EPA/600/R-08/100 | September 2008 | www.epa.gov/ord

United States
Environmental Protection
Agency

Isotron Corp. Orion™ Radiological Decontamination Strippable Coating

TECHNOLOGY EVALUATION REPORT

Office of Research and Development
National Homeland Security Research Center

EPA/600/R-08/100 | September 2008 | www.epa.gov/ord

Technology Evaluation Report

Isotron Corp. Orion™ Radiological Decontamination Strippable Coating

By

Ryan R. James and Zachary J. Willenberg
Battelle
505 King Avenue
Columbus, OH 43201

Robert V. Fox
Idaho National Laboratory
P.O. Box 1625
MS 2208
Idaho Falls, ID 83415

John Drake
Task Order Project Officer
National Homeland Security Research Center
Office of Research and Development
U.S. Environmental Protection Agency
26 Martin Luther King Drive
Cincinnati, OH 45268

Notice

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 a Blanket Purchase Agreement under General Services Administration contract number GS23F0011L-3 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.

Preface

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems, to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

In September 2002, EPA announced the formation of the National Homeland Security Research Center (NHSRC). The NHSRC is part of ORD; it manages, coordinates, supports, and conducts a variety of research and technical assistance efforts. These efforts are designed to provide appropriate, affordable, effective, and validated technologies and methods for addressing risks posed by chemical, biological, and radiological terrorist attacks. Research focuses on enhancing our ability to detect, contain, and decontaminate in the event of such attacks.

NHSRC's team of world renowned scientists and engineers is dedicated to understanding the terrorist threat, communicating the risks, and mitigating the results of attacks. Guided by the roadmap set forth in EPA's Strategic Plan for Homeland Security, NHSRC ensures rapid production and distribution of security-related products.

The NHSRC has created the Technology Testing and Evaluation Program (TTEP) in an effort to provide reliable information regarding the performance of homeland security related technologies. TTEP provides independent, quality assured performance information that is useful to decision makers in purchasing or applying the tested technologies. TTEP provides potential users with unbiased, third-party information that can supplement vendor-provided information. Stakeholder involvement ensures that user needs and perspectives are incorporated into the test design so that useful performance information is produced for each of the tested technologies. The technology categories of interest include detection and monitoring, water treatment, air purification, decontamination, and computer modeling tools for use by those responsible for protecting buildings, drinking water supplies, and infrastructure, and for decontaminating structures and the outdoor environment. In addition, environmental persistence information is important for containment and decontamination decisions.

The evaluation reported herein was conducted by Battelle as part of the TTEP program. Information on NHSRC and TTEP can be found at http://www.epa.gov/nhsrc.

Acknowledgments

The authors wish to acknowledge the support of Dr. Howard Hall of the Lawrence Livermore National Laboratory and Drs. Emily Snyder and Sang Don Lee of the U.S. EPA National Homeland Security Research Center for their review of the test/QA plan and this report.

Contents

Figures

Tables

Abbreviations/Acronyms

BQ	Bequerel
Cs	cesium
C	centigrade
cm	centimeters
D&D	decontamination and decommissioning
DARPA	Defense Advanced Research Projects Agency
DF	decontamination factor
DHS	U.S. Department of Homeland Security
DoD	Department of Defense
EPA	U.S. Environmental Protection Agency
Eu	Europium
g	gram
INL	Idaho National Laboratory
keV	kilo electron volts
kg	kilogram
mg	milligram
mL	milliliter
L	liter
m	meter
µCi	microcuries
NHSRC	National Homeland Security Research Center
ORD	Office of Research and Development
Orion™ SC	Isotron Orion™ strippable coating
%R	percent removal
PE	Performance evaluation
psi	pounds per square inch
QA	quality assurance
QC	quality control
QMP	quality management plan
RDD	radiological dispersion device
RML	Radiological Measurement Laboratory
Th	Thorium
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program

Executive Summary

The U.S. Environmental Protection Agency's (EPA's) National Homeland Security Research Center (NHSRC) Technology Testing and Evaluation Program (TTEP) 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. Under TTEP, Battelle recently evaluated the performance of Orion™ strippable coating (Orion™ SC) from Isotron Corporation (Seattle, Washington). The objective of evaluating the Orion™ SC was to test its ability to remove radioactive cesium (Cs)-137 from the surface of unpainted concrete.

The Orion™ SC contains affinity shifting and binding chemistries that are designed to extract and bind Cs-137. The Orion™ SC is applied as a paint. Following cure, the bound cesium can be removed from the surface by peeling away the Orion™ SC. Prior to the evaluation of the Orion™ SC, 15 cm × 15 cm unpainted concrete coupons were contaminated with Cs-137 at a level of approximately 53 microcuries (μCi, measured by gamma spectroscopy), and then several of these contaminated coupons were used within horizontal and vertical surfaces constructed with a total of 24 coupons.

Following manufacturer's recommendations, the Orion™ SC was applied and removed three successive times before the residual activity was measured. In addition, an evaluation of the decontamination efficacy of the Orion™ SC was performed both 7 and 30 days following application of the contaminant to the coupons. Results include the decontamination efficacies, a comparison of the decontamination efficacy between the vertical and horizontal surfaces, and a comparison between the 7-day and 30-day results. Important deployment and operational factors were also documented and reported. A summary of the evaluation results for the Orion™ SC is presented below for each performance parameter. Discussion of the observed performance can be found in Section 5 of this report.

Decontamination Efficacy: The decontamination efficacy, expressed as percent removal, %R, attained by the Orion™ SC was evaluated on separate concrete surfaces after 7 days and 30 days following the contamination of the coupons. Overall, the Orion™ SC decontaminated the concrete coupons with an average %R of 76.2 ± 7.4. The %Rs from the vertical and horizontal surfaces were determined to be not significantly different from one another. In addition, the %Rs between the 7-day and 30- day tests were also determined to be not significantly different from one another. The only factor that did seem to have a statistically significant impact on the performance of the Orion™ SC was coupon placement near the edge of the vertical surface. These coupons were shown to be slightly less efficiently decontaminated than those placed vertically among other coupons (i.e., not on the edge). This difference was likely due to differences in the application technique near the edge and not due to a deficiency in the Orion™ SC. In each of the three Orion™ SC application and removal cycles, 72%–92% of the Cs-137 was removed during the first application cycle.

Deployment and Operational Factors: Following the manufacturer's recommendations, the Orion™ SC was mixed from two concentrates to make a coating the consistency of wall paint. The Orion™ SC was applied to the surfaces with an airless paint sprayer. The surfaces had an area of 1.1 m^2 and each application coat took less than one minute. The objective was to attain a layer of paint-like coating approximately 40 mils thick. Because coating thickness was not measured, a qualitative guideline was followed. The coating was applied thick enough to cover the surface, but not so thick that the coating ran down the wall. Isotron recommended that three coats be applied with a 5 minute wait between each coat. Following application, the coating dried overnight and was removed using a paint scraper. First, coupon edges were scored. Scoring allowed the coating on each coupon to be loosened before it was pulled off. In most cases, the Orion™ SC coating was removed one coupon at a time without much removal across the border (a distance of approximately 0.3–0.7 cm) between coupons. The Orion™ SC removal rate was 1.6 m^2 per hour, the rate of waste generation (removed coating) was 0.5 kg/m^2, and the volume of the waste was, on average, 0.188 g/cm^3. Cured Orion™ SC formed flat, flaky, skin-like pieces; the inelastic coating tore easily.

This evaluation showed that the rate of decontamination will depend primarily on the surface finish or texture of the concrete. Large, smooth surfaces would permit faster removal than smaller surfaces. In addition, rough or jagged surfaces are likely to increase removal times because the Orion™ SC might tear and come off in small pieces. A limited evaluation of cross-contamination was performed and the results confirmed that cross-contamination did occur to a small extent. If there was any damage to the surface of the concrete caused by the Orion™ SC, it was not visible to the naked eye.

Conclusion: The Orion™ SC removed approximately 76% of the Cs-137 from unpainted concrete coupons placed together to form concrete surfaces with both horizontal and vertical orientations. The Orion™ SC worked equally well in either orientation and after both 7 and 30 days following the application of Cs-137 to the concrete coupons. The removal rate of Orion™ SC will likely be dependent on the characteristics of the surface being decontaminated as some scraping is required for removal.

1.0 Introduction

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, NHSRC is working to develop tools and information that will help detect the intentional introduction of chemical or biological contaminants in build-ings or water systems, the containment of these contaminants, the decontamination of buildings and/or water systems, and the disposal of material resulting from cleanups.

NHSRC's 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 the 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 evaluation design so that useful performance information is produced for each of the evaluated technologies.

Under TTEP, Battelle recently evaluated the performance of the Isotron Orion™ strippable coating (Orion™ SC) in decontaminating the radioactive isotope Cs-137 from concrete. This evaluation was conducted according to a peer-reviewed test/QA plan[1] that was developed according to the requirements of the quality management plan (QMP) for TTEP.[2] The following performance characteristics of Orion™ SC were evaluated:

- Decontamination efficacy defined as the extent of radionuclide removal following application and removal| of the Orion™ SC.
- 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; the possibility of cross-contamination; and the cost of using the Orion™ SC.

This evaluation took place from December 10, 2007 until January 21, 2008. All of the experimental work took place at U.S. Department of Energy's Idaho National Laboratory (INL). This report describes the quantitative results and qualitative observations gathered during this evaluation of the Orion™ SC. Quality Assurance oversight of this evaluation was provided by Battelle, INL, and EPA. Under the direction of the Battelle QA Manager, INL QA staff conducted a technical systems audit (TSA) during the evaluation. The Battelle QA Manager conducted a data quality audit of all evaluation data.

2.0
Technology Description

This technology evaluation report provides results on the performance of the Orion™ SC under laboratory conditions. Following is a description of the Orion™ SC, based on unverified information provided by Isotron Corp. (Seattle, Washington).

Isotron's Orion™ SC is a non-toxic, strippable coating designed for the decontamination of cesium and cobalt radionuclides, and intended for use following a radiological dispersion device (RDD) event in an urban environment, as well as other radiological decontamination applications (such as decontamination and decommissioning (D&D) activities at DOE and commercial nuclear facilities). The Orion™ SC extracts contaminants from the subsurface of porous materials through a binding agent and physically through encapsulation of the radionuclides into the cured coating. Orion™ SC is sold as a two-part concentrate that requires mixing with water. Consequently, the Orion™ SC is applied like paint; therefore, a brush, roller, or sprayer are all application options. The target thickness during application is 40 mils. Following application, the coating requires approximately 6 hours to cure prior to removal. Peeling the coating removes contamination from the substrate surface, producing a low volume, solid waste.

The left photograph in Figure 2-1 illustrates preparation of the paint-like formulation from concentrates and water. The middle photo shows application of the Orion™ SC to the concrete coupon surfaces. The coating is then removed, as shown to the right.

Figure 2-1. Preparation (left), Application (middle), and Removal of the Orion™ SC (right)

3.0 Experimental Details

3.1 Experimental Preparation

3.1.1 Concrete Coupons

The concrete coupons were prepared from a single batch of concrete made from Type II Portland cement[3]. Table 3-1 lists data provided by the ready-mix vendor about the cement clinker used in the concrete mix. The ASTM C150[3] requirement for Type II Portland cement specifies that tricalcium aluminate 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. The maximum allowable tricalcium aluminum content for Type I is 15%, so the cement used during this evaluation met the specifications for both Type I and II Portland cements.

Table 3-1. Characteristics of the Portland Cement Clinker

Cement Constituent	Percent of Mixture
Tricalcium Silicate	57.6
Dicalcium Silicate	21.1
Tricalcium Aluminate	4.5
Tetracalcium Aluminoferrite	8.7
Minor constituents	8.1

The wet concrete was poured into 0.9 meter (m) square plywood forms with the surface exposed. The concrete surface was "floated" to get the smaller aggregate and cement paste to rise to the top and then cured for 21 days. Following curing, the squares were cut to the desired size with a laser guided rock saw. For this evaluation, the "floated" surface of the concrete coupons was used. The coupons were approximately 4 centimeters (cm) thick, 15 cm square, and had a surface finish that was consistent across all the coupons and representative of exterior concrete commonly found in urban environments in the U.S. 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[4].

3.1.2 Coupon Contamination

Each contaminated coupon was spiked with 2.5 milliliters (mL) of unbuffered, slightly acidic aqueous solution containing 137 milligrams (mg)/liter (L) Cs-137 corresponding to an activity level of approximately 53 µCi over the 225 cm^2 surface. Application of the cesium in an aqueous solution was justified because even if cesium were dispersed in a particle form following an RDD event, morning dew or rainfall would likely occur before the surfaces could be decontaminated. In addition, the ability to apply liquids homogeneously across the surface of the concrete coupons greatly exceeds that for particles.

The liquid spike was delivered to each coupon using an aerosolization technique developed by INL under the DARPA/DHS project[4] and described in detail in the test/QA plan[1]. The aerosol delivery device was constructed of two syringes. The first syringe had the plunger removed and a nitrogen gas line was attached to the rear of the syringe. The second syringe contained the contaminant spiking solution and was equipped with a 27 gauge needle which penetrated through the plastic housing near the tip of the first syringe. Nitrogen gas was turned on at a flow of approximately 1 - 2 liters per minute creating a turbulent flow through the first syringe. The liquid spike in the second syringe was introduced and became nebulized by the turbulent gas 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. Coupon edges were taped and sealed with epoxy to ensure that the contaminant was applied only to the surfaces. Contaminant was sprayed to the edges of the coupons.

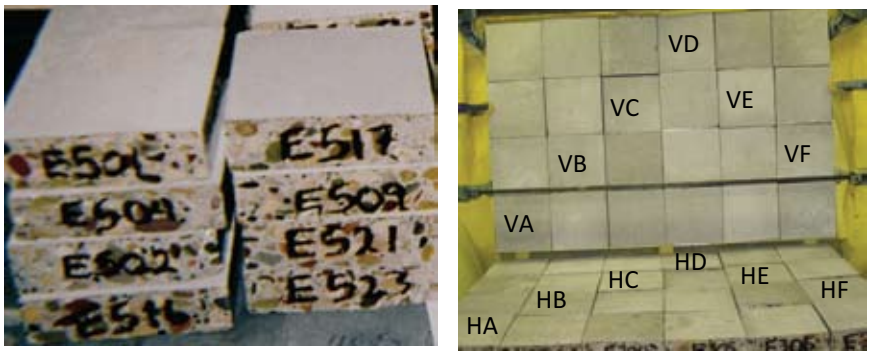
3.1.3 Measurement of Activity on Coupon Surface

Measurement of gamma radiation from the surface of concrete coupons was used to quantify contamination levels before and after application of the strippable coating. These measurements were made using one of three identical intrinsic, high purity germanium detectors following contamination and after application of the Orion™ SC. After being placed into the detector, each coupon was measured until the average activity level of Cs-137 from the surface stabilized to a relative standard deviation of less than 2%. Gamma-ray spectra, acquired from Cs-137 spiked coupons, were analyzed using the INL Radiological Measurement Laboratory (RML) data acquisition and spectral analysis programs. Radionuclide activities on coupons were calculated based on the efficiency, emission probability, and half-life values. Decay corrections were made based on reference time and date, and the duration of the counting period. Full RML gamma counting QA/Quality Control (QC), as described in the test/QA plan, was employed and certified results were provided.

3.1.4 Surface Construction Using Test Stand

To evaluate the decontamination technologies on vertical surfaces (simulating walls) as well as horizontal surfaces (simulating sidewalks and drives), a test stand was fabricated that held four rows of six concrete coupons to create surfaces that were approximately 90 cm wide × 60 cm deep (horizontal) or tall (vertical). Six of the 24 coupons used to construct each surface were contaminated with Cs-137. Figure 3-1 shows a picture of several concrete coupons and a test stand loaded with the concrete coupons. After the coupons were contaminated with Cs-137, some were

Figure 3-1. Concrete Coupons (left) and Test Stand With the Contaminated Coupons Labeled "V" for Vertical and "H" for Horizontal (right)



allowed to age for 7 days and some for 30 days prior to their placement in the test stand for application and removal of the Orion™ SC. The two different time frames were used to evaluate the effectiveness of decontamination technologies within one week of a radiological incident and also within one month. Within the surfaces on the test stand, the six contaminated coupons were arranged so there was one coupon on each side edge, one on the top edge, and several not on an edge.

Figure 3-1 shows the pattern of contaminated coupons on each surface. The coupon codes indicate the orientation of each coupon (H for horizontal and V for vertical) as well as the location within the surface (position A–E). The top surfaces of the coupons were not labeled during the evaluation.

3.2 Evaluation of the Orion™ SC

3.2.1 Application of the Orion™ SC

The decontamination process was begun 7 days (7-day test) following the application of the Cs-137 to the concrete coupons. However, because the vendor, Isotron, recommends multiple applications and removals of the Orion™ SC, three application and removal cycles were completed before the final measurement of residual activity was made. To summarize the timeline, the 7-day coupons were contaminated on December 3 and then included in the construction of the vertical and horizontal surfaces on the test stand. The first application of the Orion™ SC was made to the surfaces on December 10 and allowed to dry overnight. The first removal of the Orion™ SC was performed on December 11, the second application/removal cycle was performed on December 11 and 12, and the final application/removal cycle was performed on December 12 and 13.

Therefore, the final removal of the Orion™ SC was performed 10 days following application of the Cs-137 to the coupons. In a similar way, the 30-day coupons were contaminated on December 17 and the first of three applications of the Orion™ SC was performed on January 16 and completed over the next several days. Following the final removal of the Orion™ SC, the contaminated coupons were removed from the surfaces and residual activity was measured.

The temperature and relative humidity were recorded during both the 7-day and 30-day tests. These conditions did not vary significantly in the laboratory where the coupons were stored and the evaluation was performed. Over the duration of testing, the temperature was always within the range of 23–26°C and the relative humidity was always within the range of 11–17%.

3.2.2 Progressive Decontamination Efficacy With Each Application of Orion™ SC

The focus of this evaluation was determining the overall decontamination efficacy of the Orion™ SC following Isotron's recommended procedures. Those procedures called for the Orion™ SC to be applied and removed three times before measurement of the residual activity. However, as a side experiment during the evaluation, a few coupons were measured following each application and removal of Orion™ SC to determine the degree of decontamination that occurred with each application and removal of the Orion™ SC. The progressive decontamination efficacy was determined using two and three coupons and for the 7- and 30-day tests, respectively. Only two coupons were analyzed for the 7-day test because of the limited availability of contaminated coupons. The first 7-day coupon, labeled "HA" in Figure 3-1, was removed from the surface and transported to the RML for counting; the second 7-day coupon and all of the 30-day coupons were contaminated as extras in case of accidental breakage.These coupons were set in a horizontal orientation to the side of the test stand and the Orion™ SC was applied and removed as for the rest of the coupons on the test stand. These coupons were transported to the RML for activity measurement four times, once upon application of Cs-137 and once following each of three applications and removals of Orion™ SC.

4.0
Quality Assurance/Quality Control

QA/quality control (QC) procedures were performed in accordance with the program QMP[2] and the test/QA plan[1] for this evaluation.

4.1 Intrinsic Germanium Detector

Calibrations of intrinsic, high purity germanium detectors were established using standardized procedures from American National Standards Institute and the Institute of Electrical and Electronics Engineers[5]. 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). This calibration was performed weekly and documented by the RML. Table 4-1 shows the results of the calibrations by giving the difference between the known energy levels and those measured following calibration. The energies were compared to the previous 30 calibrations. The operator was alerted if the results exceeded three standard deviations of the other calibration results. The calibrations are shown for each of the three detectors used during this evaluation. None of these calibrations exceeded that threshold.

For each measurement of activity on each coupon, gamma ray counting was continued until the activity level of Cs-137 on the surface had a relative standard deviation of less than 2%. The final activity assigned to that coupon was a compilation of information obtained from all components of the electronic assemblage, which comprised the "gamma counter," including the raw data and the spectral analysis conducted by the spectroscopist using an INL data analysis program. Final spectra and all data which comprised the spectra were sent to a data analyst who independently confirmed the "activity" number determined by the spectroscopist. When both the spectroscopist and an expert data analyst independently arrived at the same number, then the data were certified. This entire process defines the full gamma counting QA process for certified results.

The background activity of the concrete coupons was determined by the analysis of ten arbitrarily selected coupons from the stock of concrete coupons. The ambient activity level of these coupons was measured for two hours and the activity for all of the coupons was determined to be below the minimum detectable level of 2×10^{-4} µCi. Because the background activity was not detectable, and the detectable level was more than 5,000 times lower than the post-decontamination activity levels, no background subtraction was required.

Throughout the evaluation, 12 contaminated coupons were measured as duplicates. Four duplicate analyses each were completed for three sample sets including coupons that had been contaminated, coupons decontaminated during the 7-day test, and coupons decontaminated during the 30-day test. Three of the duplicate samples showed no difference from the original measurement, while the average percent difference between the original and duplicate measurements was 0.71%, within the acceptable difference of 3%.

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

		Calibration Energy Levels in keV				
Date	Detector	Energy 1 238.632	Energy 2 583.191	Energy 3 860.564	Energy 4 1620.735	Energy 5 2614.511
11-6-2007	1	-0.002	0.008	-0.004	-0.206	0.022
	4	-0.004	0.022	-0.119	-0.028	0.013
	5	-0.002	0.007	-0.006	-0.193	0.019
12-3-2007	1	0.000	0.002	-0.025	0.028	-0.001
	4	-0.006	0.022	-0.076	-0.170	0.034
12-11-2007	1	-0.002	0.008	-0.040	-0.108	0.011
	4	-0.004	0.014	-0.041	-0.194	0.025
12-18-2007	1	-0.003	0.012	-0.026	-0.273	0.028
	4	-0.003	0.013	-0.063	-0.135	0.018
1-15-2008	1	-0.003	0.012	-0.042	-0.190	0.022
	4	-0.004	0.018	-0.069	-0.211	0.024
1-22-2008	1	-0.006	0.022	-0.022	-0.390	0.055
	4	-0.003	0.011	-0.032	-0.169	0.021

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

Date	Detector	NIST Activity (BQ)	INL RML Result (BQ)	Difference
11-11-2007	4	124,600	130,300	5%
11-13-2007	1	124,600	122,900	1%
	5	124,600	124,700	0%
12-11-2007	1	124,600	122,400	2%
	4	124,600	128,900	3%
1-15-2008	1	124,600	122,000	2%
	4	124,600	129,300	4%

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 NIST-traceable Eu-152 standard (in units of Bequerel, BQ) and comparing it 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 quality control activity performed by INL. For the purposes of this evaluation, the calibration serves as the performance evaluation (PE) audit that confirms the accuracy of the calibration standards used for the instrumentation critical to the results of our evaluation. Table 4-2 gives the results of each of these audits for each detector that was used during this evaluation. All results are within the acceptable difference of 7%.

4.2.2 Technical Systems Audit

A technical systems audit was conducted during testing at INL to ensure that the evaluation was performed in accordance with the test/QA plan[1] and the TTEP QMP[2] As part of the audit, the actual evaluation procedures were compared with those specified in the test/QA plan[1]. In addition, the data acquisition and handling procedures were reviewed. No significant adverse findings were noted in this audit. The records concerning the TSA are stored indefinitely with the Battelle Quality Assurance Manager.

One deviation from the test/QA plan occurred during this evaluation. The contaminant application was done using 2.5 mL of solution rather than 0.25 mL in order to better cover the concrete coupon.

4.2.3 Data Quality Audit

At least 10% of the data acquired during the evaluation were audited. The Battelle Quality Assurance Manager traced the data from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

4.3 QA/QC Reporting

Each assessment and audit was documented in accordance with the test/QA plan[1] and the QMP.[2] Once the assessment report was prepared by the Battelle Quality Assurance Manager, it was routed to the Test Coordinator and Battelle TTEP Program Manager for review and approval. The Battelle Quality Assurance Manager then distributed the final assessment report to the EPA Quality Manager and Battelle staff.

One test/QA plan deviation occurred during this evaluation. Instead of a 0.25 mL volume of cesium spiking solution as was stated in the test/QA plan, a 2.5 mL volume was used in order to attain a more homogeneous coverage across each coupon. The evaluation was not negatively impacted.

5.0 Evaluation Results

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 Orion™ SC and Af is the radiological activity from the surface of the coupon after removal of the strippable coating. The DFs are reported in the following data tables, but for the sake of brevity, the narrative describing the results will focus on the %R.

The following sections describe the performance of the Orion™ SC 7 and 30 days after contaminant application and on horizontal and vertical surfaces. Throughout the evaluation, Microsoft® Excel was used to perform paired t-tests in order to determine if significant differences existed within the data set. In all cases, the t-tests were two-tailed and were conducted at the 95% confidence interval.

5.1.1 7-Day Decontamination Efficacy Results

Table 5-1 gives the %R and DF for the Orion™ SC after a 7-day time period between coupon contamination and use of the Orion™ SC. The coupon codes indicate the orientation of each coupon (H for horizontal and V for vertical) as well as the location within the surface (position A–E) as illustrated in Figure 3-1. The target activity for each of the contaminated coupons (pre-decontamination) was within the acceptable range of 53 µCi ± 5.3 µCi. The average (plus or minus one standard deviation) of the contaminated coupons was 55.7 µCi ± 1.3 µCi for the horizontal surface, 53.6 µCi ± 1.5 µCi for the vertical surface, and 54.5 µCi ± 1.7 µCi overall. There was a variability of 3% across all the coupons on both surfaces.

Evaluating the Orion™ SC in the horizontal and the vertical orientations was an important objective for this evaluation. Because the Orion™ SC is applied as a liquid, the evaluation sought to find out if the coating adhered adequately to the wall to accomplish decontamination with similar efficacies as in the horizontal orientation. Post-decontamination coupon activities were significantly less than pre-decontamination activities.

For the horizontal and vertical surfaces, the %Rs (defined in Section 5.1) were 79.7 ± 4.1 and 77.5 ± 5.2, respectively. These were determined to be not significantly different as determined by paired t-test analysis (p=0.51), indicating that the decontamination efficacy of the Orion™ SC in the horizontal and vertical orientations was similar. The overall average %R for the 7-day test was 78.6 ± 4.6.

The contaminated coupons were placed at various locations across the surface and various paired t-tests were performed

Table 5-1. 7-Day Decontamination Efficacy Results

	Coupon Code	Pre-Decon Activity µCi / Coupon	Post-Decon Activity µCi / Coupon	%R	DF
Horizontal	HA	55.6	15.2	72.7	3.7
	HB	56.0	11.8	78.9	4.7
	HC	55.9	9.5	82.9	5.9
	HD	57.5	9.2	83.9	6.2
	HE	53.4	9.9	81.5	5.4
	HF	55.6	12.1	78.2	4.6
	Avg	55.7	11.3	79.7	5.1
	SD	1.3	2.3	4.1	0.9
Vertical	VA	55.6	12.2	78.1	4.6
	VB	54.8	10.4	81.0	5.3
	VC	52.4	9.1	82.6	5.8
	VD	51.9	16.7	67.8	3.1
	VE	54.5	11.7	78.5	4.7
	VF	52.5	12.0	77.1	4.4
	Avg	53.6	12.0	77.5	4.6
	SD	1.5	2.6	5.2	0.9
Overall	**Avg**	**54.6**	**11.7**	**78.6**	**4.9**
	SD	**1.7**	**2.3**	**4.6**	**0.9**

to see whether or not location on the surface impacted the decontamination efficacy. Within the 7-day coupons, those on the edge (horizontally and/or vertically) of the surfaces were compared with those not on the edges to see if significant differences existed. During the 7-day test, no such differences were identified, therefore, the Orion™ SC performed equally on the vertical and horizontal surfaces whether the coupons were located on an edge or not.

5.1.2 30-Day Decontamination Efficacy Results

Table 5-2 gives the %R and DF for the Orion™ SC after a 30-day period between contaminant application and use of the Orion™ SC. As with the 7-day results, the target activity for each of the contaminated coupons (pre-decontamination) was within the acceptable range of 53 µCi ± 5.3 µCi. The overall average (plus or minus one standard deviation) of the contaminated coupons was 53.6 µCi ± 1.8 µCi for the horizontal surface, 53.3 µCi ± 1.9 µCi for the vertical surface, and 53.5 µCi ± 1.8 µCi across all the coupons in both surfaces, a variability of 3%.

The post-decontamination coupon activities were significantly less than the pre-decontamination activities. For the horizontal and vertical surfaces respectively, the %Rs (defined in Section 5.1) were 76.2 ± 11.2 and 71.5 ± 6.3. These were determined to be not significantly different by a paired t-test analysis (p=0.50), indicating that the decontamination efficacy of the Orion™ SC in the horizontal and vertical orientations was similar. The overall average %R for the 30-day test was 73.8 ± 9.0.

As with the 7-day coupons, the contaminated coupons included on the surfaces were placed at various locations across the surface and various paired t-tests were performed to determine if location within the surface impacted the decontamination efficacy. Within the 30-day coupons, those on the edge of the surfaces were compared with those not on the edges to see if significant differences existed. During the 30-day test, the three coupons that were oriented vertically on the edge (VA, VD, and VF) had an average %R of 66.6 ± 4.3 while the three that were placed vertically not on the edge (i.e., they were surrounded by other coupons) (VB, VC, and VE) had an average %R of 76.3 ± 3.3. A paired t-test showed these two averages to be significantly different from one another at the 95% confidence interval (p=0.021). An experimental plan designed to explore this issue would be required to determine what may have caused this small difference.

5.1.3 Comparison of 7-Day and 30-Day Decontamination Efficacy

Given there were no significant differences determined between the horizontal and vertical surfaces during the 7-day or 30-day tests, the overall average %Rs can be compared to determine if the Orion™ SC performed differently during the two sets of experiments. The overall average %Rs for the 7-day and 30-day tests were 78.6 ± 4.6 and 73.8 ± 9.0, respectively, suggesting that the increased time of the contaminant binding to the concrete surface caused a slightly decreased %R. However, a paired t-test determined that these two averages were not significantly different from

Table 5-2. 30-Day Decontamination Efficacy Results

	Coupon Code	Pre-Decon Activity µCi / Coupon	Post-Decon Activity µCi / Coupon	%R	DF
Horizontal	HA	52.5	12.4	76.4	4.2
	HB	54.3	10.6	80.5	5.1
	HC	56.4	25.6	54.6	2.2
	HD	51.9	8.0	84.6	6.5
	HE	51.8	12.2	76.4	4.2
	HF	54.8	8.5	84.5	6.5
	Avg	53.6	12.9	76.2	4.8
	SD	1.8	6.5	11.2	1.6
Vertical	VA	55.2	20.1	63.6	2.7
	VB	54.7	14.9	72.8	3.7
	VC	51.7	10.8	79.1	4.8
	VD	51.5	14.7	71.5	3.5
	VE	51.7	11.8	77.2	4.4
	VF	55.2	19.5	64.7	2.8
	Avg	53.3	15.3	71.5	3.7
	SD	1.9	3.8	6.3	0.8
Overall	**Avg**	**53.5**	**14.1**	**73.8**	**4.2**
	SD	**1.8**	**5.2**	**9.0**	**1.4**

Table 5-3. Decontamination Efficacy With Each Application of Orion™ SC

Test	Orion™ SC Application[a]	Activity µCi / Coupon	Total %R	%R Each Application	% of Total Removal
7-Day	Pre-decon	55.6	NA[b]	NA	NA
	#1	21.9	60.6	60.6	83.4%
	#2	17.1	69.2	8.6	11.9%
	#3	15.2	72.7	3.4	4.7%
	Pre-decon	61.8	NA	NA	NA
	#1	13.1	78.8	78.8	91.6%
	#2	9.68	84.3	5.5	6.4%
	#3	8.61	86.1	1.7	2.0%
30-Day	Pre-decon	56.5	NA	NA	NA
	#1	22.9	59.5	59.5	81.2%
	#2	17.4	69.2	9.7	13.3%
	#3	15.1	73.3	4.1	5.5%
	Pre-decon	55.0	NA	NA	NA
	#1	29.2	46.9	46.9	72.5%
	#2	22.0	60.0	13.1	20.2%
	#3	19.4	64.7	4.7	7.3%
	Pre-decon	54.1	NA	NA	NA
	#1	19.3	64.3	64.3	81.3%
	#2	13.4	75.2	10.9	13.8%
	#3	11.3	79.1	3.9	4.9%

[a] For the 7-day test, one of the coupons was the "HA" coupon that was removed for counting, all the other coupons were not a part of either surface, but were contaminated like the others and placed horizontally alongside the test stand. The Orion™ SC was applied as usual.

[b] Not applicable as this was the initial measurement of activity.

one another at the 95% confidence interval (p=0.12). This difference is not significant because the standard deviations of the post-decontamination activity measurements across several coupons increased significantly compared with the pre-decontamination measurement of activity across the same coupons. This increase indicates the somewhat variable efficacy of the Orion™ SC in removing Cs-137 from the surface of the concrete.

In addition to the comparison of overall average, various paired t-tests were performed, including data from both the 7-day and 30-day tests to allow observation of whether or not location on the surface impacted the decontamination efficacy. The increased number of data points improved statistical power in determining significant differences in the data. Thus, all of the vertical and horizontal coupons, edge and non-edge, from both tests were compared to determine if significant differences existed. Out of these analyses, one t-test comparison generated a significant difference. The comparison included the results from the 7-day and 30-day vertical coupons on the edge of the surface versus the 7-day and 30-day vertical coupons not on the edge of the surface. Those groups of coupons had average %Rs of 70.5 ± 6.2 and 78.5 ± 3.4, respectively, which were determined to be significantly different from one another at the 95% confidence interval (p=0.013). This difference suggested that over both testing time periods, the coupons on the edge of the vertical surface were decontaminated slightly less effectively than those not on the edge of the vertical surface, which is consistent with the result determined during the 30-day test.

5.1.4 Progressive Decontamination Efficacy With Each Application of Orion™ SC

As described previously, the use of the Orion™ SC followed the procedures recommended by Isotron (i.e., three successive applications and removals). Therefore, a few coupons were measured after each application/removal cycle to determine the level of decontamination with each cycle. Table 5-3 shows the results from each measurement of activity starting with the initial measurement prior to the first application and removal of Orion™ SC through three successive applications and removals of the Orion™ SC. Table 5-3 also shows the total %R (additive across applications), the %R attributed to each successive application, and the percent of total removal attributable to each application cycle. For example, of the 72.7 %R that was attained for the first 7-day coupon, 60.9% was attained

with the first application. Overall, the first application corresponded to 83.4% of the total removal from that coupon.

The results indicated that most of the decontamination occurs with the first application and removal cycle of the Orion™ SC. While only five coupons were tested in this fashion, the results were consistent. The percent of total removal during the first cycle of application and removal of the Orion™ SC ranged from 72 to 92%, from 6% to 20% for the second cycle, and from 2% to 7% for the third and final cycle. An experimental design more focused on this aspect of the Orion™ SC's performance would be required to draw additional conclusions.

5.2 Deployment and Operational Factors

5.2.1 Description of Application

The Orion™ SC was provided as two concentrates called "Part A" and "Part B." Part A (2,200 g) was combined with Part B (550 g) along with 100 mL of water. The final product was white and had a consistency similar to paint. Prior to the application of the Orion™ SC, a Graco Magnum™ XR7 sprayer, with a Graco 417 tip obtained at a home improvement store, was primed with the wet Orion™ SC as directed by the manufacturer's instructions. The sprayer was provided by Isotron Corp. for this evaluation. Any commercially available, airless paint sprayer with similar specifications could be used. The sprayer manufacturer's operating instructions should be followed.

The Orion™ SC was applied to the concrete coupon surfaces. There was no calibrated pressure indicator. The maximum pressure of this sprayer was 3,000 pounds per square inch (psi) and the spray pattern that produced an even, covering coating with no significant runs occurred when the pressure was adjusted to the maximum and then the knob turned back approximately one-quarter of a turn.

The Orion™ SC was applied in three coats. We examined each coat to see that it covered the vertical surface of the concrete coupon but did not buildup and run. Spray application to the horizontal and vertical surfaces took approximately 1 minute. After the first and second coats, the sprayer operator paused for approximately 5 minutes, then added another coat. An average of 1.4 L of wet Orion™ SC was applied with each application to the 1.1 m^2 surfaces. Figure 5-1 shows a picture of the Orion™ SC freshly applied to the vertical surface and then again following the overnight drying time. Note that the running of coating from a few coupons had occurred.

Figure 5-1. Orion™ SC After Application (left) and After Drying Overnight (right)

Figure 5-2. Orion™ SC Removal

5.2.2 Description of Removal

The removal of Orion™ SC was done following the overnight drying, which hardened the Orion™ SC into a rigid surface. The Orion™ SC was removed mostly one coupon at a time using a paint scraper to score the edge of the coupon and free the coating from the surface. Then the loose coating was torn from the surface. Figure 5-2 shows the removal process. The total amount of dried coating removed from the surface was collected in a tared bag and weighed. The time to remove the Orion™ SC from the two surfaces (totaling 1.1 m^2) ranged from 30–52 minutes for an average rate of removal of 1.6 m^2/hour. The ease of removal depended on the thickness of the coating.

For example, during the first 30-day application and removal, a much thinner coating had been applied because too much water had inadvertently been added when mixing the concentrates. Therefore, a thinner consistency and thus, a thinner layer of coating was the result. This thin application caused the dried coating to be brittle and flaky, making the removal more labor intensive, thus taking longer (52 minutes). However, as Table 5-2 shows, the change in amount of water did not seem to negatively impact the removal of Cs-137 from the surface.

The coating was removed from one coupon at a time, with the coating breaking at the border of the coupons. The technicians noted that had a large, flat surface been used rather than a surface made of discrete coupons, a larger scraper could have been used to remove larger pieces of dried coating.

5.2.3 Miscellaneous Operational Information and Data

Table 5-4 includes important operational parameters such as the time required to apply and remove the coating, required skill level of the operator, portability of the technology, estimated cost, required utilities, and cross-contamination concerns.

Orion™ SC was applied to relatively small surfaces (1.1 m^2) that were built with concrete coupons. Therefore, some of the information given in Table 5-4 could differ if the Orion™ SC was applied to larger surfaces or surfaces that were either more smooth or more rough and jagged.

The amount of time required to apply the Orion™ SC probably will not be the limiting rate step because use of a paint sprayer is efficient. In addition, the paint sprayer can be used on a wide variety of regularly or irregularly shaped surfaces. The technicians observed that the rate of removal of the cured coating will depend heavily on the surface characteristics of the concrete.

For example, the Orion™ SC had to be removed one coupon at a time because the cured coating tended to break at the edges of the concrete coupons. Prior to the Orion™ SC being removed, the edge needed to be scored and the removal process started over again, rather than being a continuation of a similar process on the same surface.

Therefore, the removal rate might be higher for larger, continuous surfaces. Similarly, the removal rate might also depend on the smoothness of the surfaces. The Orion™ SC needed to be scraped from the surface of the concrete, so the cured coating fractured at the edges of the coupons. Removing the Orion™ SC from rough concrete would be labor intensive because the coating comes off in small pieces.

One important aspect of the shelf-life of the Orion™ SC was observed as part of this evaluation. The Orion™ SC concentrates were shipped to INL from Isotron. At some point during shipment, the concentrates froze and then thawed by the time of arrival at INL. The freeze/thaw cycle caused the Orion™ SC to solidify within the sprayer pump and tubing, preventing its application to the surface. Following that incident, Isotron shipped the Orion™ SC using a qualified shipper to ensure that the Orion™ SC did not freeze en route. Isotron recommends that Orion™ SC be stored within a temperature range of 15.6–26.7°C.

Cross-contamination of radionuclides during application and removal of Orion™ SC is an operational aspect that was considered to a minimal extent during this evaluation. As has been described, six coupons from each surface had been contaminated prior to the construction of the surfaces. The other coupons had not been contaminated and, upon placement into the test stand, indicated extremely low background levels of activity when measured with a qualitative gamma counter. When all of the coupons were removed from the test stand following the three application

Table 5-4. Operational Factors Gathered From the Evaluation

Parameter	Description/Information
Factors affecting decontamination rate	Coating Preparation: 10 minutes to mix concentrates and 20 minutes to prime pump. Application: three 1-minute applications 5 minutes apart; equaling 13 minutes, for an average of 1.4 L applied to 1.1 m^2 Drying time: overnight Removal rate: 1.6 m^2/hour
Applicability to irregular surfaces	Application to more irregular surfaces than those encountered during this evaluation would not seem to be much of a problem because a sprayer is able to reach most types of surfaces; however, removal from irregular surfaces might be more labor intensive. The technicians observed that the Orion™ SC had to be removed coupon by coupon; therefore, if the coupons were much larger, the removal might go more quickly. If the surface was rough, removal of the Orion™ SC might become difficult because the cured coating would be likely to come off in small pieces.
Skilled labor requirement	After a brief training session, and time to acclimate to using a paint sprayer, most able-bodied people could successfully perform both the application and removal procedures.
Utilities requirement	A paint sprayer generally requires 110 volt power. However, the Orion™ SC can also be applied with a roller or brush, eliminating the need for a separate power source.
Extent of portability	With the exception of extreme cold, which would prevent the application of the water-based Orion™ SC, its portability seems limitless.
Shelf life of media	The Orion™ SC concentrates were shipped to INL from Isotron. The concentrates froze at some point during the shipment and thawed by the time of arrival at INL. The freeze/thaw cycle caused the Orion™ SC to solidify within the sprayer pump and tubing. Isotron sent another batch of concentrates, using a qualified shipper to ensure that the coating did not freeze. The recommended storage temperature for Orion™ SC is 15.6–26.7°C.
Secondary waste management	Solid waste production: ~0.5 kg/m^2 Solid waste volume: ~0.188 g/cm^3 The coating was usually removed from concrete coupons one coupon at a time. However, if there had been larger continuous surfaces, the pieces might have been larger because the cured coating usually tore at the border of the coupons. Cured Orion™ SC formed flat, flaky, skin-like pieces; the coating was not elastic, so it tended to tear easily.
Surface damage	No damage was visible to the eye; some loose particles could be seen stuck to the coating.
Cost	$46.23/L corresponding to $58.84/$m^2$ for one application. Isotron suggests three applications, equaling $176.51/$m^2$, not including the cost of a paint sprayer.

and removal cycles of Orion™ SC for both the 7-day and 30-day tests, the non-contaminated coupons indicated a activity level (again using the qualitative gamma counter) that was higher than background. While the study of cross-contamination was not a focus of the evaluation, the activity from a few of the non-contaminated coupons was quantitatively measured. Over the 7-day and 30-day tests, the residual activity of ten non-contaminated coupons ranged from 0.00028 µCi–0.0042 µCi and had an average activity of 0.0014 µCi ± 0.0014 µCi. As this was not a focus of the evaluation, the proper controls were not in place to thoroughly investigate the observed cross-contamination. The possibility exists that cross-contamination occurred during the construction of the surfaces on the test stand and might be independent of Orion™ SC.

6.0 Performance Summary

Summary results from evaluation of the Orion™ SC are presented below for each performance parameter evaluated. Discussion of the observed performance can be found in Section 5 of this report.

6.1 Decontamination Efficacy

The Orion™ SC was evaluated by contaminating concrete coupons that were approximately 4 cm thick and 15 cm square with Cs-137 at a level of 53 µCi (measured by gamma spectroscopy) and placing them at edge and non-edge locations within a vertical and horizontal surface built on a test stand containing 24 of these coupons. The Orion™ SC was applied and removed three times before the residual activity was measured.

The decontamination efficacy attained by the Orion™ SC was evaluated on separate test stands after both 7 days and 30 days following the contamination of the coupons. Overall, the Orion™ SC decontaminated the concrete coupons with an average %R of 76.2 $\pm$ 7.4. The %Rs from the vertical and horizontal surfaces were determined to be not significantly different from one another. In addition, the %Rs between the 7-day and 30- day tests were also determined to be not significantly different from one another.

The only factor that did seem to have a statistically significant impact on the performance of the Orion™ SC was if the coupons were placed on the edge of the vertical surface. These coupons were shown to be slightly less efficiently decontaminated than those that were placed vertically among other coupons (i.e., not on the edge). The cause of this difference is likely due to differences in the application technique near the edge as opposed to being due to a deficiency in the Orion™ SC. In addition, a brief investigation of how much of the Cs-137 removal takes place upon successive Orion™ SC applications suggested that 72% – 92% of the removed Cs-137 is removed during the first application and removal of the Orion™ SC.

6.2 Deployment and Operational Factors

The Orion™ SC was mixed from two concentrates to make a coating with the consistency similar to wall paint. Then, the coating was applied to the surfaces with an airless paint sprayer. The surfaces used during this evaluation had an area of 1.1 m^2 and each coat took less than one minute to apply. The objective of application was to attain a layer of "paint-like" coating thick enough to cover by visual inspection, but not too thick that the coating ran down the wall. Isotron recommended that three coats be applied with a 5 minute wait between each coat. Following application, the coating was allowed to dry overnight and then removed using a paint scraper to score the edge of the coupons and then loosen the coating from each coupon before the loosened coating could be pulled off. In most cases the Orion™ SC coating was removed one coupon at a time without much removal across the border between coupons. The Orion™ SC removal rate was 1.6 m^2 per hour, the rate of waste generation was 0.5 kg/m^2, and the volume of the waste was, on average, 0.188 g/cm^3. Cured Orion™ SC formed flat, flaky, skin-like pieces; the coating was not elastic, so it tended to tear easily. The results of this evaluation suggest that the rate of decontamination will depend heavily on the surface of the concrete. Large, smooth surfaces would likely be conducive to rather fast rates of removal, while smaller surfaces (as in this evaluation) make for more labor intensive removal. In addition, rough or jagged surfaces are likely to increase removal times as the Orion™ SC may tear or come off in small pieces. Any damage to the surface of the concrete caused by the Orion™ SC was not visible to the naked eye.

6.3 Conclusion

The Orion™ SC removed approximately 76% of the Cs-137 from the unpainted concrete coupons placed together to form concrete surfaces with both horizontal and vertical orientations. The Orion™ SC worked the same in either orientation as well as at 7 or 30 days following the application of the Cs-137 to the concrete coupons. The removal rate of Orion™ SC depends on the characteristics of the surface being decontaminated because some scraping is required for removal.

7.0
References

1. Test/QA Plan, The Performance of Selected Radiological Decontamination Processes on Urban Substrates, Version 1.0, Battelle, Columbus, OH, Sept. 2007.
2. Quality Management Plan for the Technology Testing and Evaluation Program, Version 2.0, Battelle, Columbus, Ohio, January 2006.
3. ASTM Standard C 150-07, 2007, "Standard Specification for Portland Cement," ASTM International, West Conshohocken, PA, www.astm.org.
4. Radionuclide Detection and Decontamination Program, Broad Agency Announcement 03-013, U.S. Department of Defense (DoD) Defense Advanced Research Projects Agency (DARPA) and the U.S. Department of Homeland Security, classified program.
5. Calibration and Use of Germanium Spectrometers for the Measurement of Gamma Emission Rates of Radionuclides, American National Standards Institute. ANSI N42.14-1999. IEEE New York, NY (Rev. 2004).

United States
Environmental Protection
Agency

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Office of Research and Development
National Homeland Security Research Center
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300