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Technology Evaluation Report

Decontamination of Cesium, Cobalt, Strontium, and Americium from Porous Surfaces



Office of Research and Development National Homeland Security Research Center

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> UNITED STATES ENVIRONMENTAL PROTECTION AGENCY RESEARCH TRIANGLE PARK, NC 27711

Disclaimer

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Abbreviations/Acronyms

Am	americium
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
ASG	Argonne SuperGel
Bq	becquerel
°C	degrees Celsius
cm	centimeters
CMAT	Consequence Management Advisory Team
Co	cobalt
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
HSRP	Homeland Security Research Program
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
keV	kilo electron volts
1	liter
mL	milliliter
m	meter
m^2	square meters
μCi	microCuries
nCi	nanoCuries
NHSRC	National Homeland Security Research Center
NIST	National Institute of Standards and Technology
OEM	Office or Emergency Management
ORD	Office of Research and Development
%R	percent removal
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

Sr	strontium
Th	thorium
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program

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 Chemical, Biological, Radiological and Nuclear (CBRN) contamination whether it results from an intentional act (for instance, terrorism) a criminal act, or an unintentional act (such as a natural disaster or industrial accident). One way EPA helps to protect human health and the environment is by carrying out performance tests on homeland security technologies. Through its Technology Testing and Evaluation Program (TTEP), EPA recently evaluated the performance of several commercially available radiological decontamination technologies as they might be applied to a variety of contaminated building materials for decontamination of several radionuclides which might potentially be used in a nuclear device or radiological dispersal device. The results of this evaluation are intended to provide high-quality information useful to decision makers in purchasing or applying the evaluated technologies. TTEP provides potential users with unbiased third-party information that can supplement vendor-provided information.

The materials chosen are representative of those commonly used in urban infrastructure (Portland Type II concrete, asphalt) as well as for infrastructure of high cultural or historical significance (Indiana limestone, Milford Pink split face granite, Colorado Yule marble). The radionuclides chosen for this evaluation included radioactive cesium (Cs)-137, cobalt (Co)-60, strontium (Sr)-85 and americium (Am)-243. The technologies evaluated were selected based on the results of previous EPA technology evaluations, and included CBI Polymers' DeconGel 1108, Environmental Alternatives, Inc.'s Rad-Release II (RRII), Argonne National Laboratory's SuperGel (ASG), Intek Technologies' LH-21, and Kärcher Futuretech's RDS 2000. Also evaluated were Argonne National Laboratory's Wash Aid (intended specifically for removal of radiological cesium contamination) and vermiculite clay, for its ability to remove Cs-137 from the Wash Aid effluent.

Prior to the application of each decontamination technology, 15 centimeter $(cm) \times 15$ cm coupons of limestone, split face granite, marble, unpainted concrete, and asphalt were contaminated with liquid aerosols of Cs-137, Co-60, Sr-85 and/or Am-243 (not all surfaces were contaminated with all contaminants during this evaluation) and placed on test stands inside a radiological enclosure. Following manufacturer's recommendations, the decontamination technologies were applied to the coupons on the test stands. Thereafter, the residual activity on the contaminated coupons was measured and decontamination efficacy, in terms of percent removal (%R) was calculated. Important deployment and operational factors were also documented and reported.

A summary of results from this evaluation is presented in Table ES-1 with a detailed discussion of these results in Section 5.0, including a discussion of various factors related to operational

deployment. Not all combinations of technology/radionuclide/material were attempted in this evaluation and priority was given to combinations which included Cs-137 and concrete, the contaminant and material of widest concern. As noted in Table ES-1, some data are available from previous EPA evaluations.

Technology	Material	Cs-137	Co-60	Sr-85	Am-243
	Concrete	(a)	85	64	(d)
DacanCal	Limestone	35			
DeconGer	Marble	93			
	Granite	72			
	Concrete	(a)	(b)	(b)	(c)
DDII	Limestone	38			
KKII	Marble	89			
	Granite	72	(b)	(b)	(c)
	Concrete	(a)	(b)	(b)	(c)
	Limestone	15			
ASU	Marble	71			
	Granite	50	(b)	(b)	(c)
	Concrete	45			83
LH-21	Limestone	39			
	Marble	91			
	Granite	56			
RDS 2000	Concrete	11	52	43	69
Wash Aid	Concrete	24	Wash Aid was o only Cs-137 fro	lesigned specific m porous materi	ally to remove
Vermiculite Clay Effluent Treatment	Asphalt	36	Vermiculite clay means of remove effluent	y process is inter ing Cs-137 from	nded only as a n the Wash Aid

Table ES-1. Summary of decontamination efficacy in percent removal (%)

(a) U.S. EPA. Evaluation of Nine Chemical-Based Technologies for Removal of Radiological Contamination from Concrete Surfaces. U.S. Environmental Protection Agency, Washington, DC, EPA/600/S-11/009, 2011

(b) U.S. EPA. Decontamination of Concrete and Granite Contaminated with Cobalt-60 and Strontium-85. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-13/002, 2012

(c) U.S. EPA. Decontamination of Concrete and Granite Contaminated with Americium-243. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-13/204, 2013

(d) U.S. EPA. CBI Polymers DeconGel® 1108 for Radiological Decontamination of Americium. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-12/067, 2012

1.0 Introduction

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

EPA, 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. TTEP provides high-quality information that is useful to decision makers in purchasing or applying the evaluated technologies. TTEP provides potential users with unbiased third-party information that can supplement vendor-provided information. Stakeholder involvement ensures that user needs and perspectives are incorporated into the evaluated technologies.

Through TTEP, EPA recently evaluated the performance of several commercially available radiological decontamination technologies as they might be applied to a variety of contaminated building materials for decontamination of several radionuclides which might potentially be used in a nuclear device or radiological dispersal device. The materials chosen are representative of those commonly used in urban infrastructure (Portland Type II concrete, asphalt) as well as for infrastructure of high cultural or historical significance (Indiana limestone, Milford Pink split face granite, Colorado Yule marble). The technologies evaluated were selected based on the results of previous EPA technology evaluations, and included CBI Polymers' DeconGel 1108, Environmental Alternatives, Inc.'s Rad-Release II (RRII), Argonne National Laboratory's SuperGel (ASG), Intek Technologies' LH-21, and Kärcher Futuretech's RDS 2000. Also evaluated were Argonne National Laboratory's Wash Aid (intended specifically for removal of radiological cesium contamination) and vermiculite clay, for its ability to remove Cs-137 from the Wash Aid effluent. The radionuclides chosen for this evaluation included radioactive cesium (Cs)-137, cobalt (Co)-60, strontium (Sr)-85 and americium (Am)-243. Sr-85 and Am-243 were used because of the measurement difficulties of Sr-90 and Am-241 (more readily available isotopes). Sr-90 cannot be quantified with gamma counting as it is only a beta emitter and Am-241 is primarily an alpha emitter. Because of the nature of chemical isotopes, there is no reason to believe that the alternative isotopes will behave any differently than the other isotopes. This

evaluation was conducted according to a quality assurance project plan (QAPP) entitled, "Evaluation of Chemical Technologies for Decontamination of Cesium, Cobalt, Strontium, and Americium from Porous Surfaces", Version 1.0 dated February 15, 2013 which was developed according to the requirements of the TTEP Quality Management Plan (QMP) Version 3, January 2008. Not all combinations of technology/radionuclide/material were attempted in this evaluation and priority was given to combinations which included Cs-137 and concrete, the contaminant and material of widest concern. The following performance characteristics of DeconGel, RRII, ASG, LH-21, RDS 2000 and Wash Aid were evaluated:

- Decontamination efficacy defined as the extent of radionuclide removal following application of the six decontamination technologies to marble, granite, limestone, asphalt or concrete coupons to which Cs-137, Co-60, Sr-85 or Am-243 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 from March through June 2013 at the U.S. Department of Energy's Idaho National Laboratory (INL).

2.0 Technology Description

This report provides results for the evaluation of DeconGel, RRII, ASG, LH-21, RDS 2000 and Wash Aid. Following is a description of each technology based on information provided by the vendors. The information provided below was not verified during this evaluation.

2.1 CBI Polymers DeconGel 1108

DeconGel 1108 (CBI Polymers, Honolulu, HI, USA) is a strippable coating designed for safely removing radioactive contamination or as a covering to contain contamination. DeconGel is sold as a paint-like formulation. Application options include use of a paint brush, roller, or sprayer. The water-based wet coating (hydrogel) can be applied to horizontal, vertical or inverted surfaces and can be applied to most surfaces including bare, coated and painted concrete, aluminum, steel, lead, rubber, plexiglas[®], herculite[®], wood, porcelain, tile grout, and vinyl, ceramic and linoleum floor tiles. Following application, the coating requires approximately 12 hours to cure prior to removal. When dry, the product binds the contaminants into a polymer matrix. The dried coating containing the encapsulated contamination can then be peeled off the surface and disposed of. More information is available at <u>www.decongel.com</u> [accessed 9/13/13].

2.2 EAI Rad-Release II

The RRII (Environmental Alternatives, Inc., Keene, NH, USA) 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 [accessed 9/13/13].

2.3 Argonne SuperGel

ASG (Argonne National Laboratory, Lemont, IL, USA) 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.
- Low toxicity reagents and low volume radioactive waste.

The super absorbing 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 to 20 grams [g] 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 to 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, no special precautions are 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.

2.4 Intek Technology LH-21

LH-21 (Intek Technology, Fairfax, VA, USA) is a non-corrosive cleaning product developed in 2010 to remove concrete from equipment. It effectively and rapidly removes concrete, without damaging painted surfaces, aluminum, steel, synthetic or composite materials. It also removes lime scale and other mineral deposits. Because LH-21 is typically used as a concrete removal agent, the efficacy of LH-21 as a surface radiological decontamination technology was unknown prior to this testing. LH-21 is used at 1:1 dilution with fresh water and can be applied via aerosol, low-pressure foaming system, sprayer, or brush and bucket. Light to moderate deposits usually require one application. Heavy or aged deposits may require regular applications over a period of hours, days or weeks. Typically, a surface is sprayed and brushed, then sprayed again followed by an hour wait after which it is sprayed and brushed again and the decontaminant is rinsed away. Longer wait periods may require misting with water to maintain wet. Foaming the product via air ingestion at time of application can be a benefit, since the foam clings to surfaces and reduces evaporative losses.

2.5 Kärcher-Futuretech RDS 2000

The RDS 2000 (Kärcher Futuretech GmbH, Schwaikheim, Germany) radioactive decontamination agent consists of two separate components for the production of a radioactive decontaminant to be used for the decontamination of surfaces contaminated with radioactive material. RDS 2000 is made from an aqueous surfactant solution with appropriate complexing agents, oxidants or other auxiliary substances. RDS 2000 is applied as a foam or spray. After a waiting period for the RDS 2000 to become active, the RDS 2000 is rinsed off together with the radioactive contaminants with water and collected in appropriate collection basins for further disposal. With regard to environmental compatibility, RDS 2000 meets the requirements of water pollution class 1 (low hazard for water). It is sufficiently stable during storage and ensures an optimal coaction of conventional cleaning, decontamination effect and user-friendly handling.

2.6 Argonne Wash Aid

Wash Aid (Argonne National Laboratory, Lemont, IL, USA) is a two component system. The first "wash" component is a brine solution that removes Cs from the surfaces of urban materials, and the second "removal" component is vermiculite (or other specialty) clay that binds to the Cs, allowing the Cs to be removed from the wash-water. There are different embodiments of how this two component system could work, and for this pilot scale testing, the embodiment was to utilize the least amount of required specialized equipment. Wash Aid is designed to be applied as a flowing rinse decontamination agent. Wash Aid was flowed over the surface of concrete coupons at a flow rate of 600 mL per minute for 5 minutes. The Wash Aid effluent was collected and vermiculite clay was added to the aqueous rinse product to test the removal efficacy of the clay when exposed to an aqueous solution of Wash Aid contaminated with Cs-137.

3.0 Experimental Details

3.1 Experimental Preparation

3.1.1 Surface Coupons

Coupons were fabricated of five different building materials typical of those used in urban areas within the US. These materials included concrete, granite, limestone, marble, and asphalt. Table 3-1 describes these materials (all except concrete were purchased cut from the below sources).

Material				
Туре	Name	Source	Finish/Color	Example Use
Concrete	Portland Type II	Burns Redi-mix, Idaho Falls, ID	Unpolished, gray	Urban foundations/walls
Granite	Milford Pink	Milford, MA	Split face, pinkish gray, with black and white	National Archives Building
Limestone	Indiana Limestone	Oolitic, IN	Sawn, light gray	White House
Marble	Colorado Yule Marble	Gunnison County, CO	Sawn, unpolished white with gray markings	Lincoln Memorial
Asphalt	N-70 Asphalt	Chicago, IL	~20 year old street pavement	Weathered street pavement

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, USA) from which the concrete for this evaluation was obtained provided the data shown in Table 3-2 describing the cement clinker used in the concrete mix. The ASTM C150¹ 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 3-2, 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.

Percent of Mixture
57.6
21.1
4.5
8.7
8.1

 Table 3-2. Concrete Characterization

The concrete 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) project².

Concrete, granite, limestone, and marble coupons to be used for this evaluation were approximately 15 cm \times 15 cm, and 4 cm thick, with a surface finish that was consistent across all the coupons and representative of that which would be typically found on the exterior of an urban structure.

The granite coupons were approximately $16 \text{ cm} \times 16 \text{ cm}$ 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 that of 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 U.S. Department of the Interior Building in Washington, DC. The limestone was an Indiana Gray Limestone (Indiana Limestone, Oolitic, IN) which was uniformly gray with a "sandy", sawn finish. The marble coupons were a Colorado Yule Marble (West Elk Mountains, Gunnison County, CO, Colorado Stone Quaries, Inc.). The marble was white with gray markings and a sawn, but unpolished finish. The asphalt coupons were cut out of two



Figure 3-1. Surface finish of concrete, granite, limestone (top, left to right), marble (bottom left) and asphalt (bottom, middle and right) coupons.

asphalt slabs (2 feet \times 2 feet) from a street in downtown Chicago, IL using a standard asphalt saw. This asphalt had been put into place approximately 20 years ago and was taken from the street during a recent repavement. The coupons were cleaned with soap and water before contamination. Figure 3-1 shows the surface texture of each type of surface material coupon.

3.1.2 Coupon Contamination

Table 3-1 provides the number of coupons and contaminants used with each decontamination technology during this technology evaluation. Not all combinations of technology/radionuclide/material were attempted in this evaluation and priority was given to combinations which included Cs-137 and concrete, the contaminant and material of widest concern. The technology/contaminant combinations were selected to expand on previous EPA decontamination technology testing without duplication of previous results. Regardless of surface type and contaminant applied, all of these coupons were contaminated with 2.5 mL of unbuffered, slightly acidic aqueous solution containing approximately 0.4 microCurie (µCi)/mL Cs-137, Co-60, or Sr-85 or approximately 0.02 µCi/mL Am-243, which corresponds to an activity level of approximately 1 μ Ci per coupon (± 0.5 μ Ci) and 0.050 μ Ci per coupon (± 0.5 µCi), respectively. A lower target activity was used for Am-243 because it is also an alpha emitter, which is a more significant internal exposure risk; thus, INL health physicists limited the contamination levels. 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 from an experimental standpoint, the ability to apply liquids homogeneously across the surface of the 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 project². Coupons were contaminated approximately two weeks before use.

Table 3-3.	Testing			
Technology	Month	Surface	Contaminant	Coupons
		limestone		4
ASG	-	granite	cesium	4
	_	marble		4
		limestone		4
RRII	_	granite	cesium	4
	March	marble		4
	2013	limestone		4
DeconGel		granite	cesium	4
	_	marble		4
	_	limestone	cesium	4
Intek LH-21	_	granite		4
		marble		4
Intek LH-21	_		americium	4
Intek LH-21		concrete	cesium	4
DeconGel		concrete	cobalt	4
DeconGel			strontium	4
	Juno		cesium	4
DDS 2000	2013	concrete	cobalt	4
KDS 2000	2013	concrete	strontium	4
			americium	4
Wash Aid (used		concrete		4
with alternate test stand)		asphalt	cesium	6

Table 3-3. Technologies, Contaminants, and Coupons in Technology Evaluation

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 to 2 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 six decontamination technologies using an intrinsic high purity germanium detector (Canberra LEGe Model GL 2825R/S, Meriden, CT, USA). After each coupon was placed in front of the detector face, gamma ray spectra were collected until the average measured activity level of Cs-137, Co-60, Sr-85 and Am-243 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 made based on efficiency, emission probability, and half-life values. Decay corrections were made based on the date and the duration of the counting period. Full RML gamma counting QA/quality control (QC), as described in the QAPP, was employed and certified results were provided. The minimum detectable level of each radionuclide was 0.3 nanoCuries (nCi) for Cs-137, 0.3 nCi for Co-60, 0.2 nCi for Sr-85 and 0.2 nCi for Am-243 on these coupons.

The activity measurement for the aqueous samples to show the effectiveness of vermiculite clay removal was performed differently from the surface coupons. A 5 mL aliquot was removed and filtered from each sample. Then a 2 mL aliquot of this filtered portion was dried slowly onto a tare weighed metal planchet. The activity of the samples was counted in a gas-proportional gross alpha/beta counter (WPC-1050 Automatic Low Background System, Protean Instruments Company, Lenoir City, TN, USA) for 100 minutes. Activities are reported in units of μ Ci/mL. The minimum detectable level for Cs-137 in these samples was approximately $7 \times 10^{-7} \mu$ Ci/mL. All the aqueous samples were at least 50 times that activity concentration.

3.1.4 Surface Coupon Placement on Test Stands

To evaluate the decontamination technologies (with the exception of Wash Aid) on vertical surfaces (simulating walls) contaminated with Cs-137, Co-60, Sr-85 and Am-243, a stainless steel test stand ($2.7 \text{ m} \times 2.7 \text{ m}$) 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 limestone, marble and concrete coupons were placed into holders within the large test stand 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. The middle position of the bottom row contained 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. Wash Aid is designed for a high flow liquid application over surfaces so an alternative test stand was used as described in Section 3.2.6.



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

3.2 Decontamination Technology Procedures

3.2.1 DeconGel

The implementation of the DeconGel technology procedure included application of two coats of DeconGel followed by removal of the dried coating. The application was performed using a standard 4-inch paint brush. The specifications of the paint brush were not critical as a perfectly smooth application was not required. The paint brush was loaded with the wet coatings by dipping the brush into a plastic bucket containing the wet coatings and then the wet coatings were applied generously until the entire surface of the coupon was covered. The paint brush was then used to work the wet coatings into the surfaces. The brush was then used to smooth the applied wet DeconGel on each coupon. If areas of the coupons were not covered completely, additional wet DeconGel was added. The first coat of the DeconGel was allowed to set for 1.5 to 2 hours and a second coat was added on top of the initial coat following the same method. The

coupons with the wet DeconGel were allowed to dry overnight. The dry coatings were removed by first scoring the bottom edge of the coupons (now covered with dried coatings) with a plastic knife to free corners of the dried coating so they could be pulled off the surface by hand. The overall decontamination method for DeconGel included the



Figure 3-4. Wet DeconGel and DeconGel removal

application of wet coating followed by a 1.5 to 2 hour drying time and application of a second coat that was allowed to dry overnight before removal the following day. Figure 3-4 shows a granite coupon just after DeconGel application and the removal of dry DeconGel.

3.2.2 EAI RRII

The application of RRII was performed using plastic spray bottles (32-oz heavy duty spray bottle, Rubbermaid Professional, Atlanta, GA). The coupons were thoroughly wetted with RRII Formula 1 with three to four 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, USA). During this evaluation, the initial application of RRII Formula 1 took only 15 to 20 seconds for each coupon. The next step was a 30-minute dwell time for RRII Formula 1 to reside on the surfaces of the coupon surfaces were kept damp with one to two sprays of additional RRII Formula 1 approximately every 5 minutes. The additional one to two 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 [DI] water) using another spray bottle. The surface was then vacuumed (12 gallon, 4.5 horsepower, QSP[®] Quiet Deluxe, Shop-Vac Corporation, Williamsport, VA, USA) which took about 25 seconds per coupon. The above procedure was then repeated for RRII Formula 2. Altogether, the RRII procedure (including all the steps above) took 79 and 72 minutes to complete for the two sets of coupons that were decontaminated during this technology evaluation. Figure 3-5 shows the rinse and vacuuming step of the RRII procedure.



Figure 3-5. Rinsing and vacuuming RRII from concrete coupon

3.2.3 Argonne National Laboratory ASG

The ASG was prepared by mixing two dry powders with water as directed by Argonne staff members via e-mailed written instructions and phone conversations. The mixture was then stirred with a drill equipped with a mixing tool until the mixture was homogeneous. The ASG was applied using a 4-inch paint brush to smooth the ASG across the surface. The specifications of the paint brush 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, USA) which required approximately 20 seconds per coupon. Figure 3-6 shows the application and vacuum removal steps for ASG.



Figure 3-6. ASG before application, as applied to coupon, and during vacuum removal

3.2.4 Intek LH-21

The application of LH-21 was performed using plastic spray bottles (32-oz heavy duty spray bottle, Rubbermaid Professional, Atlanta, GA, USA) as directed by Intek staff members. The LH-21 was diluted 1:1 in DI water prior to addition to the spray bottles for application to the contaminated coupons. The coupons were thoroughly wetted with LH-21 with three to four sprays. The solution was then worked into the surface of the coupon by scrubbing the entire surface of the coupon once with a medium bristle brush. This initial application of LH-21 took only 25 seconds for each coupon and was followed by a quick spray to rewet the surface of the coupons. The coupon surfaces were kept damp with one to two sprays of additional LH-21 approximately every 10 minutes. After the 60-minute dwell time, the coupon surfaces were thoroughly wetted with DI water using another spray bottle. The surface was then vacuumed which took about 25 seconds per coupon. The total elapsed time for the entire LH-21 procedure (including all the steps detailed above) for the nine coupons decontaminated with LH-21 was approximately 70 minutes.

3.2.5 Kärcher-Futuretech RDS 2000

The application of RDS 2000 included use of a hand-pump pressurized sprayer. Futuretech supplied two different components that had to be combined following the instructions that were provided by Futuretech. That new solution was then diluted with DI water to make a 2% solution by volume which was added to the hand sprayer. Each coupon was then wetted with the RDS 2000 and scrubbed in with a medium bristle brush followed by a 5-minute dwell time. Following the 5-minute dwell, each coupon received another application of RDS 2000 using the hand sprayer, followed by another 5-minute dwell, and then rinsed with DI water. These application steps were repeated once and then the rinse water was removed with a vacuum. Application of the RDS 2000 solutions to each coupon took approximately 10 seconds. The total elapsed time for the entire RDS 2000 procedure (including all the steps detailed above) for the nine coupons decontaminated with RDS 2000 was approximately 17 minutes.

3.2.6 Argonne National Laboratory Wash Aid

Wash Aid was made up of a solution of 1 millimolar sodium dodecyl sulfate prepared in 0.5 Molar ammonium chloride. Wash Aid was applied to contaminated coupons individually using a custom designed decontamination test stand that provided a way for flowing Wash Aid across

the entire surface of the Cs-137 contaminated concrete and asphalt coupons at a flow rate of 600 mL/min. Each coupon was decontaminated with Wash Aid for 5 minutes and the Wash Aid effluents from all the concrete and asphalt coupons were collected separately as composite samples. The Wash Aid decontamination approach included a step to remove Cs-137 from the Wash Aid effluent (post-decontamination) using the addition of vermiculite clay (Vermiculite Ore Concentrate, VCX 205, Specialty Vermiculite Corp., Enoree, SC, USA) to the Wash Aid effluent. Because a total of four concrete and six asphalt coupons were decontaminated, the resulting composite concrete Wash Aid effluent totaled 12 L and the asphalt Wash Aid effluent totaled 18 L. For each of the Wash Aid effluents, a 3 L aliquot was treated through three successive additions of approximately 300 g of vermiculite clay (for a total of 900 g used for each Wash Aid effluent sample). The clay was added and a kitchen mixer (MixMaster, Sunbeam, Jarden Consumer Products, Inc., USA) was used to thoroughly mix the clay with the Wash Aid effluent for 15 minutes. The clay was allowed to settle for 5 minutes and then the supernatant Wash Aid effluent was poured off the clay that had settled to the bottom of the glass mixing bowl. The clay remaining in the mixing bowl was discarded and the mixing bowl cleaned. The supernatant Wash Aid effluent was then added back into the mixing bowl and the clay treatment process was repeated two additional times. Wash Aid effluent samples were collected for activity measurements before clay addition and after each successive clay treatment. Figure 3-7 shows the Wash Aid test stand, the experimental setup (Wash Aid container, peristaltic pump, and test stand), and the clay mixing setup.



Figure 3-7. Wash Aid test stand, Wash Aid experimental setup, and clay mixing setup

3.3 Decontamination Conditions

The decontamination technology testing was performed over the course of three days during two different testing cycles (March and June 2013). Table 3-2 presents the temperature (or range) in degrees Celsius (°C) and the percent relative humidity measured during the evaluation.

	Temperature during	Humidity during
Testing Month	Decontamination (°C)	Decontamination (%)
March 2013	18-21	16
June 2013	20-24	16-24

Table 3-4. Details of Each Testing Time Period

4.0 Quality Assurance/Quality Control

QA/QC procedures were performed in accordance with the QMP and the QAPP 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. Each row shows the difference between the known energy levels and those measured following calibration (rolling average across the six most recent calibrations). Each row represents a 6-week rolling average of calibration results. These energies were compared to the previous 30 calibrations to confirm that results were within three standard deviations of the previous calibration results. All the calibrations fell within this requirement.

Maggunomont		Calibration Energy Levels (keV)						
Month		Energy 1	Energy 2	Energy 3	Energy 4	Energy 5		
WIOITUI	Date Range	238.632	583.191	860.564	1620.735	2614.511		
March/April 2013	3-18-13 to 4-30-13	-0.003	0.009	-0.023	-0.184	0.018		
April/May 2013	4-23-13 to 5-15-13	-0.005	0.017	-0.056	-0.228	0.023		
May/June 2013	5-15-13 to 6-17-13	-0.001	0.001	0.016	-0.095	0.008		
June/July 2013	6-11-13 to 7-16-13	-0.002	0.004	0.006	-0.117	0.010		

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

Gamma ray counting was continued for each coupon until the measured activity level of Cs-137, Co-60, Sr-85 and Am-243 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 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 Cs-137, 0.3 nCi for Co-60, 0.2 nCi for Sr-85 and 0.2 nCi for Am-243 on these coupons.

Throughout the evaluation, a second measurement was taken on 15 coupons to provide duplicate measurements to evaluate the repeatability of the instrument. Eight of the duplicate measurements were performed after contamination but prior to application of the decontamination technologies and seven were performed after decontamination. All but two of the duplicate pairs showed a percent difference in activity level of 8% or less, and all were below the acceptable percent difference of 10%.

Seven transport control samples (one from each contaminant/surface combination) were analyzed during the evaluation. These samples were contaminated, measured for the pre-decontamination activity, transported to the testing facility, and then shipped back to the RML for a follow-up measurement of activity. The activity measured before and after shipment was measured to determine the consistency of the gamma detector. All seven samples had percent differences of less than 8%, well below the acceptable percent difference of 25%.

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 Becquerel, 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 provides 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%.

4.2.2 Technical System Audit (TSA)

A TSA was performed during the June 2013 testing to confirm compliance with the QAPP. No findings were observed during the TSA.

4.2.3 Data Quality Audit

At least 10% of the data acquired during the evaluation were audited. The data was traced 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 were checked for accuracy. No significant findings were noted.

4.3 QA/QC Reporting

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

	En 152	NIST Activity	INI DMI	
Date	(keV)	(Bq)	Result (Bq)	Difference
	Average	124,600	120,500	3.3%
March 2012	122	124,600	118,100	5.2%
March 2015 -	779	124,600	118,500	4.9%
	1408	124,600	122,500	1.7%
	Average	124,600	120,200	3.5%
4 mmil 2012	122	124,600	118,000	5.3%
April 2015	779	124,600	117,600	5.6%
	1408	124,600	119,000	4.5%
	Average	124,600	121,000	2.9%
	122	124,600	118,500	4.9%
	779	124,600	118,800	4.7%
-	1408	124,600	121,000	2.9%
	Average	124,600	121,400	2.6%
$J_{\rm up} = 2012$	122	124,600	117,900	5.4%
June 2015 -	779	124,600	119,500	4.1%
-	1408	124,600	123,400	1.0%
	Average	124,600	122,300	1.8%
$\frac{1}{100}$	122	124,600	119,500	4.1%
July 2015 -	779	124,600	120,800	3.0%
-	1408	124,600	123,000	1.3%

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

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:

$$\label{eq:R} \begin{split} \%R &= (1\text{-}A_f/A_o) \times 100\% \\ and \\ DF &= A_o/A_f \end{split}$$

where A_o is the radiological activity from the surface of the coupon before application of the decontamination technologies and A_f is the radiological activity from the surface of the coupon after decontamination. While the DFs are reported in the following data tables, the narrative describing the results will focus on the %R.

While given in each of the tables below, the overall (DeconGel, RRII, ASG and LH-21 included) average pre-decontamination activity (plus or minus one standard deviation) of the Cs-137 contaminated coupons was $1.11 \pm 0.04 \ \mu$ Ci for marble (4% RSD); $1.17 \pm 0.07 \ \mu$ Ci for granite (6% RSD; and $0.99 \pm 0.03 \ \mu$ Ci for limestone (3% RSD). For Cs-137, Sr-85, and Co-60 on concrete the average activities were $0.96 \pm 0.05 \ \mu$ Ci (5% RSD), $1.56 \pm 0.09 \ \mu$ Ci (6% RSD), and $0.57 \pm 0.03 \ \mu$ Ci (5% RSD), respectively. For Am-243 on concrete, the average activity was $0.050 \pm 0.003 \ \mu$ Ci (5% RSD).

5.1.1 DeconGel Results

Table 5-1 presents the decontamination efficacy, expressed as both %R and DF, for DeconGel when decontaminating Cs-137 from limestone, granite, and marble surface coupons. Table 5-2 presents the same data for Co-60 and Sr-85 decontamination from concrete. The decontamination efficacies of DeconGel in terms of %R for Cs-137 were $35 \pm 13\%$ for the limestone surfaces, $72 \pm 4\%$ for the granite surfaces and $93 \pm 1\%$ for the marble surfaces. These results are comparable to the Cs-137 removal from concrete of $67 \pm 9\%$ derived from previous EPA evaluations of DeconGel⁴. Co-60 removal from concrete surfaces was $85 \pm 2\%$ and for Sr-85 was $64 \pm 6\%$. Several t-tests were performed to determine the likelihood that the %R results for each surface were the same. The t-test results indicated that the %R from each of the three surfaces contaminated with Cs-137 were significantly different from one another at least at the 95% confidence level (p-values < 0.002). Similarly, the %Rs for concrete contaminated with Co-60 and Sr-85 were also determined to be significantly different from one another (p < 0.001). As indicated by the %Rs above, Cs-137 was most effectively removed from marble followed by

granite and then limestone. Also, Co-60 was removed more effectively from concrete than was Sr-85.

		Pre-	Post-		
		Decontamination	Decontamination		
		Activity	Activity		
Surface Material		(µCi/Coupon)	(µCi/Coupon)	%R	DF
		1.02	0.67	34%	1.5
		1.01	0.78	23%	1.3
Limostono		1.00	0.47	53%	2.1
Liniestone		1.02	0.71	30%	1.4
	Avg	1.01	0.66	35%	1.6
	SD	0.01	0.13	13%	0.4
		1.30	0.40	69%	3.3
		1.19	0.37	69%	3.2
Cronito		1.16	0.32	72%	3.6
Granite		1.06	0.24	77%	4.4
	Avg	1.18	0.33	72%	3.6
	SD	0.10	0.07	3.9%	0.6
		1.19	0.074	94%	16.1
		1.08	0.088	92%	12.3
Marhla		1.12	0.073	94%	15.3
warble		1.10	0.073	93%	15.1
	Avg	1.12	0.08	93%	14.7
	SD	0.05	0.01	0.9%	1.7

 Table 5-1. DeconGel Cs-137 Decontamination Efficacy Results

		Pre-	Post-		
		Decontamination	Decontamination		
Surface		Activity	Activity		
Contaminant		(µCi/Coupon)	(µCi/Coupon)	%R	DF
		0.54	0.092	83%	5.9
		0.53	0.081	85%	6.5
Co-60		0.56	0.085	85%	6.6
0-00		0.58	0.075	87%	7.7
	Avg	0.55	0.08	85%	6.7
	SD	0.02	0.01	1.7%	0.8
		1.53	0.47	69%	3.3
		1.60	0.52	68%	3.1
Sr 85		1.56	0.57	63%	2.7
51-05		1.55	0.69	55%	2.2
	Avg	1.56	0.56	64%	2.8
	SD	0.03	0.09	6.1%	0.4

Table 5-2. DeconGel Concrete Decontamination Efficacy Results

As described above in Section 3.1.4, a cross-contamination blank was included in the test stand during testing with each contaminant to evaluate the potential for cross contamination due to application of DeconGel on wall locations above the blank. Each cross contamination blank was an uncontaminated concrete coupon that had pre-decontamination activity measurements indicating extremely low background levels (below the detection limit) of activity. These coupons were decontaminated using DeconGel along with the other contaminated coupons and the post-decontamination measurement of activity of the cross-contamination blank was found to be $0.0053 \,\mu$ Ci for Cs-137 and not detectable for the cross-contamination blank corresponding to the coupons contaminated with Co-60 and Sr-85. In the case of the Cs-137 cross-contamination blank, this increased level of activity was less than 1% for Cs-137 of the activity applied to each of the contaminated coupons. Therefore, the cross contamination was minimal but still detectable, and enough to note that cross contamination to locations previously not contaminated is a possibility when using DeconGel in a wide area application.

5.1.2 RRII Results

Table 5-3 presents the decontamination efficacy, expressed as both %R and DF, for RRII when decontaminating Cs-137 from limestone, granite, and marble surface coupons. The decontamination efficacies of RRII in terms of %R for Cs-137 were $38 \pm 13\%$ for the limestone surfaces, $72 \pm 2.5\%$ for the granite surfaces, and $89 \pm 5\%$ for the marble surfaces. These results are comparable to the Cs-137 removal from concrete of $85 \pm 2\%$ derived from previous EPA evaluations of RRII⁵. Several t-tests were performed to determine the likelihood that the %R results for each surface were the same. The t-test results indicated that the %R from each of the three surfaces contaminated with Cs-137 were significantly different from one another at least at the 95% confidence level (p-values < 0.002). As indicated by the %Rs above, Cs-137 was most effectively removed from marble followed by granite and then limestone.

As described above in Section 3.1.4, cross-contamination blanks were included in the test stand during testing to evaluate the potential for cross contamination due to application of RRII on wall locations above the blank. Each cross contamination blank was an uncontaminated concrete coupon that had pre-decontamination activity measurements indicating extremely low background levels (below the detection limit) of activity. This coupon was decontaminated using RRII along with the other contaminated coupons and the post-decontamination measurement of activity of these blanks was found to be 0.056 μ Ci for Cs-137. This increased level of activity was less than 6% 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.

		Pre-	Post-		
		Decontamination	Decontamination		
		Activity	Activity		
Surface Material		(µCi/Coupon)	(µCi/Coupon)	%R	DF
		1.00	0.55	45%	1.8
		0.98	0.73	26%	1.3
Limostono		0.99	0.48	52%	2.1
Linestone		0.99	0.71	28%	1.4
	Avg	0.99	0.62	38%	1.7
	SD	0.01	0.12	13%	0.3
		1.26	0.36	71%	3.5
		1.20	0.30	75%	4.0
Cronito		1.11	0.29	74%	3.8
Granite		1.14	0.35	69%	3.3
	Avg	1.18	0.33	72%	3.6
	SD	0.07	0.04	3%	0.3
		1.12	0.073	94%	15
		1.07	0.081	92%	13
Manhla		1.14	0.163	86%	7.0
warble		1.12	0.175	84%	6.4
	Avg	1.11	0.12	89%	11
	SD	0.03	0.05	5%	5

Table 5-3. RRII Cs-137 Decontamination Efficacy Results

5.1.3 ASG Results

Table 5-4 presents the decontamination efficacy, expressed as both %R and DF, for ASG when decontaminating Cs-137 from limestone, granite, and marble surface coupons. Similar data exist for decontamination of concrete contaminated with Cs-137 using ASG⁶. The decontamination efficacies of ASG in terms of %R for Cs-137 were $15\pm 6\%$ for the limestone surfaces, $50\pm 3\%$ for the granite surfaces, and $71\pm 4\%$ for the marble surfaces. These results are comparable to the Cs-137 removal from concrete of $71\pm 4\%$ derived from previous EPA evaluations of ASG⁶. Several t-tests were performed to determine the likelihood that results for each contaminant and

surface were the same. Several t-tests were performed to determine the likelihood that the %R results for each surface were the same. The t-test results indicated that the %Rs from each of the three surfaces contaminated with Cs-137 were significantly different from one another at least at the 95% confidence level (p-values < 0.0005). As indicated by the %Rs above, Cs-137 was most effectively removed from marble followed by granite and then limestone.

		Pre-	Post-		
		Decontamination	Decontamination		
Surface Material		(uCi/Coupon)	(uCi/Coupon)	%R	DF
		1.02	0.86	16%	1.2
		0.98	0.89	9%	1.1
T !		0.98	0.85	13%	1.2
Limestone		1.02	0.78	24%	1.3
	Avg	1.00	0.84	16%	2.0
	SD	0.02	0.05	6.3%	0.1
		1.09	0.59	46%	1.8
		1.22	0.62	49%	2.0
Cronito		1.21	0.60	50%	2.0
Granite		1.22	0.56	54%	2.2
	Avg	1.19	0.59	50%	2.0
	SD	0.06	0.03	3%	0.1
		1.20	0.32	73%	3.8
		1.12	0.37	67%	3.0
Marble ^(a)		1.13	0.31	73%	3.6
	Avg	1.15	0.33	71%	3.5
	SD	0.04	0.03	4%	0.4

Table 5-4. ASG Cs-137 Decontamination Efficacy R	Results
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(a) Data from one marble coupon were not used because wrong side of coupon was decontaminated.

As for the above testing, the cross-contamination blanks were included in the test stand during testing to evaluate the potential for cross contamination due to application of ASG on wall locations above the blank. Each cross contamination blank was an uncontaminated concrete coupon that had pre-decontamination activity measurements indicating 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 was found to be less than 0.002 μ Ci for Cs-137. This increased level of activity was approximately 0.2% of the activity added to each of the contaminated coupons for Cs-137. Therefore the cross contamination was very minimal during application of ASG.

5.1.4 LH-21 Results

Table 5-5 presents the decontamination efficacy, expressed as both %R and DF, for LH-21 when decontaminating Cs-137 from limestone, granite, marble, and concrete surface coupons and Table 5-6 presents the same data for Am-243 decontamination from concrete. The decontamination efficacies of Intek LH-21 in terms of %R for Cs-137 were $39\pm 10\%$ for the

limestone surfaces, $56 \pm 5\%$ for the granite surfaces, and $90 \pm 5\%$ for the marble surfaces. For concrete surfaces, the %Rs were $45 \pm 16\%$ for Cs-137 and $87 \pm 7\%$ for Am-243. Several t-tests were performed to determine the likelihood that the %R results for each surface were the same. The t-test results indicated that the %Rs from limestone, granite, and marble are each significantly different from one another (p-values < 0.03). The %Rs for Cs-137 from granite and limestone were not significantly different from the %Rs from concrete (p-values > 0.2) when compared individually with concrete. As indicated by the %Rs above, Cs-137 was most effectively removed from marble followed by granite, concrete, and limestone. Also, Am-243 was more effectively removed from concrete than was Cs-137.

As for the above 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 LH-21 on wall locations above the blank. Each cross contamination blank was an uncontaminated concrete coupon that had pre-decontamination activity measurements indicating extremely low background levels (below the detection limit) of activity. These coupons were decontaminated using LH-21 along with the other contaminated coupons. The post-decontamination measurement of activity of these blanks was found to be 0.017 μ Ci for Cs-137. This increased level of activity was approximately 2% of the activity added to each of the contaminated coupons for Cs-137. Therefore, the cross contamination was minimal but still detectable, and enough to note that cross contamination to locations previously not contaminated is a possibility when using LH-21 in a wide area application.

		Pre-	Post-		
		Decontamination	Decontamination		
		Activity	Activity		
Surface Material		(µCi/Coupon)	(µCi/Coupon)	%R	DF
		0.92	0.58	37%	1.6
		1.02	0.58	43%	1.8
Limostono		0.94	0.46	51%	2.0
Limestone		1.02	0.75	26%	1.4
	Avg	0.98	0.59	39%	1.7
	SD	0.05	0.12	10%	0.3
		1.11	0.51	54%	2.2
		1.18	0.53	55%	2.2
Cronito		1.17	0.43	63%	2.7
Granite		1.06	0.52	51%	2.0
	Avg	1.13	0.50	56%	2.3
	SD	0.06	0.05	5%	0.3
		1.11	0.12	89%	9.2
		1.01	0.02	98%	40
Marbla		1.08	0.08	92%	13
wiarbie		1.10	0.18	83%	5.9
	Avg	1.08	0.11	90%	12
	SD	0.05	0.06	5%	5.0
		0.86	0.63	27%	1.4
		1.01	0.39	61%	2.6
Congrata		0.99	0.43	57%	2.2
Concrete		0.93	0.59	37%	1.6
	Avg	0.95	0.51	45%	2.0
	SD	0.07	0.12	16%	0.6

Table 5-5. LH-21 Cs-137 Decontamination Efficacy Results

Table 5-6. LH-21 Am-243 from Concrete Decontamination Efficacy Results

Contaminant and Surface		Pre- Decontamination Activity (µCi/Coupon)	Post- Decontamination Activity (µCi/Coupon)	%R	DF
		0.052	0.0077	85%	6.8
		0.054	0.0116	79%	4.7
Am-243 on		0.053	0.0045	92%	11.8
Concrete		0.048	0.0032	93%	15.0
	Avg	0.052	0.007	87%	9.5
	SD	0.003	0.004	7%	4.7

5.1.5 RDS 2000

Table 5-7 presents the decontaminating on efficacy, expressed as both %R and DF, for RDS 2000 when decontaminating Cs-137, Co-60, Sr- 85 and Am-243 from concrete surface coupons. The %R values were $11 \pm 4.3\%$ for Cs-137, $52 \pm 3.1\%$ for Co-60, $43 \pm 11\%$ for Sr-85, and $69 \pm 10\%$ for Am-243. Several t-tests were performed to determine the likelihood that the %R results between the contaminants on concrete were all the same. The t-test results indicated that the %R of Sr-85 and Co-60 were not significantly different from one another. As indicated by the %Rs above, Am-243 was most effectively removed from concrete followed by Co-60 and Sr-85, and then Cs-137.

		Pre-	Post-		
		Decontamination	Decontamination		
Surface		Activity	Activity		
Contaminant		(µCi/Coupon)	(µCi/Coupon)	%R	DF
		1.02	0.86	16%	1.2
		0.96	0.91	5%	1.1
Cc 137		0.97	0.86	11%	1.1
08-157		1.00	0.89	11%	1.1
	Avg	0.99	0.88	11%	1.1
	SD	0.03	0.02	4.3%	0.1
		0.56	0.28	50%	2.0
		0.61	0.27	56%	2.3
Co 60		0.58	0.29	50%	2.0
C0-00		0.60	0.30	50%	2.0
	Avg	0.59	0.28	52%	2.1
	SD	0.02	0.01	3.1%	0.1
		1.54	0.83	46%	1.9
		1.71	0.82	52%	2.1
Sr 85		1.39	1.01	27%	1.4
51-05		1.59	0.87	45%	1.8
	Avg	1.56	0.88	43%	1.8
	SD	0.13	0.09	11%	0.3
		0.049	0.012	75%	4.0
		0.044	0.010	77%	4.3
Am 2/2		0.048	0.021	56%	2.3
AIII-243		0.048	0.015	69%	3.2
	Avg	0.047	0.015	69%	3.4
	SD	0.002	0.005	9.5%	0.9

Table 5-7. RDS 2000 Decontamination Efficacy from Concrete Results

As for the above 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 RDS 2000 on wall locations above the blank. Each cross contamination blank was an uncontaminated concrete coupon that had pre-decontamination activity measurements indicating extremely low background levels (below the detection limit) of activity. These

coupons were decontaminated using RDS 2000 along with the other contaminated coupons. The post-decontamination measurement of activity of these blanks was found to be undetectable for any of the applicable radionuclides. Therefore, the cross contamination was not measurable during application of RDS 2000.

5.1.6 Wash Aid Results

Table 5-8 presents the decontamination efficacy, expressed as both %R and DF, for Wash Aid when decontaminating Cs-137 from concrete and asphalt surface coupons. The decontamination efficacies of Wash Aid in terms of %R for Cs-137 were $24 \pm 18\%$ for decontamination of the concrete surfaces and $36 \pm 9\%$ for decontamination of the asphalt surfaces. A t-test was performed to determine the likelihood that the %R results between the two different surfaces were all the same. The results indicated that the %R of Cs-137 from concrete and asphalt were not significantly different from one another.

Surface Material		Pre-Decontamination Activity (µCi/Coupon)	Post-Decontamination Activity (µCi/Coupon)	%R	DF
		0.96	0.49	49%	2.0
		0.98	0.88	10%	1.1
Comente		0.97	0.85	12%	1.1
Concrete		0.95	0.70	26%	1.4
	Avg	0.97	0.73	24%	1.4
	SD	0.01	0.18	18%	0.4
		0.794	0.558	30%	1.4
		0.842	0.462	45%	1.8
	Action of the second s	0.824	0.503	39%	1.6
Agnhalt		0.787	(Coupon)(μ Ci/Coupon)%R0.960.4949%0.980.8810%0.970.8512%0.950.7026%0.970.7324%0.010.1818%0.7940.55830%0.8420.46245%0.8240.50339%0.7870.42147%0.8170.59727%0.7910.56129%0.810.5236%0.020.079%	1.9	
Asphan		0.817	0.597	27%	1.4
		0.791	0.561	29%	1.4
	Avg	0.81	0.52	36%	1.6
	SD	0.02	0.07	9%	0.2

 Table 5-8. Wash Aid Decontamination Efficacy for Removal of Cs-137 from Concrete and Asphalt Results

Table 5-9 presents the activity concentration of the Wash Aid effluents that were used to decontaminate the concrete and asphalt surfaces. For concrete, the average pre-decontamination activity was 0.97 μ Ci per coupon and four concrete coupons (3.88 μ Ci total) were rinsed with Wash Aid with an average %R of 24%. Therefore, 24% of total activity (0.97 μ Ci) should have been present in the 12 L of Wash Aid used on the concrete coupons. This would correspond to an activity concentration of 0.081 nCi/mL. The actual activity concentration measured in the concrete Wash Aid effluent was 0.110 nCi/mL. For asphalt, the average pre-decontamination activity was 0.81 μ Ci per coupon and six concrete coupons (4.86 μ Ci total) were rinsed with Wash Aid with an average %R of 36%. Therefore, 36% of total activity (1.74 μ Ci) should have

been present in the 18 L of Wash Aid used on the concrete coupons. This would correspond to an activity concentration of 0.097 nCi/mL. The actual activity concentration measured in the concrete Wash Aid effluent was 0.143 nCi/mL. Therefore, both the concrete and the asphalt Wash Aid effluents exhibited more Cs-137 than would have been expected. However, the uncertainty in the average %Rs was 75% for concrete and 25% for asphalt (reasons for large uncertainties may include coupon surface inconsistencies and approach to Wash Aid application) so such a mass balance calculation should be considered an approximation.

5.1.7 Cs-137 Removal from Wash Aid Effluent with Vermiculite Clay

Table 5-9 presents the efficacy of vermiculite clay in removing Cs-137 from Wash Aid that had been used to decontaminate concrete and asphalt coupons. The table gives the average initial activity of the Wash Aid effluent collected following decontamination of four concrete coupons and six asphalt coupons. The table also gives the average activity of the Wash Aid effluent after three separate treatments with clay. The standard deviations of three replicate measurements were very small so only the average activities were used to calculate the %Rs. From these data, %Rs were calculated based on the initial activities before any clay treatment. For the concrete Wash Aid effluent, the first treatment of clay resulted in a 46 %R, the second treatment of clay resulted in a total %R of 69%, and the final treatment resulted in a 55 %R, the second treatment of clay resulted in a total %R of 92%.

			Post-clay		Post-clay		Post-clay	
Surface		Initial	Addition #1	%R	Addition #2	%R	Addition #3	Total
Material		(nCi/mL)	(nCi/mL)	#1	(nCi/mL)	#2	(nCi/mL)	%R
Comencia	Avg.	0.110	0.059	460/	0.034	600/	0.018	83%
Concrete	SD	0.001	0.005	40%	0.000	0970	0.001	
A amh a lá	Avg.	0.143	0.065	550/	0.026	2 20/	0.011	92%
Aspnan	SD	0.001	0.003	33%	0.001	82%	0.000	

Table 5-9. Cs-137 Removal from Wash Aid (with Vermiculite Clay) Results

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, Co-60, Sr-85 and Am-243 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 needed to be 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 by the presence of Cs-137, Co-60, Sr-85 and Am-243.

5.2.1 DeconGel

A number of operational factors were documented by the technician who performed the testing with DeconGel. The application process of DeconGel was described in Section 3.2.1 and

included use of a standard 4-inch paint brush. DeconGel did not cause any visible damage to the surface of the coupons. Table 5-10 provides some additional detail about the operational factors for DeconGel as observed during the use of this experimental setup/test stand with relatively small concrete coupons. The below information is applicable only to the experimental scenario using small concrete coupons.

Parameter	Description/Information
Decontamination	Coating preparation: Provided ready for use.
rate	Application: Approximately 5 min and 375 mL per coat onto 0.2 square meter (m ²)
	for an application rate of 2.4 m^2 /hour and a DeconGel volumetric use rate of 1.9 L/m ²
	for each coat
	Drying time: overnight
	Removal time: 8 minutes for all nine coupons for a rate of 1.5 m ² /hour
	Estimated volume used per application of nine coupons (0.2 m ²) included 375 mL
	DeconGel.
Applicability to	Application to more irregular surfaces than what is encountered during this evaluation
irregular surfaces	would not seem to be much of a problem as a paint brush can reach most types of
	surfaces as long as the operator can access the surfaces. DeconGel cures into a rather
	rigid coating that was conducive for use on the surfaces made from concrete coupons
	used during this evaluation.
Skilled labor	After a brief training session to explain the procedures, most able-bodied people
requirement	would successfully perform both the application and removal procedures.
Utilities	None was required in this case because a paint brush application was used.
requirement	According to the vendor, DeconGel can be applied using a paint sprayer.
Extent of portability	With the exception of extreme cold, which would prevent the application of
	DeconGel (which is water-based), its portability seems limitless.
Shelf life of media	Shelf life according to the manufacturer is five years.
Secondary waste	Solid waste production: 200 g/m^2 for application of two costs
management	Solid waste production. ~200 g/m for application of two coats
Surface damage	Not visible to the eye, removed only loose particles that were seen to be stuck to the
	coating.
Cost	Material cost is \$40/L for DeconGel which corresponds to approximately \$76/m ² for
	each coat if used in a similar way as used during this evaluation. Labor costs were not
	calculated. Waste management costs were not included as they would be highly
	dependent on the individual situation.

Table 5-10. Operational Factors of DeconGel

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 plastic spray bottles. 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. Table 5-11 provides some additional detail about the operational factors for RRII as observed using this experimental setup/test stand with relatively small concrete coupons.

Table 5-11	Operational Factors	of RRII
Table 5-11.	Operational ractors	01 KKII

Parameter	Description/Information
Decontamination	Technology Preparation: RRII is provided ready to use. The solutions (Formula 1
rate	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 16 minutes in addition to the two 30 minutes dwell times for RRII. Aside from the dwell times, this corresponds to a rate of approximately 0.8 m ² /hour for RRII.
	Estimated volumes used per application of nine coupons (0.2 m ²) included 225 mL RRII Formula 1, 250 mL RRII Formula 2, and 200 mL of the rinse solution.
Applicability to	Application to irregular surfaces would not seem to be problematic, RRII is easily
irregular surfaces	sprayed into hard to reach locations. Irregular surfaces may pose a problem for
	vacuum removal.
Skilled labor	Adequate training would likely include a few minutes of orientation so the technician
requirement	is familiar with the application technique including dwell times and requirement of
	keeping the surface wet. Larger surfaces may require more complex equipment such
Litilities	as spray of roam application.
requirement	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
Extent of portability	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
Secondary waste	Approximately 675 mL of liquid was applied per nine coupons used during this
management	evaluation. That volume corresponds to a waste generation rate of approximately 3
management	L/m^2 depending on how much of the solutions absorb to the surfaces. Waste solution
	had to be neutralized from acidic pH before disposal.
Surface damage	Concrete and granite surfaces appeared to have a thin layer of residual RRII Formula
	II left after the final rinse and removal. Initially it appeared as if the coupon just had
	not fully dried after rinse, but close inspection revealed the residual material.
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 projects 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 ASG. Once fully mixed, ASG had the look of cooked oatmeal but was very "slippery" and tended to slide off any plastic tools. ASG caused no visible damage to the surface of the coupons. Table 5-12 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.

Parameter	Description/Information
Decontamination	Technology Preparation: 15 minutes to measure and mix powder with water.
rate	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 four inch paint brush to each coupon in approximately 30 seconds. 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 30 seconds per coupon (3 m ² /hour). Aside from the wait time (which is independent of the surface area), the application and removal rate was approximately 1 m ² /hour. Estimated volumes used per nine coupons included 2 L of ASG. Overall that volume corresponds to a loading of approximately 10 L/m ² .
Applicability to	Application to irregular surfaces may be problematic as ASG could slide off
irregular surfaces	jagged edges and be difficult to apply to hard to reach locations. During use
	on the rough split face granite, a small amount of ASG could be seen
Skilled labor	Adequate training would likely include a few minutes of orientation so the
requirement	technician is familiar with the application technique. Larger surfaces may
1	require more complex equipment such as sprayer application.
Utilities	As evaluated here, electricity was required to operate the wet vacuum. Larger
requirement	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	0.5-1 L of ASG was applied per nine coupons during this evaluation. That
management	volume corresponds to a waste generation rate of approximately 5 -10 L/m^2 .
<u>C</u>	ASG was collected entirely by the wet vacuum.
Surface damage	Concrete and granite surfaces appeared undamaged.
Cost	Material cost is approximately $\frac{50.30}{L}$. This cost corresponds to $\frac{51.50}{1.50}$ -
	Labor costs were not calculated Waste management costs were not included as
	they would be highly dependent on the individual situation.

Table 5-12. Operational Factors of ASG

5.2.4 LH-21

The application of LH-21 was described in Section 3.2.4 and included use of a plastic spray bottle. According to the manufacturer, if LH-21was 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. LH-21 did not cause any visible damage to the surface of the coupons.

Table 5-13 provides some additional detail about the operational factors for LH-21 as observed using this experimental setup/test stand with relatively small concrete coupons.

Parameter	Description/Information
Decentamination	Technology Dreparation: Five minutes to dilute I H 21 1:1 with water and
rete	transformed into approx bottle for application
rate	transferred into spray bottle for application.
	Application: Using this experimental setup, the initial application of LH-21 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 60 minute dwell time, rinsing and vacuuming took approximately 45 seconds per coupon. In all, the application and removal steps took 10 minutes in addition to the 60 minute dwell time. Aside from the dwell time, this corresponds to a decontamination rate of approximately 1 m ² /hr for LH-21.
	Estimated volumes used per application of nine coupons (0.2 m ²) included 475 mL LH-21 and 200 mL of rinse water.
Applicability to	Application to irregular surfaces would not seem to be problematic, LH-21 is
irregular surfaces	easily sprayed into hard to reach locations. Irregular surfaces may pose a
	problem for vacuum removal.
Skilled labor	Adequate training would likely include a few minutes of orientation so the
requirement	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	Electricity for the wet vacuum. Larger surfaces may require more complex
requirement	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 LH-21 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	Approximately 675 mL of liquid was applied per nine coupons used during
management	this evaluation. That volume corresponds to a waste generation rate of
	approximately 3 L/m ² depending on how much of the solutions absorb to the
	surfaces.
Surface damage	No visible damage to the surface was observed.
Cost	Material cost is \$1.50/L for the LH-21. This corresponds to approximately \$4/
	m ² for LH-21. Labor costs were not calculated. Waste management costs were
	I not included as they would be highly dependent on the individual situation.

 Table 5-13. Operational Factors of LH-21

5.2.5 RDS 2000

The application of RDS 2000 was described in Section 3.2 and included use of a hand-pump pressurized sprayer. These application and removal times are applicable only to the experimental scenario involving these rather small concrete coupons. According to the manufacturer, if RDS 2000 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. RDS 2000 did not cause any visible damage to the surface of the coupons.

Table 5-14 provides some additional detail about the operational factors for RDS 2000 as observed using this experimental setup/test stand with relatively small concrete coupons.

Parameter	Description/Information
Decontamination	Technology Preparation: 15 minutes to combine the two parts of the solution
rate	and dilute the mixture to a 2% solution by volume.
	Application: Using this experimental setup, the initial application of RDS 2000 to the coupons took only seconds followed by a light scrubbing and then a five minute dwell time; a second RDS 2000 application, a water rinse and the repeat of the 1^{st} two applications ending with a water rinse and vacuum removal. In all, the application and removal steps took 17 minutes including the dwell times. Aside from the dwell time, this corresponds to a decontamination rate of approximately 1 m ² /hour for RDS 2000.
	Estimated volumes used per application of nine coupons (0.2 m ²) included approximately 1 L RDS 2000 and 1 L of rinse water.
Applicability to	Application to irregular surfaces would not seem to be problematic, RDS 2000
irregular surfaces	is easily sprayed into hard to reach locations. Irregular surfaces may pose a
	problem for vacuum removal.
Skilled labor	Adequate training would likely include a few minutes of orientation so the
requirement	technician is familiar with the application technique including dwell times and
	requirement of keeping the surface wet. Larger surfaces may require more
Litilities	Electricity for the wet vacuum. Larger surfaces may require more complex
requirement	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 factors. However, for larger scale applications, limiting factors would include the ability to apply RDS 2000 (including application and scrubbing of surface) 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	Approximately 2 L of liquid was applied per nine coupons used during this
management	evaluation. That volume corresponds to a waste generation rate of
	approximately 10 L/m ² depending on how much of the solutions absorb to the
Sunface domage	Surfaces.
Surface damage	No visible damage to the surface was observed.
Cost	Material cost is $\frac{515}{L}$ for the KDS 2000. This corresponds to approximately $\frac{575}{m^2}$ for RDS 2000. Labor costs were not colculated. Waste mergement
	of 5/111 101 KDS 2000. Labor costs were not calculated, waste management
	situation
Applicability to irregular surfaces Skilled labor requirement Utilities requirement Extent of portability Secondary waste management Surface damage Cost	 Estimated volumes used per application of nine coupons (0.2 m²) included approximately 1 L RDS 2000 and 1 L of rinse water. Application to irregular surfaces would not seem to be problematic, RDS 2000 is easily sprayed into hard to reach locations. Irregular surfaces may pose a problem for vacuum removal. 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. Electricity for the wet vacuum. Larger surfaces may require more complex equipment such as spray or foam application requiring additional utilities. At a scale similar to that used for this evaluation, vacuum removal would be the only portability factors. However, for larger scale applications, limiting factors would include the ability to apply RDS 2000 (including application and scrubbing of surface) 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. Approximately 2 L of liquid was applied per nine coupons used during this evaluation. That volume corresponds to a waste generation rate of approximately 10 L/m² depending on how much of the solutions absorb to the surfaces. No visible damage to the surface was observed. Material cost is \$15/L for the RDS 2000. This corresponds to approximately \$\$75/m² for RDS 2000. Labor costs were not calculated. Waste management costs were not included as they would be highly dependent on the individual situation.

Table 5-14.Operational Factors of RDS 2000

5.2.6 Wash Aid

Wash Aid was applied to concrete and asphalt surface material coupons with a very specialized application setup. Such a setup was purely for technology evaluation purposes and in no way was meant to mimic an actual decontamination scenario. Therefore, no additional operational factors are provided. The Wash Aid effluent was solidified in super absorbing polymer and disposed of as low-level radioactive waste.

6.0 References

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