the spectroscopist and the data analyst independently arrived at the same value the data were considered certified. This process defined the full gamma counting QA process for certified results.

The background activity of laboratory blank coupons was determined by analyzing five arbitrarily selected coupons from the stock of concrete and granite 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 nCi for Co-60 and 0.2 nCi for Sr-85 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 but prior to application of the decontamination technologies and two were performed after decontamination. All four of the duplicate pairs showed percent difference in activity level of 4% or less, below the acceptable percent 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 and Technology (NIST)-traceable europium (Eu)-152 standard (in units of Bequerel, Bq) and comparing the results 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 of the detector that was used during this evaluation. All results were within the acceptable difference of 7%.

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

Date	Eu-152 (keV)	NIST Activity (Bq)	INL RML Result (Bq)	Difference
July 2012	Average	124,600	122,000	2.1%
	122	124,600	118,900	4.6%
	779	124,600	121,000	2.9%
	1408	124,600	120,600	3.2%
August 2012	Average	124,600	122,300	1.8%
	122	124,600	118,600	4.8%
	779	124,600	121,300	2.6%
	1408	124,600	122,600	1.6%

4.2.2 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 audited data undergoing. No significant findings were noted.

4.3 QA/QC Reporting

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

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:

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

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.

5.1.1 RRII Results

Table 5-1 presents the decontamination efficacy, expressed as both %R and DF for RRII when decontaminating Co-60 from concrete and granite surface coupons and

Table 5-2 presents the same data for Sr-85 decontamination. The target activity for each of the contaminated coupons (pre-decontamination) was between 0.5 µCi and 1.5 µCi. The overall (both RRII and ASG included) average activity (plus or minus one standard deviation) of the Co-60 contaminated coupons was 0.83 µCi ± 0.05 µCi, a variability of 6% and for Sr-85, 1.06 µCi ± 0.08 µCi, a variability of 8%.

The decontamination efficacies of RRII in terms of %R for Co-60 were 79% ± 6% for the concrete surfaces and 64% ± 10% for the granite surfaces. For Sr-85, the %Rs were 70% ± 6% for the concrete surfaces and 44% ± 4% for the granite surfaces. Several t-tests were performed to determine the likelihood that results for each contaminant and surface were the same. The %R of Co-60 decontaminated by RRII from concrete was not significantly different than the %R of Co-60 decontaminated by RRII from granite at the 95% confidence interval ($p=0.15$). However, the %R of Sr-85 decontaminated by RRII from concrete was significantly different (higher) than the %R of Sr-85 decontaminated by RRII from granite ($p=0.02$). The %Rs of Co-60 and Sr-85 decontaminated by RRII from concrete were not significantly different from one another ($p=0.22$) while the %R of Co-60 decontaminated by RRII from granite was significantly different (higher) than was the %R of Sr-85 decontaminated by RRII from granite ($p=0.03$).

As described above in Section 3.1.4, cross contamination blanks were included in the test stand during testing with both contaminants to evaluate the potential for cross contamination due to application of RRII on wall locations above the blank. In both cases the cross contamination

Table 5-1. RRII Co-60 Decontamination Efficacy Results

Surface Material		Pre-Decon Activity (µCi/Coupon)	Post-Decon Activity (µCi/Coupon)	%R	DF
Concrete		0.86	0.20	77%	4.4
		0.89	0.11	88%	8.2
		0.83	0.18	78%	4.5
		0.86	0.23	74%	3.8
	Avg	0.86	0.18	79%	5.2
	SD	0.02	0.05	6%	2.0
Granite		0.84	0.33	61%	2.5
		0.73	0.35	52%	2.1
		0.86	0.27	69%	3.2
		0.88	0.22	75%	4.0
	Avg	0.83	0.29	64%	3.0
	SD	0.07	0.06	10%	0.8

Table 5-2. RRII Sr-85 Decontamination Efficacy Results

Surface Material		Pre-Decon Activity (µCi/Coupon)	Post-Decon Activity (µCi/Coupon)	%R	DF
Concrete		1.13	0.38	66%	3.0
		1.12	0.40	64%	2.8
		1.12	0.30	73%	3.7
		1.15	0.26	77%	4.4
	Avg	1.13	0.34	70%	3.5
	SD	0.01	0.07	6%	0.8
Granite		0.91	0.57	37%	1.6
		0.97	0.52	46%	1.9
		0.96	0.54	44%	1.8
		1.00	0.53	47%	1.9
	Avg	0.96	0.54	44%	1.8
	SD	0.04	0.02	4%	0.1

blanks were concrete coupons that had not been contaminated and the pre-decontamination activity measurements indicated extremely low background levels (below the detection limit) of activity. These coupons were decontaminated using RRII along with the other contaminated coupons and the post-decontamination measurements of the activity of these blanks were found to be 0.048 µCi for Co-60 and 0.011 for Sr-85. This increased level of activity was less than 6% and 2% for Co-60 and Sr-85, respectively, of the activity applied to each of the contaminated coupons. Therefore, the cross contamination was minimal but still detectable, and enough to note that the possibility exists that cross contamination to locations previously not contaminated is a possibility when using RRII in a wide area application.

5.1.2 ASG Results

Table 5-3 present the decontamination efficacy, expressed as both %R and DF for ASG when decontaminating Co-60 from concrete and granite surface coupons and Table 5-4 presents the same data for Sr-85 decontamination. As with the previous technology, the overall average activity (plus or minus one standard deviation) of the Co-60 contaminated concrete coupons was 0.83 µCi ± 0.05 µCi, a variability of 6% and for Sr-85, 1.06 µCi ± 0.08 µCi, a variability of 8%.

Table 5-3. ASG Co-60 Decontamination Efficacy Results

Surface Material		Pre-Decon Activity (µCi/Coupon)	Post-Decon Activity (µCi/Coupon)	%R	DF
Concrete		0.76	0.31	59%	2.5
		0.87	0.263	70%	3.3
		0.86	0.33	62%	2.6
		0.89	0.37	58%	2.4
	Avg	0.85	0.32	62%	2.7
	SD	0.06	0.04	5%	0.4
Granite		0.81	0.46	43%	1.8
		0.79	0.254	68%	3.1
		0.78	0.43	45%	1.8
		0.80	0.52	35%	1.5
	Avg	0.80	0.42	48%	2.1
	SD	0.01	0.11	14%	0.7

Table 5-4. ASG Sr-85 Decontamination Efficacy Results

Surface Material		Pre-Decon Activity (µCi/Coupon)	Post-Decon Activity (µCi/Coupon)	%R	DF
Concrete		1.18	0.81	31%	1.5
		1.04	0.65	38%	1.6
		1.11	0.58	48%	1.9
		1.14	0.65	43%	1.8
	Avg	1.12	0.67	40%	1.68
	SD	0.06	0.10	7.1%	0.20
Granite		1.04	0.72	31%	1.4
		1.08	0.72	33%	1.5
		0.96	0.68	29%	1.4
		1.03	0.68	34%	1.5
	Avg	1.03	0.70	32%	1.47
	SD	0.05	0.02	2.2%	0.05

The decontamination efficacies of RRII in terms of %R for Co-60 were 62% ± 5.2% for decontamination of the concrete surfaces with ASG and 48% ± 14% for decontamination of the granite surfaces with ASG. For Sr-85, the %Rs were 40% ± 7% for decontamination of the concrete surfaces with ASG and 32% ± 2% for decontamination of the granite surfaces with ASG. As for RRII, several t-tests were performed to determine the likelihood that results for each contaminant and surface were the same. The %R of Co-60 by ASG from concrete was significantly different (higher) from the %R from granite at the 95% confidence interval ($p=0.048$), but the %R of Sr-85 by ASG from concrete was not significantly different from the %R from granite ($p=0.13$). The %Rs of Co-60 from concrete were significantly different from the %R of Sr-85 from concrete ($p=0.015$) while the %R of Co-60 and Sr-85 from granite were not significantly different from one another ($p=0.11$).

As for the RRII testing, the cross contamination blanks were included in the test stand during testing with both contaminants to evaluate the potential for cross contamination due to application of ASG on wall locations above the blank. The cross contamination blanks were concrete coupons that had not been contaminated and the pre-decontamination activity measurements indicated extremely low background levels (below the detection limit) of activity. These coupons were decontaminated using ASG along with the other contaminated coupons. The post-decontamination measurement of activity of these blanks were found to be 0.56 nCi for the Co-60 and 1.2 nCi for the Sr-85. This increased level of activity was approximately 0.1% of the activity added to each of the contaminated coupons for Co-60 and Sr-85. Therefore, the cross contamination was very minimal during application of ASG.

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 Co-60 and Sr-85 on the coupon surfaces. Whenever radiological material was handled, anti-contamination PPE was required and any waste (e.g., from removal of the decontamination technology foams and reagents) was considered at a minimum as low level radioactive waste (and was disposed of accordingly). The requirement for this level of PPE was not driven by the use of the decontamination technologies (which are not hazardous), but rather the presence of Co-60 and Sr-85.

5.2.1 RRII

A number of operational factors were documented by the technician who performed the testing with RRII. The application process of RRII was described in Section 3.2.1 and included use of a plastic spray bottle. Application of 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 RRII was approximately 68 and 73 minutes for Co-60 and Sr-85, respectively. These application and removal times are applicable only to the experimental scenario using small concrete coupons. According to the manufacturer, if RRII were to be 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 during the use of 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: Using this experimental setup, the initial application of RRII Formula 1 to the coupons took only seconds and then the coupons were kept damp (to simulate the ongoing presence of a foam during a large-scale application) with reapplication every 10 minutes during the dwell time. Following the 30 minute dwell time, rinsing and vacuuming took approximately 25 seconds per coupon. This process was repeated for RRII Formula 2. In all, the application and removal steps took 8-13 minutes in addition to the two 30 minutes dwell times for RRII. Aside from the dwell times, this corresponds to a decontamination rate of approximately 1 m^2/hr for RRII. Estimated volumes used per application of nine coupons (0.2 m^2) included 280 mL RRII Formula 1, 280 mL RRII Formula 2, and 200 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 RRII at a 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.
Secondary waste management	Approximately 760 mL of liquid was applied per nine coupons used during this evaluation. That volume corresponds to a waste generation rate of approximately 4 L/m^2 depending on how much of the solutions absorb to the surfaces.
Surface damage	Concrete and granite surfaces appeared undamaged.
Cost	RRII solutions are not sold as a stand-alone product but are only available 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.

5.2.2 ASG

A number of operational factors were documented by the technician who performed the testing with ASG. Once fully mixed, ASG had the look of cooked oatmeal but was very slippery. A paint brush was used to apply the ASG onto the concrete coupons. However, once on the concrete, ASG adhered rather well. Altogether, the application of ASG took approximately 20 seconds per coupon and removal with a wet vacuum took approximately 20 seconds per coupon.

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 during the use of this experimental setup/test stand with relatively small concrete coupons.

Table 5-6. Operational Factors of ASG

Parameter	Description/Information
Decontamination rate	Technology Preparation: 15 minutes to measure and mix powder with water. ASG is able to be used for several days after mixing as long as ASG is kept moist by covering the mixture as it will dry out if left exposed to air for several days. Application: ASG was applied with a paint brush to each coupon in approximately 20 seconds (4 square meters (m^2)/hour (hr)). After a 90 minute dwell time, ASG was removed with a wet vacuum and the surface was wiped with a paper towel at a rate of approximately 20 seconds per coupon (4 m^2/hr). Aside from the wait time (which is independent of the surface area), the application and removal rate was approximately 2 m^2/hr for application and corresponding removal. Estimated volumes used per nine coupons included 0.5-1 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 ASG could slide off jagged edges and be hard to apply to hard to reach locations. During use on the rough split face granite, small amount of ASG could be seen remaining in the crevices after 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	As evaluated here, electricity was required to operate the wet vacuum. Electricity for the wet vacuum. Larger surfaces may require more complex equipment such as spray 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 ASG at scale applicable to an urban contamination (area of city blocks or square miles).
Secondary waste management	0.5-1 L of ASG was applied per nine coupons during this evaluation. That volume corresponds to a waste generation rate of approximately 5 -10 L/m^2. ASG was collected entirely by the wet vacuum.
Surface damage	Concrete and granite surfaces appeared undamaged.
Cost	Cost of materials (labor not included) is approximately \$0.30/L for 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.

6.0 References

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