Journal of Hazardous Materials 196 (2011) 115–122

Contents lists available at SciVerse ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Efficacy of liquid and foam decontamination technologies for chemical warfare agents on indoor surfaces

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ARTICLE INFO

Article history:
Received 27 April 2011
Received in revised form 1 September 2011
Accepted 1 September 2011
Available online 8 September 2011

Keywords:
Chemical warfare agent
Decontamination
Sarin
Soman
Sulfur mustard
VX

ABSTRACT

Bench-scale testing was used to evaluate the efficacy of four decontamination formulations on typical indoor surfaces following exposure to the liquid chemical warfare agents sarin (GB), soman (GD), sulfur mustard (HD), and VX. Residual surface contamination on coupons was periodically measured for up to 24 h after applying one of four selected decontamination technologies [0.5% bleach solution with trisodium phosphate, Allen Vanguard Surface Decontamination Foam (SDF™), U.S. military Decon Green™, and Modec Inc. and EnviroFoam Technologies Sandia Decontamination Foam (DF-200)]. All decontamination technologies tested, except for the bleach solution, performed well on nonporous and nonpermeable glass and stainless-steel surfaces. However, chemical agent residual contamination typically remained on porous and permeable surfaces, especially for the more persistent agents, HD and VX. Solvent-based Decon Green™ performed better than aqueous-based bleach or foams on polymeric surfaces, possibly because the solvent is able to penetrate the polymer matrix. Bleach and foams out-performed Decon Green for penetrating the highly polar concrete surface. Results suggest that the different characteristics needed for an ideal and universal decontamination technology may be incompatible in a single formulation and a strategy for decontaminating a complex facility will require a range of technologies.

1. Introduction

Implementing an efficient remediation and recovery process after a civilian facility is contaminated with a chemical warfare agent (CWA) requires understanding the efficacy of a range of decontamination technologies. Many liquid and foam decontaminants have been developed to address the decontamination needs and performance criteria for military operations [1,2]. Far less is known about the performance of such technologies for application to civilian infrastructure [3]. Even trace amounts of residual chemical contamination may prove unacceptable in civilian settings [4,5].

As part of an effort funded by the U.S. Department of Homeland Security to improve the nation's preparedness for indoor facility restoration after a CWA release, four liquid and foam decontamination technologies for typical indoor surfaces were evaluated experimentally for efficacy against GB, GD, HD, and VX contamination. The U.S. Environmental Protection Agency has evaluated separately the efficacy of other technologies, principally fumigation, for decontaminating CWAs on typical indoor surfaces [6–8].

Although it was anticipated that each of the decontamination technologies tested as part of the present investigation would have some efficacy under the conditions for which it was designed, it is important to compare and quantify the efficacy of each technology as part of an effort to develop an effective overall decontamination strategy for civilian applications. The results of decontamination efficacy are typically reported in two ways: (1) by a commercial vendor through marketing material, which often does not contain the level of experimental detail necessary to evaluate the validity of efficacy claims, or (2) in military reports that describe efficacy in terms of meeting military criteria. Many efficacy evaluations are not performed on target chemicals themselves but, rather, on chemical surrogates [9,10] that may have limited ability to mimic all the important physico-chemical properties of target chemicals. In addition, previous decontamination efficacy testing [11] is often performed on the simplest of substrates, namely nonporous and

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doi:10.1016/j.jhazmat.2011.09.005

nonpermeable surfaces, where the CWA resides as a free liquid on the surface instead of being bound physically or chemically by the surface. Furthermore, because no experimental data are available that compare the performance of different liquid and foam decontamination technologies using similar testing protocols, the relative performance among existing technologies is not known.

Surface decontamination technologies require contact between an active decontamination component and a CWA. If the kinetics of a reaction with a CWA are slow, or there are mass-transport limitations, increasing the contact time may increase the overall decontamination performance. Decontamination foams or gels [12] cling to surfaces and are designed to increase the contact time of the decontamination technology on the surface compared to liquid formulations that rapidly run off some surfaces, such as vertical walls and ceilings. Although numerous decontamination technologies are in development, the current availability of a particular technology is also a critical operational consideration when rapid facility decontamination and restoration are paramount.

The four surface decontamination technologies evaluated in this study were chosen to span a range of available technology characteristics. Bleach (sodium hypochlorite) is a strong oxidizing aqueous solution that has widespread availability and a long history of use in CWA decontamination [8]. Liquid bleach does not have good contact time on vertical walls or ceilings, thus typical decontamination operations with bleach employ bleach scrubbing or multiple applications. Bleach is highly corrosive and should not be applied to sensitive electronic equipment intended for reuse. Two commercially available, aqueous-based, oxidizing foams were tested. The Allen Vanguard Surface Decontamination Foam (SDF™) formulation, which is a member of the foam family based on the Canadian Aqueous System for Chemical/Biological Agent Decontamination (CASCAD™), is specifically designed for building decontamination. Sandia Decontamination Foam (DF-200) is available from Modec Inc. and EnviroFoam Technologies. Both of these foam decontamination technologies feature a less aggressive oxidation technology, compared to bleach, and both result in better corrosion prevention. The fourth surface decontamination technology tested is the latest U.S. military liquid formulation, Decon Green™, which represents a solvent-based decontamination technology in contrast with aqueous-based technologies. Decon Green™ is not commercially available, but has been licensed to Strategic Technologies Enterprises, Inc. (STE), a subsidiary of STERIS Corp. Although corrosion concerns for solvent-based liquid decontamination technologies are minimal, potential materials-compatibility issues with plastics and polymers may prevent the reuse of such materials after decontamination.

2. Experimental

2.1. Agent synthesis

Neat liquids of four CWAs were synthesized at Lawrence Livermore National Laboratory (LLNL): (1) sarin, (GB, isopropyl methylphosphonofluoridate); (2) soman, (GD, pinacolyl methylphosphonofluoridate); (3) sulfur mustard, (HD, bis (2-chloroethyl) sulfide); and (4) VX, (O-ethyl S-[2-(diisopropylamino)ethyl] methylphosphonothioate). The purity of each of the four CWAs was verified to be >97% using gas chromatography–mass spectrometry (GC–MS) analysis.

International treaties regulate possession of highly toxic chemical warfare agents, and handling is only permitted in laboratories approved for CWAs under strict scrutiny. All work was performed through the Forensic Science Center and Lawrence Livermore National Laboratory, which has the authority and capability to synthesize and safely handle small quantities of CWAs. All experiments were conducted in triplicate, using standard scientific QA procedures, including positive and negative controls and routine instrument calibrations.

2.2. Indoor materials

Materials chosen for exposure to CWAs were selected from a range of typical indoor surfaces. Common materials that are easily removable (e.g., carpeting, acoustic ceiling tiles, and furniture) were not considered. Materials purchased and used as-is for the evaluation were stainless-steel coupons made from 1/16-in.-thick (~1.56-mm) sheets of 304 stainless steel; vinyl floor tile [Armstrong commercial flooring, Standard Excelon vinyl composition tiles, Pattern 51858, Imperial Texture, sandrift white, 1/8-in. (3.175-mm) thick]; latex-painted drywall [standard 0.438-in. (11.1-mm) drywall painted with 1 coat of Glidden commercial latex primer and 1 coat of interior eggshell paint]; and glass (Gold Seal Microslides, Becton Dickinson and Co., soda-lime microscope slide glass, precleaned, ground polished edges, plain). Concrete coupons were made at LLNL from a water and Portland cement mass ratio commonly used in construction (0.485:1.0), but made lean in sand (sand to cement ratio = 3, instead of 5–6) to be workable and to avoid extensive entrapped air in the cast coupons (35-mm diam, 17-mm thick). Portland cement type I/II (Quikrete brand) was used with a well-graded sand aggregate from U.S. Silica (ASTM 20/30, C-778), with 98% of the particles between 600 and 850 μm (20 and 30 mesh). Because the reactivity of newly cured concrete with CWA may not be representative of most concrete in facilities [13], concrete coupons were rapidly aged in a 25% CO_2 atmosphere for 2 weeks to reduce the reactivity through carbonation, the same mechanism by which concrete naturally reduces its reactivity, albeit more slowly. Other than the cast concrete coupons, all other materials for chamber exposure were cut into pieces, with top surface areas ranging from approximately 2 to 10 cm^2.

2.3. Preparation of decontamination technologies

All decontamination technologies were prepared immediately prior to surface application. The liquid bleach decontamination formulation was prepared by diluting Clorox® regular bleach (5% by mass sodium hypochlorite) with Milli-Q water in a 1:9 ratio to create a 0.5% by mass sodium hypochlorite solution. Trisodium phosphate was added as a surface wetting agent so that the final decontamination solution contained 0.0625% by mass of trisodium phosphate.

Decon Green™ was prepared in 100-mL batches according to the formulation described in U.S. military reports [11], namely 60% propylene carbonate, 10% aqueous H_2O_2, 10% triton X-100, 2.07 g K_2CO_3, and 0.48 g K_2MoO_4.

Easy Decon™ DF-200 foam was purchased and prepared in a 2-L beaker by mixing the 3-part formulation in the same ratios as those specified by the manufacturer. Initially, 95 mL each of Part 1 “Penetrator,” containing quaternary ammonium compounds and benzyl-C12-C16 alkyl di-methyl chlorides, and Part 2 “Fortifier,” containing liquid hydrogen peroxide, were mixed well. Then, 4 mL of Part 3 “Fortifier Booster,” containing diacetin, was added, and a Cuisinart hand blender was used to create the decontamination foam.

SDF™ Foam was purchased and prepared according to the manufacturer’s directions for the multicomponent formulation. Thus, 1.8 g of GPB-2100 dry-powder buffer component was rinsed using Milli-Q water into a 50-mL cylinder. Then 4.5 mL of GCE-2000 surfactant or foaming agent component was added to the graduated cylinder, and the total volume in the graduated cylinder was increased to 50 mL with Milli-Q water. A micro stir-bar was used to mix until dissolved. Separately, 7.8 g of GP-2100 dry-powder decontaminant component was dissolved in Milli-Q water and