Performance Evaluation of Decontamination Technologies for Dirty Bomb Cleanup – 10036

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) is responsible for protecting human health and the environment from the effects of accidental and intentional releases of radiological materials, including terrorist incidents such as a radiological dispersal device (RDD) or "dirty bomb". A primary EPA responsibility is cleanup and restoration of urban areas which would be affected if such an incident were to occur. In order to prepare for such an event, the EPA's National Homeland Security Research Center (NHSRC) is conducting performance evaluations of commercial, off-the-shelf radiological decontamination technologies, such as those originally developed for the nuclear power industry and the U.S. Department of Energy. Desirable decontamination technologies must not only be effective in removing threat contaminants from typical building materials, but must do so without being destructive to building surfaces. Due to the large areas likely to be affected by such an event, the time required to perform effective decontamination and the cost of deployment are significant issues as well. In FY2009, NHSRC evaluated the performance of five candidate technologies for their effectiveness in the removal of cesium from concrete through NHSRC's Technology Testing and Evaluation Program (TTEP). An emphasis on "low-tech" methodologies led to the selection of simple, low cost, easy to use technologies which can be transported and deployed quickly, requiring only minimal support services or infrastructure. The process and results of this testing, along with an assessment of any deployment issues associated with each technology, are being made available to the larger homeland security community for use in developing clean up guidance and to support decisions concerning the selection and use of decontamination technologies for large outdoor environments contaminated with specific radiological threat agents.

INTRODUCTION

EPA has evaluated commercially available technologies for their ability to remove radioactive cesium-137 from the surface of concrete building material according to the test/QA plan[1] developed for this evaluation. The test procedure was designed to simulate a cleanup scenario that included decontamination of the outside of a concrete building contaminated as a result of a notional radiological dispersion device. The concrete used during the evaluation was standard Portland type building concrete positioned in a vertical orientation. To summarize the evaluation, the cesium-137 was applied to 15 centimeter (cm)-square concrete coupons and measured to confirm an activity level of approximately 1 microCurie (μCi). The contaminated coupons were then positioned in a 9' × 9' test stand in a vertical orientation to simulate the wall of a building. This simulated wall was then decontaminated using one of the technologies selected for evaluation. The test program including testing of five different technologies, selected based on wide availability, simplicity, anticipated deployment cost and difficulty, and a judgment as to their performance being only minimally destructive. Three of these technologies utilized a handheld grinder equipped with sanding, steel brush, or diamond wheel heads, all equipped with a vacuum assisted shroud to control and collect contaminated effluent. The other two technologies tested included a rotating head hot water blasting technology and a grit blasting technology, both of which were also equipped with vacuum assisted effluent collection. Following application of the decontamination technology, the residual activity on the coupons was measured. The decontamination efficacy was determined from the difference in activity before and after application of the decontamination technologies. In addition to decontamination efficacy, qualitative factors such as amount of secondary waste, cost, ease of application and removal, health and safety issues, etc. were documented during the evaluation.

EXPERIMENTAL METHODS

Concrete Coupons

The concrete coupons were prepared in a single batch of concrete made from Type II Portland cement[2]. The concrete was poured into 0.9 meter (m) square plywood forms and the surface was "floated" to bring the smaller aggregate and cement paste to the top, and then cured for 21 days. Following curing, square coupons were cut to the desired size with a laser guided saw. A "floated" surface was used as the working surface to minimize the possibility of chemical interferences due to mold release agents. The coupons were approximately 4 cm thick, and 15 cm square, with a surface finish that was consistent across all the coupons and representative of concrete structures typically found in an urban environment. The edges of the coupons were sealed with epoxy and masked with an impervious tape to ensure that the contaminant would be applied only to the working surface of the coupon. These coupons were used for both the contaminated samples as well as the clean, uncontaminated, control samples.

Coupon Contamination

Each coupon selected for contamination was spiked with 2.5 milliliters (mL) of an unbuffered, slightly acidic aqueous solution containing 137 ppm Cs-137, which corresponds to an activity level of approximately 44 μCi /m^2, or about 1 μCi per coupon. The liquid spike was delivered to each coupon using an aerosolization technique. The aerosol delivery device was constructed of two syringes. The first syringe had the plunger removed and a pressurized air line attached to the rear of the syringe. The second syringe contained the aqueous contaminant solution and was equipped with a 27 gauge needle which penetrated through the plastic housing near the tip of the first syringe. Air was supplied at a flow rate 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. The result was a very fine aerosol ejected from the tip of the first syringe, creating a controlled and uniform spray of fine liquid droplets deposited over the entire coupon working surface.

Measurement of Activity on Coupon Surface

The level of gamma radiation emanating from the surface of concrete coupons was measured both before and after application of the decontamination technologies to evaluate their decontamination efficacy. These measurements were made using an intrinsic, high purity germanium detector which was regularly calibrated over the course of the tests performed using standard instrument calibration procedures[3].

Surface Construction Using Test Stand

In order to evaluate the performance of the decontamination technologies in a realistic environment, a large vertical surface (simulating a building wall) was fabricated of stainless steel which held three rows of three concrete coupons embedded and evenly distributed across the surface. Figure 1 shows the concrete coupons mounted in the assembled test stand which was approximately 3 m × 3 m.

Figure 1. Close-up of Several Concrete Coupons and the Loaded Test Stand

Technology Descriptions and Application

Five different decontamination technologies were evaluated, three of which utilized a handheld grinder equipped with sanding, steel brush, or diamond wheel heads. The other two technologies tested included a rotating hot water blasting technology and a grit blasting technology. All five technologies were equipped with a vacuum assisted shroud for effluent and secondary waste collection. The five technologies that were evaluated are pictured in Figure 2. The technology shown on the far left was used with two different heads, an iron brush and a diamond wheel. The second technology used a 24 grit sanding head. The third and fourth pictures show the water and grit blasting technologies, respectively. Prior to the actual test, each of the technologies was used in a "dry run", to determine appropriate application techniques and durations. It was decided that the grinder type technologies would be applied to each coupon for approximately 30-60 seconds, whereas the water and grit blasting technologies would be applied for approximately 10-15 seconds. Following the application of the technologies to both the contaminated and the control coupons, the coupons were removed from the test stand and the residual activity on the surfaces of the coupons was measured. Comparison of the activity level following use of the decontamination technologies to that measured prior to application provided the means to calculate the decontamination efficacy achieved.

Figure 2. Radiological Decontamination Technologies

Calculation of Decontamination Efficacy

The decontamination efficacy calculated for each of the contaminated coupons is expressed in terms of percent removal (%R) and decontamination factor (DF) as defined by the following equations:

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

where A_o is the radiological activity of the coupon before application of the decontamination technology and A_f is radiological activity of the coupon afterwards. The %R and DF are reported in Table 1 followed by a narrative description of the results focused on %R.

RESULTS AND DISCUSSION

Decontamination Efficacy

Table 1 presents a summary of the results of the evaluation in terms of the activity levels on the coupons before decontamination and after application of the decontamination technologies, as well as the calculated %R and DF for each technology. Each cell in the table represents the average and standard deviation of eight replicate concrete coupons. Final peer-reviewed results are not yet available so the identity of the technology has been omitted from Table 1.

Table 1. Decontamination Efficacy Results (Average ± Standard Deviation, N=8)

Decontamination Technology	Pre-Decon Activity µCi / Coupon	Post-Decon Activity µCi / Coupon	%R	DF
Technology #1	1.15 ± 0.07	0.53 ± 0.12	54 ± 10	2.3 ± 0.7
Technology #2	1.16 ± 0.05	0.72 ± 0.09	38 ± 7	1.6 ± 0.2
Technology #3	1.13 ± 0.07	0.12 ± 0.09	89 ± 8	14 ± 8.5
Technology #4	1.13 ± 0.03	0.72 ± 0.05	36 ± 4	1.6 ± 0.09
Technology #5	1.17 ± 0.04	0.04 ± 0.03	96 ± 3	55 ± 54

The results of this evaluation indicate that the five decontamination technologies tested produced a wide range of decontamination efficacies, ranging from 96 %R for Technology #5 to less than 40% for Technologies #4 and #2. Overall, the repeatability of the results was very good, as the standard deviations of the %R were relatively small with respect to the average %R. The decontamination efficacies achieved by each technology were evaluated through observation of standard deviation around the average %Rs. By evaluating the data in this fashion, the decontamination efficacies of Technologies #1, #2, and #4 all overlap one another and Technologies #3 and #5 overlap one another. A paired t-test was also performed to determine any significant differences between the data sets at a 95% confidence interval. The t-test analysis revealed that Technology #1 was significantly different from Technologies #2 and #4 which were statistically similar. Also, Technologies #3 and #5 were determined to be significantly different from one another.

Operational Factors

During the evaluation, detailed observations and measurements of several practical aspects of using these technologies were made. These deployment and operational factors, included rate of surface area decontamination (m^2/hr), applicability to irregular surfaces, skilled labor requirements, utilities required, extent of portability, set-up/tear-down time, reliability of equipment, secondary waste management (estimated amount and characteristics of effluent and/or spent media), and itemization of the capital and operating costs. Table 2 summarizes some of the operation information for the two major technology categories, the grinder technologies and the blasting technologies.

Table 2. Summary of Operational Factors for Grinding and Blasting Technologies

Parameter	Grinding Technologies	Blasting Technologies
Decontamination rate	Decontaminate concrete surfaces at a rate of ~ 1-3 m^2/hr	Decontaminate concrete surfaces at a rate of ~ 5 m^2/hr
Applicability to irregular surfaces	Irregularities kept sanding head from making good contact with the surface; the more aggressive the head the less it mattered because the aggressive heads removed the surface irregularities	Very applicable as surface is receiving a pressurized blast of abrasive or water; not dependent on surface terrain
Skilled labor requirement	Brief training session adequate	Brief training session adequate
Utilities required	110v for both grinder and vacuum	High pressure air compressor, hot water pressure washer
Extent of portability	Very portable	Equipment requirements more significant, but hoses would likely allow access to most locations
Set-up time	30 minutes	2 days to assemble equipment following shipment, but once together set-up for use it would be minimal
Secondary waste management	Very little waste as vacuum effective in dust collection	Water spray during water blasting was difficult and could be a safety concern; grit blasting vacuum worked well
Surface damage	Varied depending on aggressiveness of head	Varied depending on blasted media

References

1. Test/QA Plan, The Performance of Selected Radiological Decontamination Processes on Urban Substrates, Version 1.0, Battelle, Columbus, OH, July 2009.
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3. 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).