Sequestration Coating Performance Requirements for Mitigation of Contamination from a Radiological Dispersion Device

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ABSTRACT

Immediate action would be necessary to minimize the effects of a radiological “dirty bomb” detonation in a major city. After a dirty bomb has been detonated, vehicular and pedestrian traffic, as well as weather effects, would increase the spread of loose contamination, making control and recovery more difficult and costly. While contaminant migration and chemical binding into surface materials can be relatively rapid, the immediate treatment of surfaces with large quantities of an appropriate compound could alleviate much of the difficulty in decontamination. The EPA’s National Homeland Security Research Center (NHSRC), in collaboration with ASTM International, is currently developing performance standards for materials which could be applied to exterior surfaces contaminated by an RDD to mitigate the spread and migration of radioactive contamination. These performance standards are being promulgated via an ASTM Standard Specification to be published by ASTM International. Test methods will be developed to determine if candidate coatings meet the performance requirements stipulated in the ASTM performance standard. These test methods will be adapted from existing standard methods, or will be devised through laboratory research. The final set of test methods will be codified in an ASTM or other standard test method. The principal market for products described in the ASTM performance standard would be federal, state and local government emergency responders and response planners, decontamination service providers and those whose interests include protection and recovery of real estate potentially at risk from radiological terrorism.

BACKGROUND

A radiological dispersal device (RDD) refers to any method used to deliberately disperse radioactive material in the environment in order to cause harm. An explosive RDD, also called a “dirty bomb,” may be produced by packaging explosives, such as dynamite, with radioactive material which would be dispersed when the bomb went off. Other possible RDDs include passive (i.e., nonexplosive) methods of dispersing radioactive material, such as by using sprayers or simply spreading radioactive material by hand.[1]

A dirty bomb — depending on the radioactive material type, form (e.g., solid or powder), chemical composition, amount (curies), and concentration — could cause short-term radiation health effects in people located nearby and result in serious economic costs, social disruption associated with the evacuation and subsequent cleanup of the contaminated area, and possible long-term health risks from inhalation or ingestion of the dispersed radioactive material. A review of the British Polonium-210 incident in 2006 [2] or the Cobalt-60 incident in Goiania, Brazil in 1987 [3] provides insight into the extent of contamination and subsequent cleanup required following even a very small incident. Although the exact nature and location of an RDD attack is impossible to predict, it is generally believed that such an attack would most likely occur in an urban area because of the high density of people, high commercial value of the buildings and real estate, the potential to cause the most significant economic disruption, and the ability to achieve maximum propagandist effect.

An explosive RDD attack would result in the dispersal of radioactive material over a considerable area. A large fraction of the dispersed material, consisting of the larger pieces and fragments, would settle to the ground very near the point of the blast. Smaller particles, not subject to immediate gravitational settling, would remain airborne and would move downwind in what is referred to as a "plume." As the plume progressed downwind, radioactive material would settle out, contaminating the ground, building surfaces, vehicles, and other property. Although the level of contamination would depend on the characteristics of the dispersal device and the weather conditions at the time of the event, the concentrations of contaminants in the plume and deposited on the ground would generally decrease relatively quickly with distance from the point of origin. Consequently, a dirty bomb attack could result in a relatively small area with a high concentration of radioactive contamination and a much larger area with less contamination that would decrease with distance from the source. Passive (non-explosive) methods of dispersal could also result in widespread radioactive contamination as illustrated in the Goiania incident. The spatial extent and distribution of the contamination would depend on the type and quantity of material being dispersed and the method used for dispersal.

DECONTAMINATION AND RECOVERY FROM A RADIOLOGICAL DISPERSAL DEVICE EVENT

There are many challenging issues surrounding the response to an RDD event. The National Response Framework (NRF) describes the way in which the Federal Government would respond to acts of terrorism, including those involving a radiological dispersion device.[4] The NRF describes the response in terms of activities and Federal responsibilities during three distinct, but likely overlapping, phases. The Early phase would focus on protecting the population and include taking immediate life-saving measures, such as treating blast victims and initiating downwind evacuations (if deemed necessary). The Intermediate phase would involve evaluating the extent of contamination, taking measures to control further contamination, and minimizing additional human exposures. The Late phase would involve recovery and cleanup efforts, including decontamination and remediation of contaminated property. The U.S. Environmental Protection Agency (EPA) will play a major role in executing the cleanup phase of the recovery. EPA has recently published the Protective Action Guidance for Radiological Incidents (PAG) which outlines a process of optimization by which local cleanup criteria and levels will be determined.[5] The EPA has established the National Homeland Security Research Center (NHSRC) which, as part of its mission, seeks to understand and advance the state of the art in the science and technology of radiological decontamination of the environment.[6]

The US Department of Homeland Security (DHS) has developed a postulated RDD event, referred to as National Disaster Planning Scenario 11, which provides a reasonable starting point for use in response planning and preparation.[7] Cleanup after an RDD attack would be conducted according to federal regulations and guidance, and would include proper disposal of contaminated materials and equipment, probably as low-level radioactive waste (LLRW).

Disposal of waste such as from an RDD event is an extremely challenging task because it involves many geopolitical, as well as technical and economic, issues which have no obvious solution, and only minimal precedent. Waste minimization is therefore an important aspect of the cleanup process.

A large number of different types of radioactive sources are available in the world, there are numerous ways in which the material could be prepared and dispersed, and countless environments that could be attacked. Attempting to evaluate all possible combinations and permutations in detail quickly becomes an intractable problem. However, in all cases, returning the affected area to use as quickly as possible is highly desirable, as well as minimizing the cost to do so. Of the many important issues surrounding the cleanup process for any RDD event, two of particular interest to EPA are (1) how to reduce the total area requiring cleanup (the "footprint"), and (2) how to maximize the effectiveness of cleanup efforts.

Reducing the Radiological Footprint

After a dirty bomb has been detonated, vehicular and pedestrian traffic, as well as wind and weather effects, would increase the spread of loose contamination, making control and recovery more difficult and costly. Evacuation of the affected population would occur in the immediate hours, and possibly days, following detection of the event. Movement of emergency response, criminal investigation, and law enforcement personnel into and out of the affected area will contribute to this "tracking" of loose contamination, effectively enlarging the affected area. In all likelihood there will be weather events, such as precipitation and wind conditions, which will further increase the total contaminated area requiring cleanup. Due to all of these factors, the area which will require radiological decontamination, the "radiological footprint", will grow with time, increasing the difficulty and cost of cleanup. NHSRC is seeking to identify technologies and protocols which could mitigate this spread of contamination and reduce this footprint.

Mitigating Contaminant Migration and Binding

Certain radiological materials which are contaminants of concern tend to react with common urban building materials, causing a chemical binding between the contaminant and the substrate. For instance, one of the principal radionuclides of concern has an affinity for Portland cement based concrete, one of the most prevalent of urban building materials. The presence of moisture (e.g., humid environment or precipitation) also appears to exacerbate this binding phenomenon, as well as promote increased migration of contaminants into the matrix of the materials. The deeper and more affixed a contaminant becomes to the substrate, the harder the surface will be to decontaminate, resulting in a less effective decontamination and/or more surface damage resulting from the cleaning process, as well as increasing the cost and complexity of the process. Since this contaminant migration and chemical binding can be relatively rapid, the immediate treatment of surfaces with large quantities of an appropriate compound which could chemically sequester the radioactive contamination would alleviate much of the difficulty in subsequent decontamination. For the purposes of this discussion, sequestration refers to a process by which the chemical affinity of the substrate with the radionuclide would be reversed, such that the contaminant would preferentially bond with the sequestration coating. This sequestration process would mitigate migration of the radionuclide into the substrate, contain the radionuclide to prevent further reaerosolization, and provide a medium which, when removed, would take the contaminant away with it. This same compound, if formulated to withstand abrasion and weather effects, could also prevent much of the spread of contamination associated with vehicular or pedestrian tracking and resuspension. Deployment of such a compound very early in the response timeline could have a tremendous impact on the overall cost and timely completion of the restoration process. Having such a capability also reduces the effectiveness of the RDD as a weapon of mass disruption, consequently reducing the risk of occurrence of an event.

Development of a Sequestration Coating Performance Standard

The development of sequestration coating performance requirements is a collaborative effort between NHSRC and the ASTM International committee on Homeland Security Applications (E54).[8] These performance requirements describe materials which could be applied to exterior surfaces contaminated by an RDD to mitigate the spread and binding behavior of radioactive contamination and are being promulgated via a standard specification to be published by ASTM for industry use. This ASTM standard will provide performance specifications for such a sequestration coating. The method of application would be dependent on the nature of the compound. However, wide area application would suggest a sprayable type of coating, amenable to application with commercially available equipment. It is hoped that the coatings industry will respond to this need by either reformulating existing products, or developing new ones. The principal market for these products would be Federal, state and local government emergency responders and response planners, decontamination service providers, and those whose interests include protection and recovery of real estate potentially at risk from radiological terrorism.

The standard establishes performance specifications for a stabilizer, coating, or coating system that is intended to:

- Physically and chemically bind with and immobilize dispersible radioactive contamination deposited on buildings and equipment;
- Be removable during subsequent decontamination and recovery operations;
- Act as a decontamination agent (upon removal) by encapsulating contaminants;
- Be used primarily in an urban environment. However, it may be used in other environments such as suburban or rural areas;
- Withstand a degree of mechanical abrasion, weather effects, and environmental conditions; and
- Be applicable to both vertical and horizontal surfaces.

When the coating is subsequently removed, it is expected that a certain amount of contamination will be removed from the treated surface as a function of removing the coating, thereby accomplishing a degree of decontamination. The stabilizer is intended to be used as soon as possible after a dispersal event to minimize the spread of contamination and maximize the effectiveness of subsequent remediation activities, ideally at the earliest practical point during the Early Phase of a response. Use of the stabilizer will also reduce the airborne intake hazards associated with Intermediate and Late Phase operations within the contamination zone. The stabilizer is not intended to be used by first responders immediately after an incident or to extinguish fires that may be present at the site of a radiological dispersal. Depending on the specific formulation used, the stabilizer may be harmful to vegetation. Safety considerations are addressed for all phases of the material life-cycle, including staging prior to need, the operational environment during application, the period of time between application and removal (which may be on the order of months to years), and eventual removal and disposal. It is recognized that the sum of these capabilities represents a very ambitious performance requirement, and the standard emphasizes that a product that meets some, but not all, of these requirements may still have value, and the standard may be used as a guide by which to evaluate such products. Table I presents coating performance requirements included in the draft specification.

This work is not yet final. A draft ASTM specification has been submitted for review and ballot to the Committee on Homeland Security Applications, and subsequent publication by ASTM International. Comments have been received from Committee members and technical discussions have resolved most of the comments. The final review and approval process is expected to conclude in early 2009. Follow-on work has been proposed for development of a set of standard test methods to be used to evaluate the performance of candidate coatings against the final standard specification. For some performance parameters existing test methods will suffice while for others, such as decontamination factor (DF), new methods will need to be developed and verified.

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KEYWORDS

Radiological dispersal device; RDD; dirty bomb; decontamination; coating; sequestration; mitigation; ASTM.

Table I. Physical and Mechanical Properties

Property	**Measure**
Binding	Shall trap, physically or chemically or both, radiological contamination.
Application Method	Shall be compatible with conventional spray, foam, brush, or roll application systems.
Weatherability	Shall be stable (maintain film integrity) under a variety of outdoor environmental conditions (for example, ultraviolet (UV) exposure, water, high and low temperatures, and common bacteria) for a minimum of one year
Tear Strength	200 psi (1379 kPa) (ASTM Test Method D 1004)
Abrasion Resistance	<0.002-oz (50-mg) loss (ASTM Test Method D 4060)
Adhesion	>50 psi (345 kPa) on concrete (ASTM Test Method D 4541)
Tensile Strength	500 psi (3447 kPa) (ASTM Test Method D 412)
Shelf Life	Five years
Toxicity	Nontoxic during the application process as an aerosol, vapor, liquid, or solid at application concentrations. Personnel applying the agent may be required to wear PPE including breathing protection. The potential for inadvertent exposure to members of the public shall be minimized. After curing the stabilizer shall be nontoxic.
Flammability	Nonflammable (Test Methods E 108) in both its dispersible form and after application.
Cure Time	Shall form a film that meets the physical, mechanical, and other requirements within 2 hr after application.
Working Life	Sufficient to meet a realistic deployment schedule, depending on application method.
Persistence	Shall have sufficient mechanical properties to withstand foot traffic, incidental abrasion, and abrasive traffic conditions that are likely to be present in an emergency environment and/or decontamination site to prevent resuspension or tracking of the stabilized contaminant or adherence to responder assets/equipment.
Applicability/Orientation	Shall form a film when applied to vertical and horizontal surfaces in a variety of environmental conditions (for example, wet, dry, freezing, or hot).
Residual Effects	Shall not permanently discolor or damage surfaces.
Biological	Shall not attract or be a foodstuff for animals, insects, pests, or undesirable bacteria.
Decontamination Factor (DF)	No minimum. Desirable decontamination factor would be >25.0 when applied to urban construction materials contaminated with any of the Department of Homeland Security (DHS) radionuclides of interest. DF = initial contamination/final contamination in dpm/100 cm^2
Hazardous Material Category	Nonhazardous after curing and removal as waste. Shall not generate hazardous by-products

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