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Evaluation of Commercial Off-the-Shelf (COTS) Products for Personnel Decontamination

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

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When faced with a mass casualty, live-person decontamination event, preventing the absorption of chemical warfare agents into human skin is critical to prevent or reduce adverse health effects. This study evaluated commercial off-the-shelf (COTS) products for decontamination efficacy in a post-contamination scenario on Strat-M skin surrogate (MilliporeSigma; Billerica, MA), as well as a barrier to agent contamination on a silicone elastomer. Of the tested products, the reactive skin decontamination lotion provided the most decontamination efficacy against soman (GD) and distilled mustard (HD) contamination, while Softsoap liquid hand soap provided the most efficacy against VX contamination. Further studies are warranted to determine the efficacy of high-performing products on additional skin surrogates such as excised pig skin.

15. SUBJECT TERMS

In vitro	Personnel decontamination	Distilled mustard (HD)
Panel test	Barrier cream	Pinacolyl methyl phosphonofluoridate (GD)
Percutaneous absorption	Skin decontamination	*O*-Ethyl *S*-(2-diisopropylaminoethyl) methylphosphonothiolate (VX)
Silicone membrane	Strat-M skin surrogate	Soman (GD)

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PREFACE

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The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

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EVALUATION OF COMMERCIAL OFF-THE-SHELF (COTS) PRODUCTS FOR PERSONNEL DECONTAMINATION

1. INTRODUCTION

Historical approaches to mass casualty decontamination have focused on human remains and decontamination of personal items. A chemical agent contamination event would present a challenge regarding the decontamination of a contaminated military or civilian population. When faced with a mass casualty, live-person decontamination event, preventing the absorption of chemical warfare agents (CWAs) into human skin is critical in reducing adverse health effects. Military skin decontamination methods have included the use of "Skin Exposure Reduction Paste against Chemical Warfare Agents (SERPACWA) as a barrier skin cream and the M291 Skin Decontamination Kit, 0.5% hypochlorite solution (household bleach diluted 1 to 10) and 1% soapy water solution"[1] along with reactive skin decontamination lotion (RSDL). Typical studies of skin decontaminants use a protective ratio (defined as the median lethal dose [LD_{50}] of the treatment condition divided by the LD_{50} of the untreated group) as a metric or model as opposed to the quantitative reduction of contaminant in or on the skin.

In the event of a CWA release, there is a likelihood of CWA deposition on exposed skin of an unprotected population, regardless of military or civilian setting. Historically, the efficacy of skin decontaminants such as RSDL and soapy water have been evaluated for protective ratios, which compare the CWA lethality dosage observed in an animal model after use of the decontaminant. A data gap exists regarding the quantitative contaminant reduction observed from skin when using these technologies or other commercial off-the-shelf (COTS) products approved for use on humans. The adverse health effects associated with CWA contact increase with duration of exposure. The use of products that can quickly remove bulk CWA from exposed skin in an immediate decontamination scenario would be advantageous in reducing adverse health effects to unprotected personnel. The need also exists for products that would act as barriers to the absorption of CWA into exposed skin, resulting in less of a decontamination challenge after a contamination event.

COTS products have been used for CWA decontamination in other potential contamination mitigation areas. The Decontamination Sciences Branch (DSB) at U.S. Army Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC) has previously investigated the use of COTS products as CWA decontaminants on materials such as paints, metals, and plastics and is well versed in the methods used to determine the efficacy of a decontaminant.[2] Other colleagues at DEVCOM CBC have also investigated the use of COTS products as CWA decontaminants in the liquid phase using NMR spectroscopy.[3] The current report provides the screening study results of COTS and other common CWA skin decontaminants for skin decontamination and barrier efficacy against CWAs on a skin surrogate.

2. EXPERIMENTAL METHOD

2.1 Contamination

The COTS evaluation was completed using remaining agent test procedures from the *Chemical Contaminant and Decontaminant Test Methodology Source Document, Second Edition* (SD2ED).[4] The products were screened for decontamination and barrier efficacy against neat distilled mustard (HD), soman (GD), and *O*-ethyl *S*-(2-diisoproylaminoethyl) methylphosphonothiolate (VX). Chemical Agent Standard Analytical Reference Material or high-purity grade contaminants with purity on record obtained from either NMR or gas chromatography/mass spectroscopy analyses were used for the study. All purity documentation was maintained by the DEVCOM CBC DSB. Chemical contaminants were used only in properly certified surety facilities. Personnel handling the chemical contaminants were fully trained and certified for safely handling such materials.

Strat-M panels (product no. SKBM02560 EMD; MilliporeSigma; Billerica, MA) were contaminated in the decontamination evaluations. Strat-M is a synthetic two-layer system designed to mimic the diffusion of a compound into human skin. Studies have shown similar diffusion parameters of various chemicals in Strat-M to those in excised human and rat skins.[5] A silicone elastomer was used for the barrier evaluations. Silicone was previously shown to be useful in establishing a ranking of barrier product efficacy against a VX challenge,[6] and it fit the needs of this study.

Test panel contamination was performed in accordance with SD2ED contamination options for the test samples. The chemical contaminant was removed from cold storage and allowed to equilibrate to room temperature in the test location chemical surety hood prior to testing. The panel trays were removed from the environmental chamber after preconditioning at approximately 21 °C and 50% relative humidity, and the contaminant was applied using an Eppendorf Repeater Plus pipette (part no. 2026020–1; Eppendorf; Hamburg, Germany). Each panel received an approximately 4 g/m^2 starting challenge applied as a 2 µL droplet on a 1 in. diameter panel.

2.2 Panel Treatments

The products selected for the skin surrogate evaluations are provided in Table 1. Many skin products are available for multiple uses such as UV protection, body cleanliness, and hand sanitation. During the initial stages of product down-selection, information such as pH and ingredient molecular weight or percentage was not readily available. As a result, the selections could not be chosen based on these properties. Therefore, multiple products were chosen from each “class” of product. Efforts were made to choose products in the same class that contained different ingredients.

Table 1. Products for Skin Surrogate Evaluations

Common CWA Skin Decontaminants and Other Products	Body Cleansers	Facial Cleansers	Hand Cleansers	UV Protectants
0.5% Bleach solution	Dove body wash* (Unilever; London, UK)	Clean & Clear continuous control acne daily cleanser^* (Johnson and Johnson; New Brunswick, NJ)	Germ-X hand sanitizer* (Germ-X; St. Louis, MO)	Banana Boat sport performance SPF30* (Edgewell; North Bergen, NJ)
RSDL	Neutrogena body clear body wash* (Neutrogena Corporation; Los Angeles, CA)	Cetaphil daily facial cleanser* (Galderma Laboratories; Dallas, TX)	Softsoap liquid hand soap* (Colgate-Palmolive)	Aveeno natural protection lotion SPF50* (Johnson and Johnson)
Soapy water†	Irish Spring body wash* (Colgate–Palmolive; New York, NY)	Biore deep pore charcoal cleanser* (KAO; London, UK)	Fast Orange dry skin pumice lotion* (Permatex; Solon, OH)	
Fuller's earth‡	Eucerin skin calming dry skin body wash* (Beiersdorf, Inc.; Hamburg, Germany)			
Mineral oil	Sebamed liquid face and body wash (Sebamed USA; Irvine, CA)			
Sand				
Industry wipe				
Calamine lotion				

*Products were used in the barrier evaluations.
^Diluted 5:1 in deionized water prior to application to test panel.
†General purpose detergent NSN 7930-00-282-9699 diluted 1812:1 in deionized water prior to application to the test panel.
‡Powder (CAS 8031-18-3; Sciencelab.com, Inc.; Houston, TX).

2.3 Decontamination Procedure

After a 5 min contaminant–material interaction period, 250 µL of each liquid product was applied to a corresponding contaminated panel using a positive-displacement pipette while ensuring the entire panel surface area was covered with decontaminant. The product was applied directly from the original packaging. For Fuller's earth and sand, 1 g and 1.5 g were applied to the contaminated panels, respectively. The industry wipe was applied using a weighted mandrel. The wipe and a piece of aluminum foil were held to the bottom of the mandrel, and the mandrel was placed onto the panel as shown in Figure 1. The mandrel apparatus was rotated 90° to the left and then 90° to the right a total of three times before the mandrel was removed. The liquid and solid products remained stagnant on the panels during the decontamination period. The products were not rubbed into the test panels. After a 10 min decontaminant dwell time, the panels were rinsed with 120 mL of deionized water to remove any excess product, and the panels were extracted in the appropriate solvent to determine the contaminant remaining on or in the panel after the decontamination process.

Figure 1. Industry wipe application.

2.4 Barrier Product Procedure

A 50 µL volume of each liquid barrier product was applied to a corresponding 1 in. diameter silicone panel (Goodfellow, Inc.; QC, Canada) to achieve an approximate thickness of 0.1 mm.[7] A 2 µL droplet of contaminant was applied to each panel 15 min after the barrier applications. After a 30 min contaminant dwell time, a 120 mL deionized water rinse was performed to remove the contaminant and barrier product from each panel. The panels were then extracted in the appropriate solvent to determine the amount of contaminant that diffused through the barrier and absorbed into the silicone substrate.

2.5 Remainder Contaminant Evaluation

To determine the mass of contaminant in each panel after the decontamination or barrier treatment, the panels were placed face-up in 20 mL clear scintillation vials with Teflon-lined polypropylene lids (product no. 170808; Scientific Specialties Service, Inc.; Hanover, MD). The appropriate solvent in the amount of 20 mL was added to each vial using a bottle-top organic solvent dispenser (part no. 4701351; Brandtech Scientific, Inc.; Essex, CT). Several solvents could have been appropriate for use with chemical contaminant analytes. In prior method-development activities, extraction solvents were used based on the compatibility with the contaminant, the ability of the solvent to extract the contaminant from the test materials, and the chromatography analysis performance. Chloroform, acetonitrile, and isopropanol were used to extract HD, GD, and VX, respectively. The panels remained in the extraction solvents for 60 min. At the end of the extraction period, the vials were swirled to homogenize the samples. A Pasteur transfer pipette (part no. 13–678–8C; Thermo Fisher Scientific, Inc.; Waltham, MA) was used to place samples into autosampler vials for chromatography analysis. The details of the analytical techniques used during these studies, including solvent recovery, extraction efficiency, quality control, and quality assurance practices, are available in previous reports.[8,9]

2.6 Data Analysis Summary

Development of a comprehensive experimental design and analysis of the resulting data are fundamental components of a successful research program. The data generated by hazard mitigation testing can be influenced by many variables and produces a wide array of experimental results. The data presented in this report was generated by analytical methodology and was quality reviewed to ensure the data was fit for analysis.

Successful analysis and interpretation of the results may be obtained by simple statistical techniques or may require advanced regression and modeling techniques (e.g., response surface models, linear least-squares models, etc.). The statistical techniques used in this report included statistical hypothesis testing and the log-difference (LD) relative performance metric calculation. The ability to remove contaminant from a panel was evaluated using an LD relative performance metric. The log-difference panel (LDP),

$$\mathrm{LDP} = \log_{10}\left(\frac{\mathrm{M_0}}{\mathrm{M_{Decon}}}\right) \quad (1)$$

quantifies the difference between the contaminant mass retained after a control condition (M_0) and the remaining contaminant mass after decontamination (M_{Decon}). The 95% confidence interval (CI) for the difference was used to determine statistical significance between the two conditions. If the CI included zero (i.e., if CI >LDP), the evaluated decontaminant did not remove contaminant from the material. If the LDP ± CI did not include zero, the decontaminant reduced the quantity of contaminant in the material by a statistically significant amount. The reduction can be described as LDP orders of magnitude (or by a factor of 10 LDP, or percent reduction by [1–10–LDP] × 100%) compared to the control condition. Larger values of LDP indicate better performance.

The LD relative performance metric analysis was executed for these data using two reference conditions. The reference condition used for the decontamination evaluations was the average remaining contaminant result after weathering (i.e., no treatment) to illustrate the overall removal performance of each COTS product. The reference condition used for the barrier evaluations was a water rinse condition (no barrier applied to the panel) to illustrate the advantages of applying the product prior to contamination.

The LD can be interpreted as the order of magnitude performance difference between the reference condition and the physical removal techniques. A value of 1 LD corresponds to a 10× difference in performance; a value of 2 LD corresponds to a 100× difference in performance. Higher LD values indicate that the decontaminant or barrier technique was able to remove or minimize absorption of the contaminant from the panel. The maximum LD that could be detected was equivalent to the difference between the log 10 (remaining contaminant) of the reference condition and the log 10(level of quantitation, remaining contaminant mass) for each material or treatment process. The remaining contaminant data was within the detection range of the method for each decontaminant–material combination. The maximum LD was not reached for any decontaminant or barrier condition evaluated.

3. DECONTAMINANT EVALUATION

3.1 VX Results

Figure 2 presents the remaining contaminant results for VX-contaminated Strat-M panels. There was a trend in overall performance with regard to the type of COTS product used. Overall, the best performance was observed for hand cleansers (Softsoap liquid hand soap and Germ-X hand sanitizer), followed by body washes (Neutrogena body clear, Eucerin dry skin, Irish Spring, and Dove). The facial cleansers (Clean & Clear continuous control acne daily cleanser and Cetaphil daily face cleanser) demonstrated lower performance. Previous studies have shown that the permeability of VX may vary across different areas of the skin (for example, the forehead as compared to the forearm[10]). Considering the area of skin that the Strat-M best emulates and the area for which a cleanser is formulated may help to explain the grouping of the COTS product performance against VX.

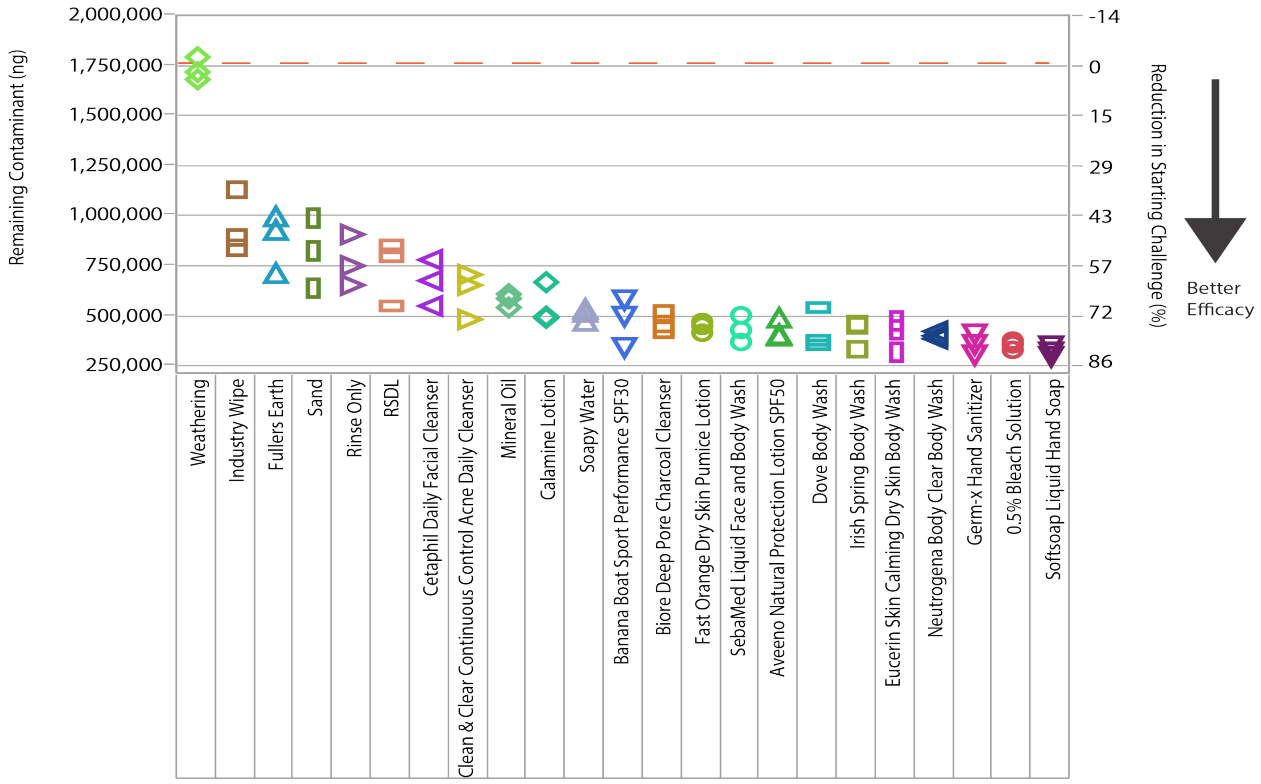

Figure 2. VX COTS decontamination evaluation results. Red dashed line represents mass of VX applied to panel.

Figure 3 presents the VX log difference results for each product compared to the weathering control. Although all products showed increased decontamination performance as compared to the weathering condition, none of the products achieved a 90% reduction from the reference condition. Softsoap liquid hand soap was the top performing decontaminant against VX. Two of the top three performers, 0.5% bleach and the Germ-X hand sanitizer, were expected to be among the top performers. Previous studies have shown 0.5% bleach has efficacy against VX-contaminated skin,[11] and alcohol, a main component of the Germ-X hand sanitizer, can readily extract VX from materials. Each of these two products removed over 75% of the initially applied VX from the Strat-M panel.

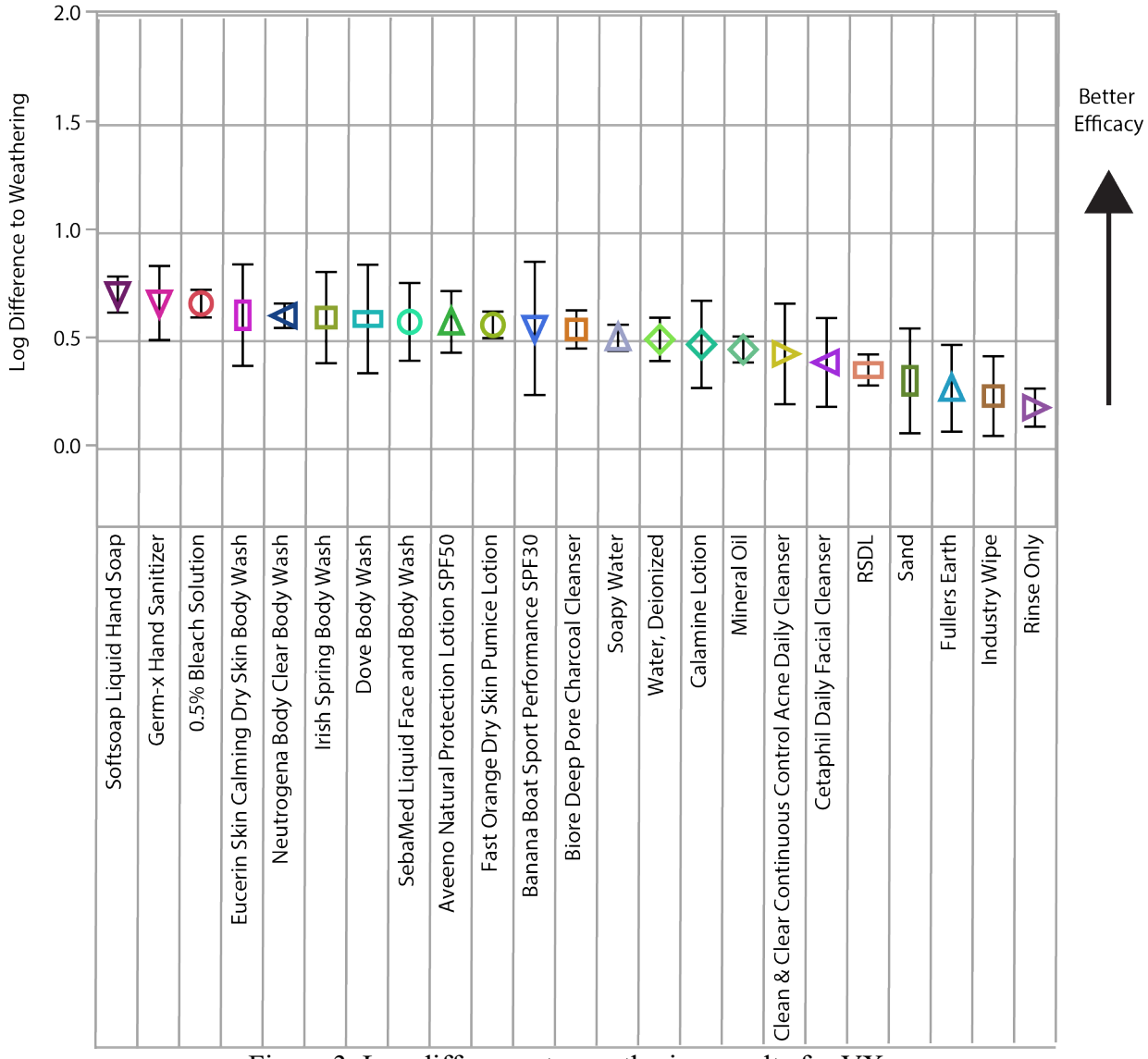

Figure 3. Log difference to weathering results for VX.

3.2 GD Results

Figure 4 presents the remaining contaminant results for GD-contaminated Strat-M panels. Overall, the best performers were the Germ-X hand sanitizer, Banana Boat sport performance SPF30, and Eucerin skin calming dry skin body wash. These products each removed more than 60% of the initially applied GD.

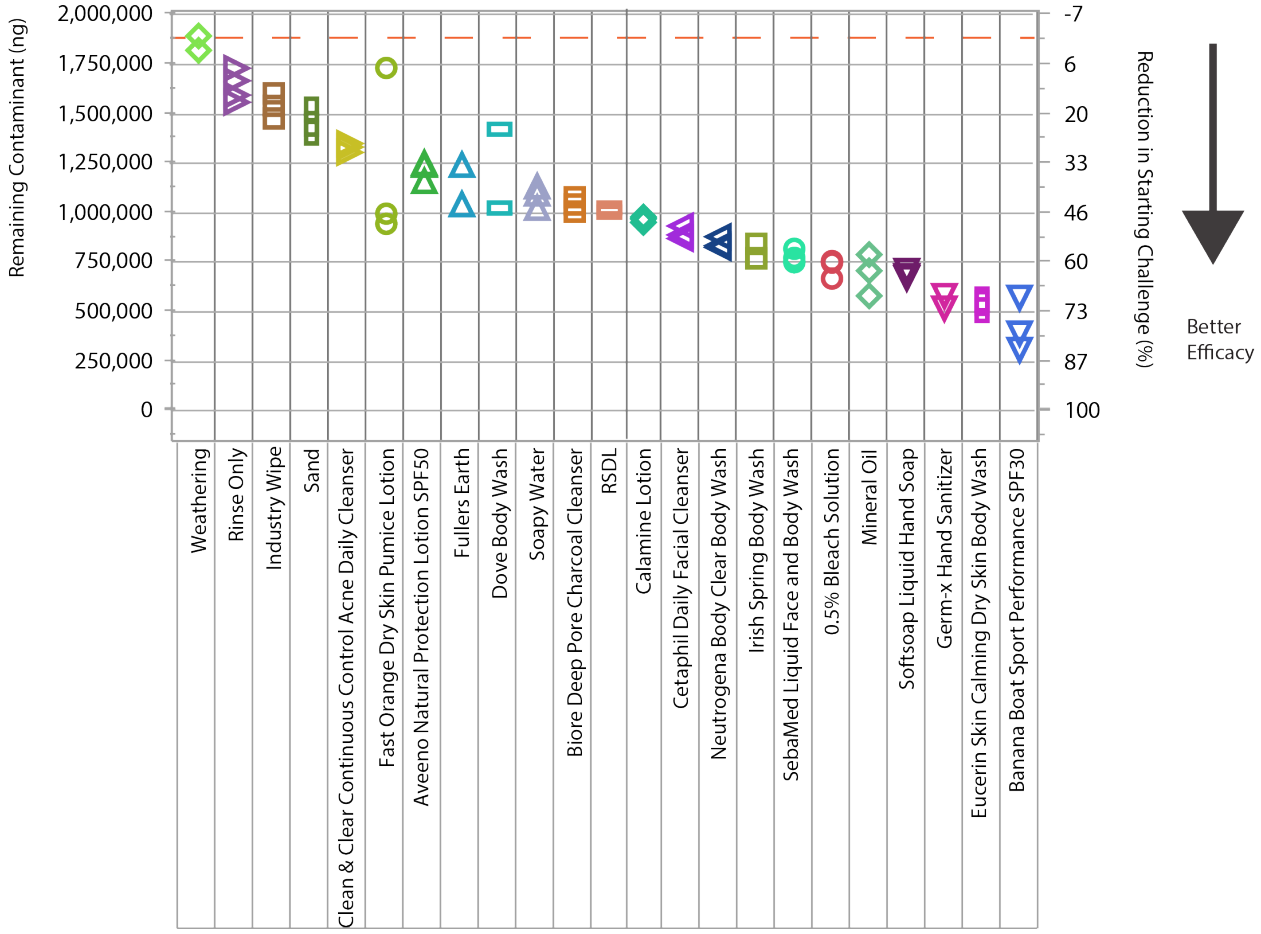

Figure 4. GD COTS decontamination evaluation results. Red dashed line represents mass of GD applied to panel.

RSDL demonstrated up to 40% removal of GD from the Strat-M panel when compared to the weathering condition. RSDL was shown to provide notable GD skin decontamination efficacy in previous experiments.[1] Variations in RSDL performance across studies may be due to differences between experiments involving live animals in vivo compared to in vitro Strat-M model experiments. In this study, the application of RSDL occurred 5 min after contamination, compared to the study by Braue and colleagues,[1] in which the RSDL was applied 2 min after contamination. The application method used for the RSDL differed as well. The RSDL was applied with a tongue depressor and rubbed onto the animals in the Braue and colleagues study, whereas the RSDL was applied passively to the Strat-M panel using a pipette

in the current study. These variations in performance across studies emphasize that the timing and method of decontamination application can influence the amount of contaminant absorption into the skin.

Figure 5 presents the GD log-difference results for each product compared to the weathering control. Many of the COTS products showed increased decontamination performance when compared to the weathering condition, but none of the products achieved a 90% reduction from the reference weathering condition. Some products, such as the sand and rinse-only conditions, were statistically similar to the weathering control.

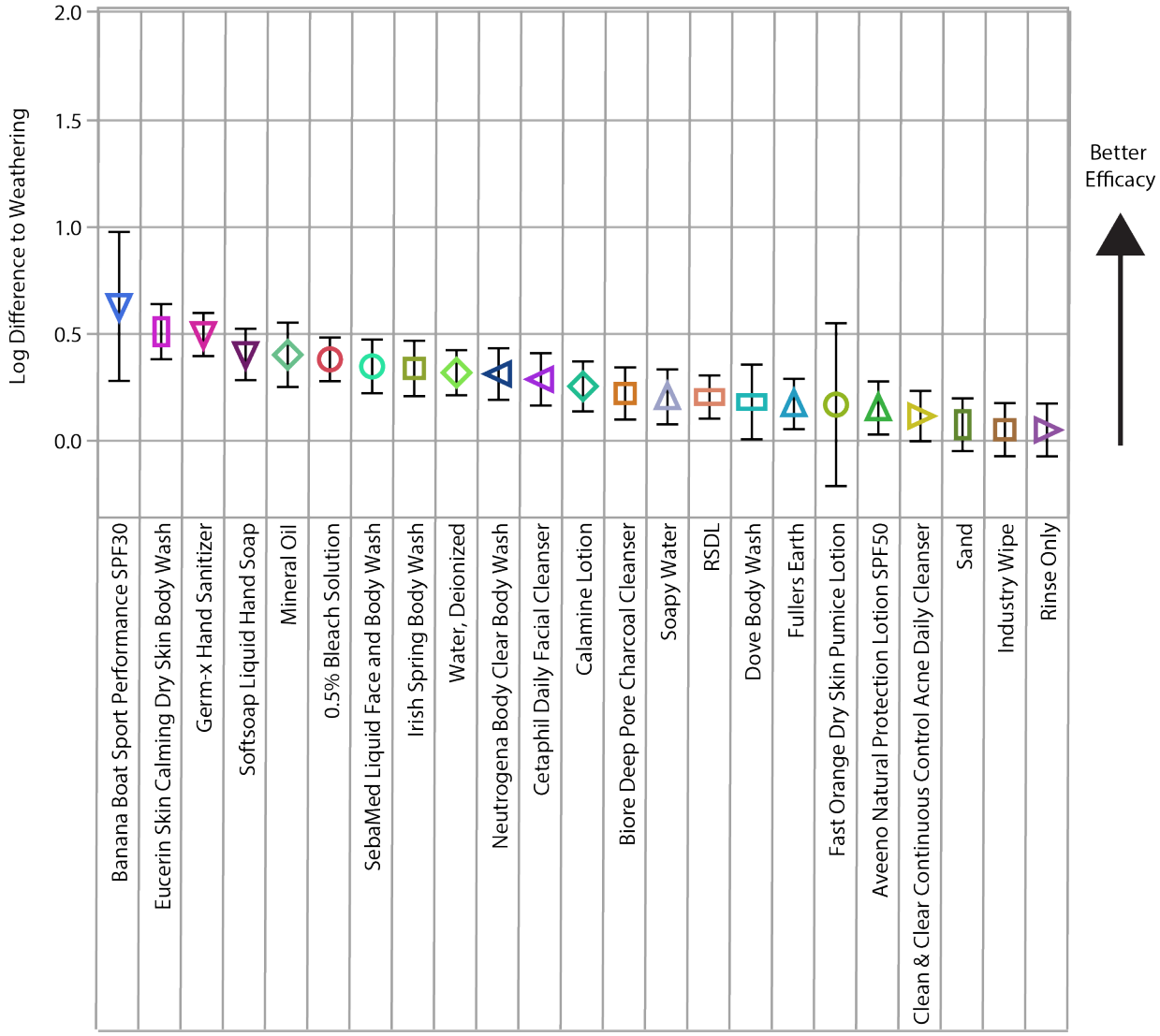

Figure 5. Log difference to weathering results for GD.

3.3 HD Results

Figure 6 presents the remaining contaminant results for HD-contaminated Strat-M panels. Overall, HD was the most difficult contaminant to remove from the Strat-M panels, as shown by the larger remaining contaminant results. Only RSDL, Eucerin skin calming dry skin body wash, and 0.5% bleach were able to reduce the HD contamination by more than 50% (remaining contaminant result less than 1,000,000 ng). Most of the products evaluated were aqueous, and with HD being a hydrophobic material, this may have prevented the product from sufficiently interacting with the HD to facilitate removal from the Strat-M panels.

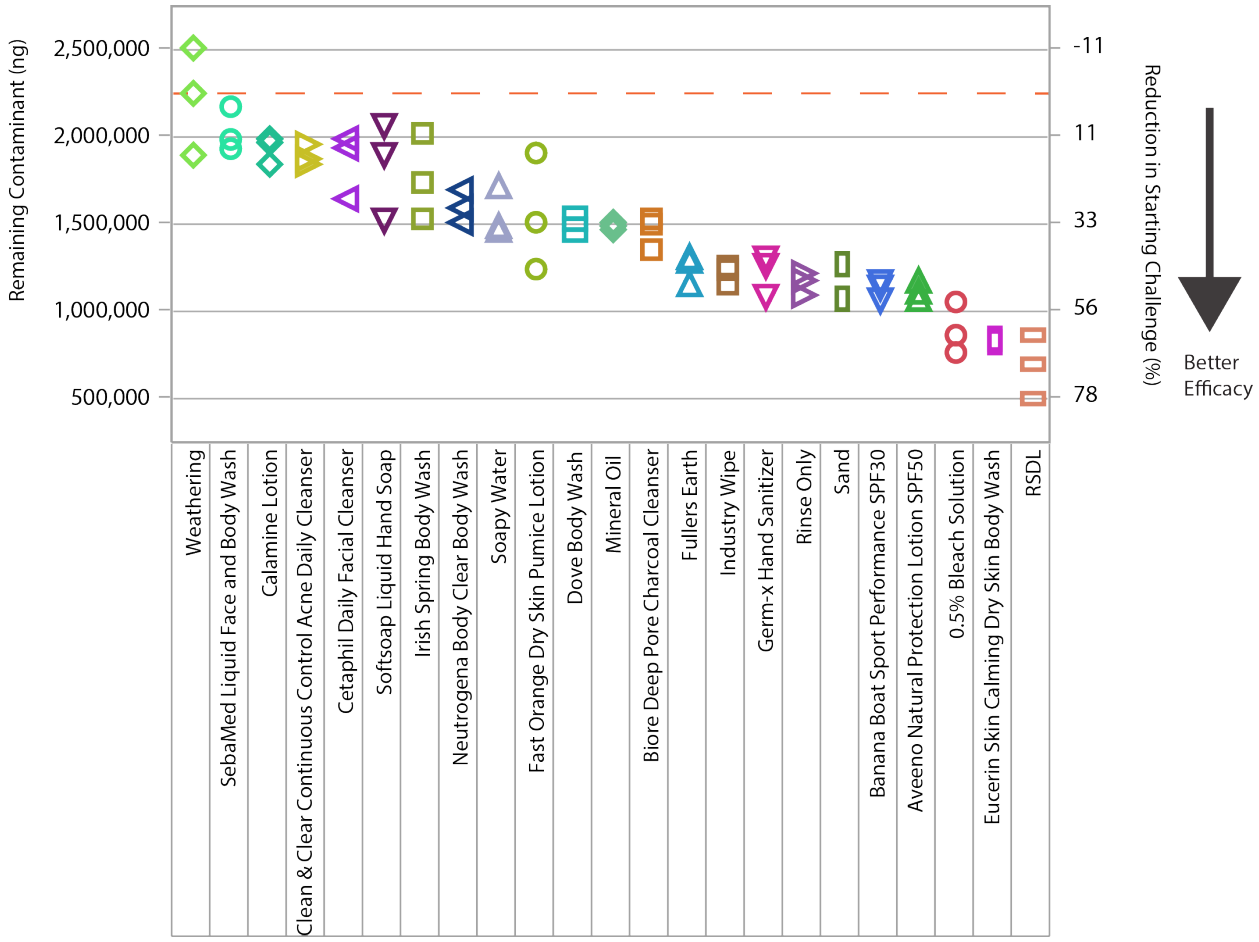

Figure 6. HD COTS decontamination evaluation results. Red dashed line represents mass of HD applied to the panel.

Figure 7 presents the HD log-difference results for each product compared to the weathering control. The performance of most of the products against HD was statistically similar to those of the weathering control. None of the products were able to provide a 90% reduction of HD from the Strat-M panels when compared to the weathering condition. Overall, the best performers were RSDL, Eucerin skin calming dry skin body wash, and 0.5% bleach solution.

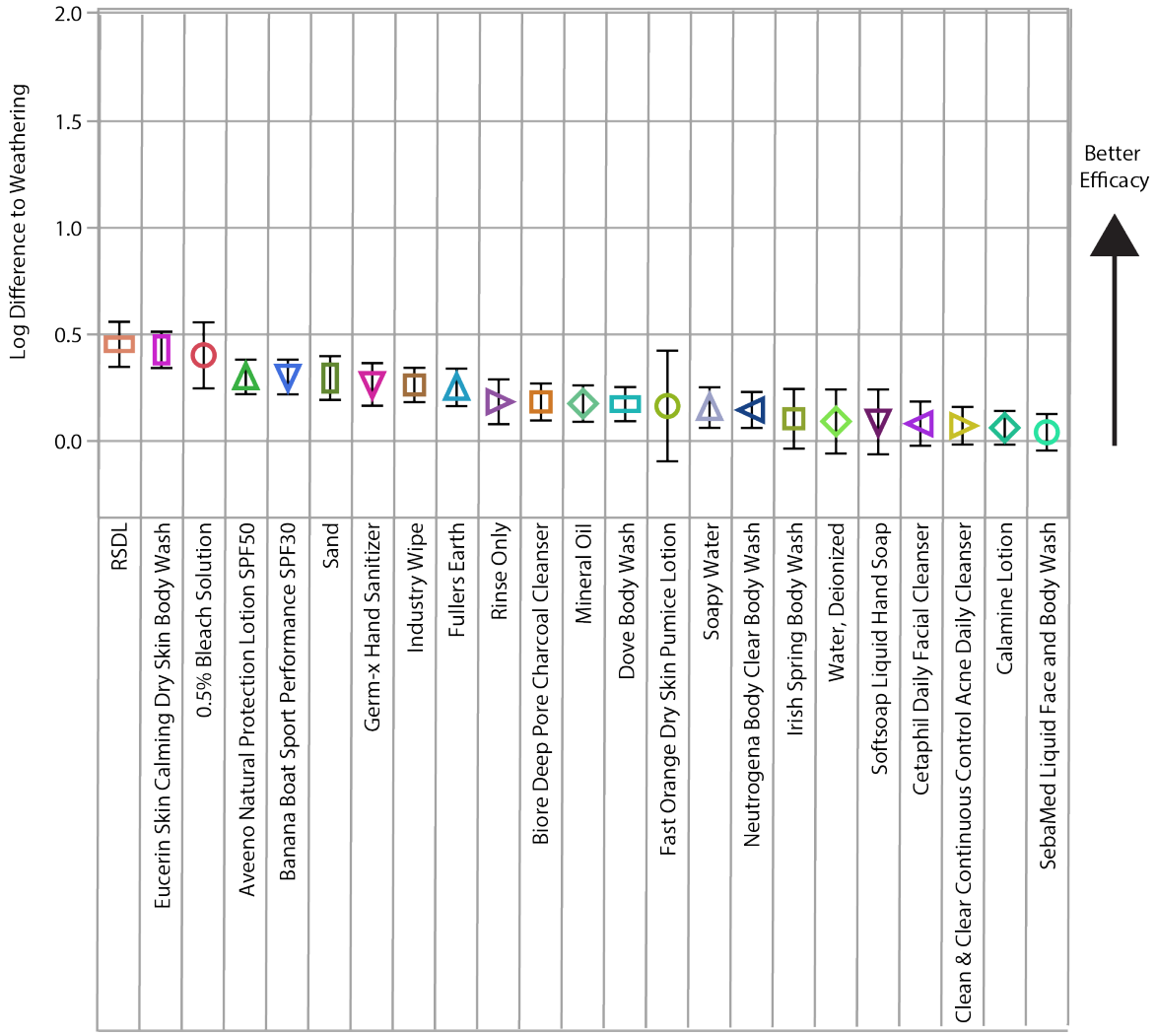

Figure 7. Log difference to weathering results for HD.

4. BARRIER EVALUATION

A down-selected group of COTS products was also evaluated as items intended to mitigate the absorption of chemical contaminants into the skin. The down-selected products did not include the category of common decontaminants from Table 1 because those products are not left on the skin. A successful product would act as a barrier and prevent the contaminant from penetrating skin, thereby providing an increased time frame in which to decontaminate and prevent adverse health effects to the contaminated individual.

4.1 VX Results

Figure 8 presents the results for the VX on silicone barrier study. Most of the products evaluated resulted in greater VX absorption than that of the rinse-only treatment. On average, the body washes such as Dove and Eucerin skin calming as well as the Clean & Clear continuous control acne daily cleanser resulted in less VX penetrating the silicone substrate compared to the rinse-only condition.

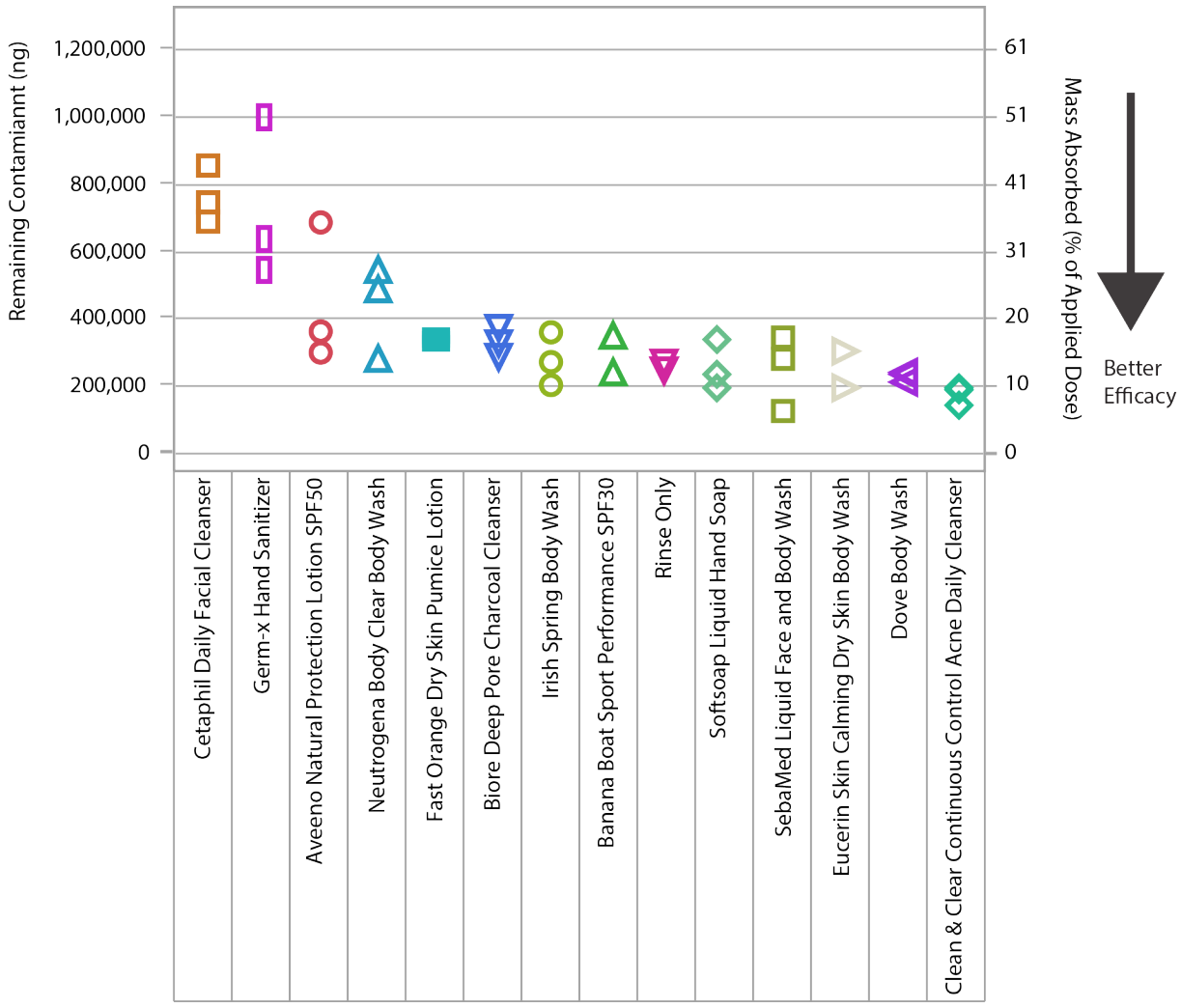

Figure 8. VX barrier test results on silicone.

Figure 9 presents the VX log difference results for each barrier product compared to the rinse-only control. All products demonstrated barrier performance that was statistically similar to or performed worse than the rinse-only treatment. The products may have interacted with the silicone or VX to create solubility conditions that caused the silicone to more readily absorb VX.

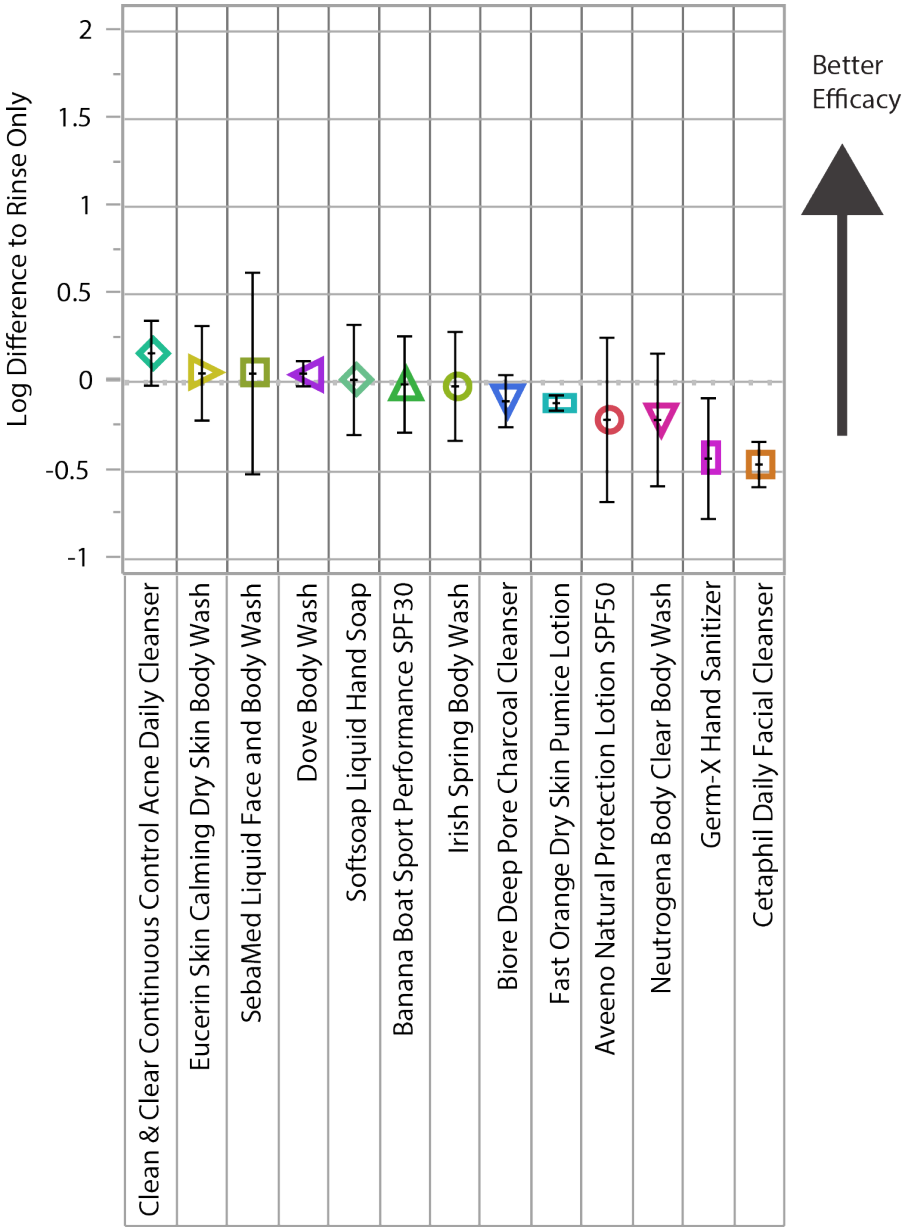

Figure 9. Log difference to rinse-only results for VX.

4.2 GD Results

Figure 10 presents the results for the GD on silicone barrier study. The amount of GD retained in the silicone varied approximately an order of magnitude across all products evaluated. The products that best limited the absorption of GD into silicone were Softsoap liquid hand soap and Dove body wash. These products performed significantly better than the rinse-only treatment.

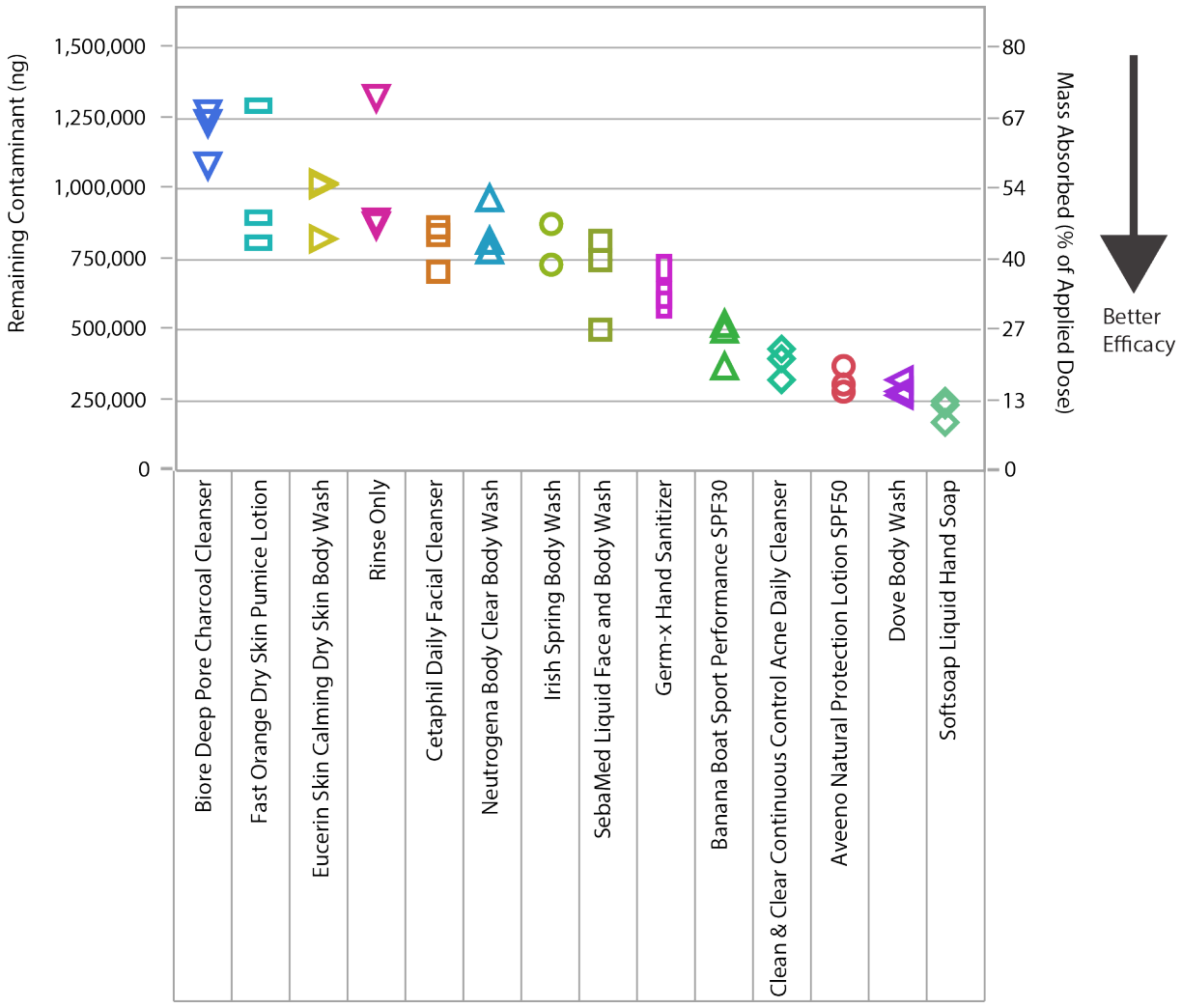

Figure 10. GD barrier test results on silicone.

Figure 11 presents the GD log-difference results for each barrier product compared to the rinse-only control. Much like the VX results, most products demonstrated barrier performance that was similar to or less than that of the rinse-only treatment. Softsoap liquid hand soap and Dove body wash were significantly better performers than the rinse-only treatment and other products evaluated.

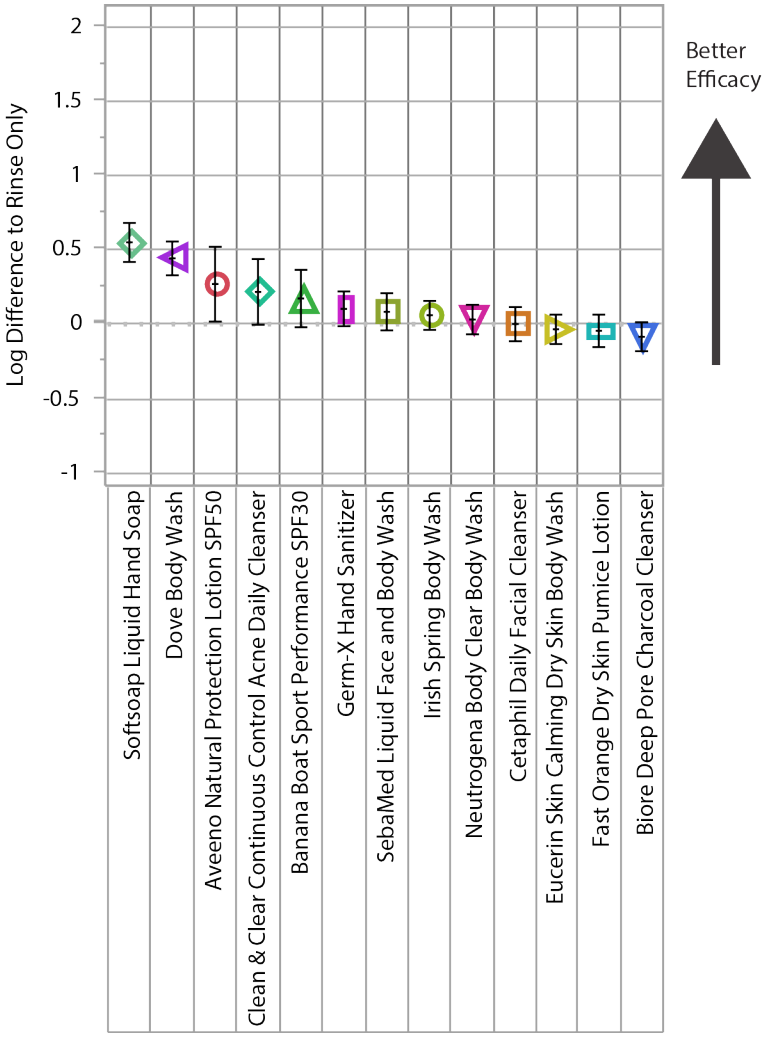

Figure 11. Log difference to rinse-only results for GD.

4.3 HD Results

Figure 12 presents the results for the HD on silicone barrier study. All products provided similar or better protection than the rinse-only treatment against HD absorption on silicone. There appeared to be an inverse relationship between decontamination and barrier performance for HD. Products that provided barrier efficacy against HD did not provide notable efficacy as a decontaminant. HD is a hydrophobic material; therefore, it would not readily interact with aqueous-based products. Most of the COTS products evaluated were aqueous based. The HD was most likely not very soluble in the material and remained at the surface of the barrier.

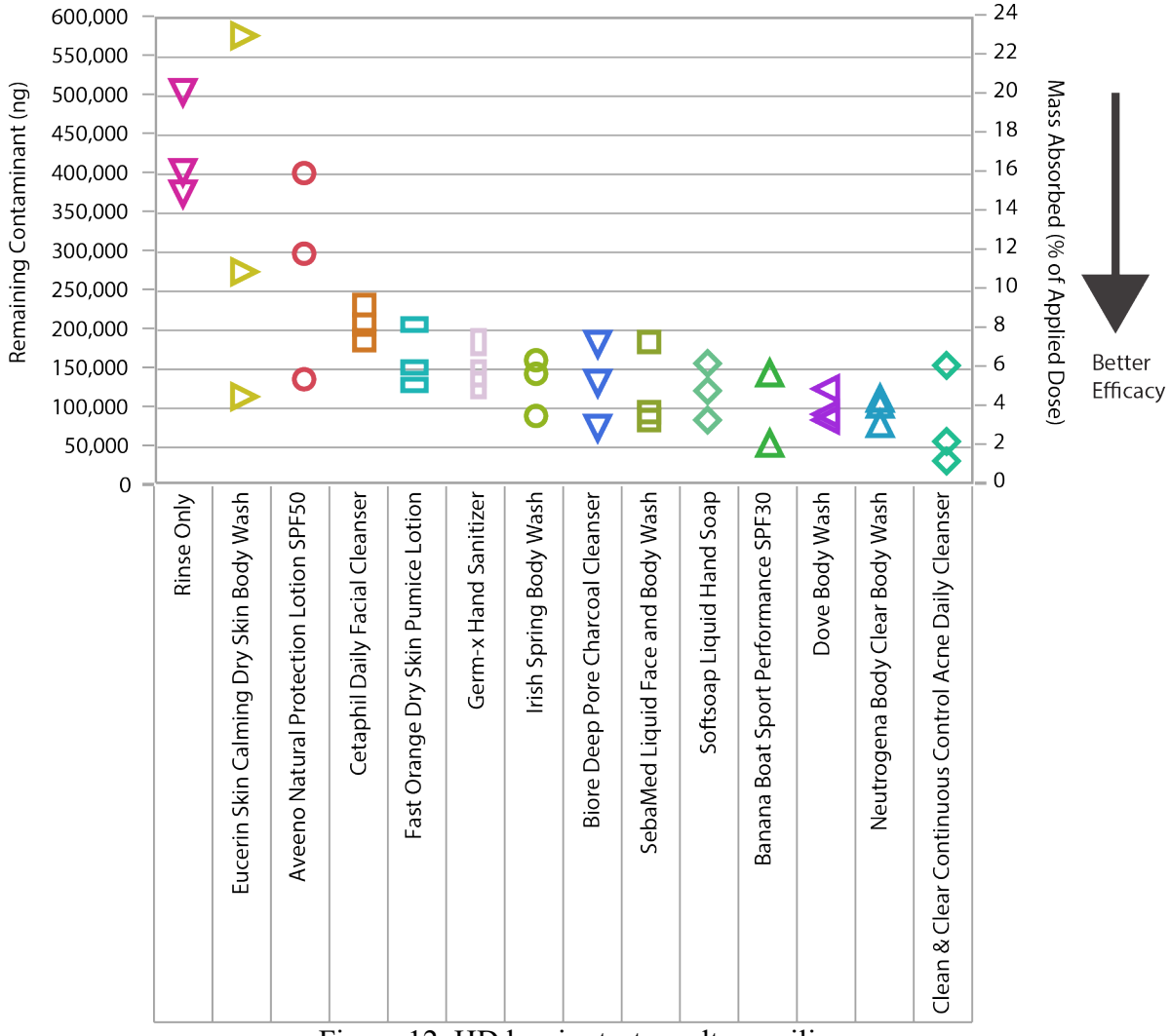

Figure 12. HD barrier test results on silicone.

Figure 13 presents the HD log-difference results for each barrier product compared to the rinse-only control. Much like GD, Softsoap liquid hand soap and Dove body wash were significantly better performers than the rinse-only treatment. These results indicate that these products may provide protection across a variety of chemistries.

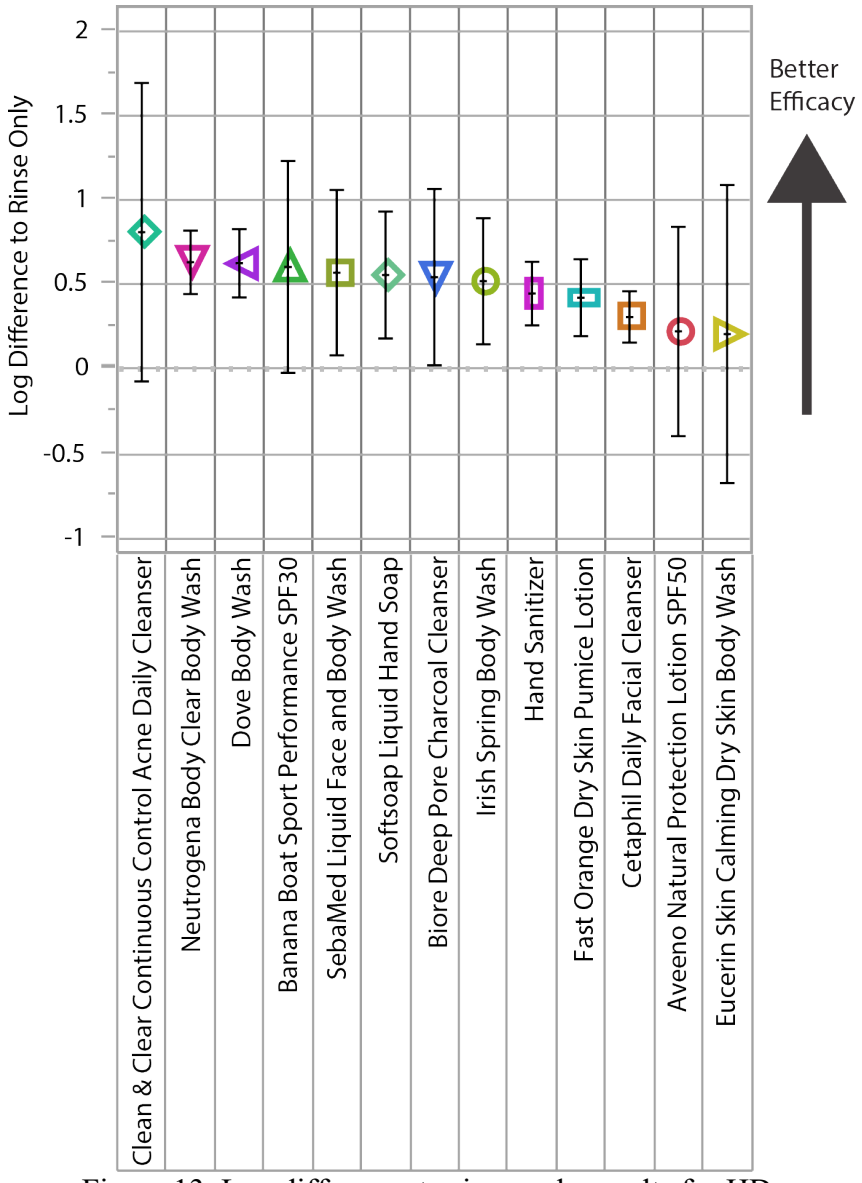

Figure 13. Log difference to rinse-only results for HD.

5. CONCLUSIONS

The evaluation of CWA decontamination products on skin has typically been executed in vivo to determine protection factors for the product of interest,[1,7,11,12] or in vitro via diffusion studies to determine the change in flux of a contaminant through excised skin caused by a decontamination treatment.[6,13–15] This study illustrated a novel technique to establish an initial ranking of product efficacy as skin decontaminants or barriers. The remaining contaminant test successfully illustrated differences in the amount of contaminant retained by a skin surrogate material after a treatment by a decontamination product. This study successfully quantified the performance of the COTS products on a skin surrogate. The best-performing products evaluated for removal of contaminant post-contamination are provided in Table 2.

Table 2. Products with Lowest Mean Remainder Contaminant on Strat-M Skin Surrogate

Contaminant	**Top Performer**	**Reduction in Starting Challenge* (%)**
VX	Softsoap liquid hand soap	82 ± 2
GD	Banana Boat sport performance SPF30	77 ± 7
HD	RSDL	69 ± 8

*Values are means ± standard deviations.

The remaining contaminant method used in this study determined the mass of contaminant remaining in or on a panel after a treatment. The method did not differentiate between physical removal and neutralization of the eliminated contaminant. Future studies may be warranted to determine the reactivity of the high-performing decontaminants with the contaminants. Although the removal of the contaminant from the skin surrogate may be due to physical removal alone, there is potential for the product to be reactive in the rinse effluent, thus reducing the hazard in the bulk liquid that may be present after decontamination procedures.

Design-Expert software (version 10.0; Stat-Ease, Inc.; Minneapolis, MN) was used to perform a multi-objective optimization related to the log difference with respect to a weathering reference condition, which delivered a global optimal decontaminant across all three contaminants. With no contaminant weighted higher or lower priority, the Eucerin skin calming dry skin body wash was determined to be the best overall decontaminant.

The top performing products evaluated as a barrier to contaminant absorption into a skin surrogate are provided in Table 3.

Table 3. Products with Lowest Absorbed Contaminant on Silicone Substrate

Contaminant	Top Performer	Contaminant Retained* (%)
VX	Clean & Clear continuous control acne daily cleanser	9 ± 0.1
GD	Softsoap liquid hand soap	12 ± 2
HD	Clean & Clear continuous control acne daily cleanser	3 ± 3

*Values are means ± standard deviations.

Design-Expert software was also used to perform a multi-objective optimization related to the log difference with respect to the rinse-only reference condition, which delivered a global optimal barrier cross all three contaminants. With no contaminant weighted higher or lower priority, the Clean & Clear continuous acne daily cleanser was determined to be the best overall barrier.

Much like the decontamination studies, the remaining contaminant method used for the barrier studies did not differentiate between neutralization and impedance of contaminant absorption by the barrier product. This study measured the mass of contaminant absorbed into a silicone substrate after 30 min. Future studies using high-performing barrier products are needed to determine the duration at which contaminant absorption is mitigated, whether the contaminant is neutralized by the barrier product, and the performance of the barrier products on different skin materials.

LITERATURE CITED

1. Braue, E.H., Jr.; Smith, K.H.; Doxzon, B.F.; Lumpkin, H.L.; Clarkson, E.D. Efficacy Studies of Reactive Skin Decontamination Lotion, M291 Skin Decontamination Kit, 0.5% Bleach, 1% Soapy Water, and Skin Exposure Reduction Paste against Chemical Warfare Agents, Part 2: Guinea Pigs Challenged with Soman. *Cutan. Ocul. Toxicol.* **2011,** *30* (1), 29–37.

2. Mantooth, B.A.; Willis, M.P.; Procell, L.; Davies, J. *Transport and Reactivity of Decontaminants to Provide Hazard Mitigation of Chemical Warfare Agents from Materials*; ECBC-TR-1383; U.S. Army Edgewood Chemical Biological Center: Aberdeen Proving Ground, MD, 2016. UNCLASSIFIED Report (AD1011071).

3. Wagner, G.W. Decontamination of Chemical Warfare Agents Using Household Chemicals. *Ind. Eng. Chem. Res.* **2011,** *50* (21), 12285–12287.

4. Lalain, T.; Mantooth, B.; Shue, M.; Pusey, S.; Wylie, D. *Chemical Contaminant and Decontaminant Test Methodology Source Document, Second Edition*; ECBC-TR-980; U.S. Army Edgewood Chemical Biological Center: Aberdeen Proving Ground, MD, 2012. UNCLASSIFIED Report (ADA566601).

5. Uchida, T.; Kadhum, W.R.; Kanai, S.; Todo, H.; Oshizaka, T.; Sugibayashi, K. Prediction of Skin Permeation by Chemical Compounds Using the Artificial Membrane, Strat-M™. *Eur. J. Pharm. Sci.* **2015,** *67*, 113–118.

6. Millerioux, J.; Cruz, C.; Bazire, A.; Polly, V.; Lallement, G.; Lefeuvre, L.; Josse, D. Evaluation of In Vitro Tests to Assess the Efficacy of Formulations as Topical Skin Protectants against Organophosphorus Compounds. *Toxicol. In Vitro* **2009,** *23* (1), 127–133.

7. Chilcott, R.P.; Dalton, C.H.; Hill, I.; Davison, C.M.; Blohm, K.L.; Clarkson, E.D.; Hamilton, M.G. Evaluation of a Barrier Cream against the Chemical Warfare Agent VX Using the Domestic White Pig. *Basic Clin. Pharmacol. Toxicol.* **2005,** *97* (1), 35–38.

8. Shue, M.; Lalain, T.; Mantooth, B.; Humphreys, P.; Hall, M.; Smith, P.; Sheahy, M. *Low-Level Analytical Methodology Updates to Support Decontaminant Performance Evaluations*; ECBC-TR-883; U.S. Army Edgewood Chemical Biological Center: Aberdeen Proving Ground, MD, 2011. UNCLASSIFIED Report (ADA546021).

9. Unaegbu, A.E.; Shue, M. *Interference Evaluations of HD, GD, and VX to Provide Confident Analytical Support for Contaminant-Material Interaction Studies*; ECBC-TR-1035; U.S. Army Edgewood Chemical Biological Center: Aberdeen Proving Ground, MD, 2013. UNCLASSIFIED Report (ADB392114).

10. Craig, F.N.; Cummings, E.G.; Sim, V.M. Environmental-Temperature and Percutaneous Absorption of a Cholinesterase Inhibitor, VX. *J. Invest. Dermatol.* **1977,** *68* (6), 357–361.

11. Braue, E.H., Jr.; Smith, K.H.; Doxzon, B.F.; Lumpkin, H.L.; Clarkson, E.D. Efficacy Studies of Reactive Skin Decontamination Lotion, M291 Skin Decontamination Kit, 0.5% Bleach, 1% Soapy Water, and Skin Exposure Reduction Paste against Chemical Warfare Agents, Part 1: Guinea Pigs Challenged with VX. *Cutan. Ocul. Toxicol.* **2011,** *30* (1), 15–28.

12. Misik, J.; Pavlik, M.; Novotny, L.; Pavlikova, R.; Chilcott, R.P.; Cabal, J.; Kuca, K. In Vivo Decontamination of the Nerve Agent VX Using the Domestic Swine Model. *Clin. Toxicol.* **2012,** *50* (9), 807–811.

13. Dalton, C.H.; Hattersley, I.J.; Rutter, S.J.; Chilcott, R.P. Absorption of the Nerve Agent VX (*O*-Ethyl-*S*-[2(di-isopropylamino)ethyl] Methyl Phosphonothioate) through Pig, Human and Guinea Pig Skin In Vitro. *Toxicol. In Vitro* **2006,** *20* (8), 1532–1536.

14. Loden, M. The Effect of 4 Barrier Creams on the Absorption of Water, Benzene, and Formaldehyde into Excised Human-Skin. *Contact Dermatitis* **1986,** *14* (5), 292–296.

15. Millerioux, J.; Cruz, C.; Bazire, A.; Lallement, G.; Lefeuvre, L.; Josse, D. In Vitro Selection and Efficacy of Topical Skin Protectants against the Nerve Agent VX. *Toxicol. In Vitro* **2009,** *23* (3), 539–545.

ACRONYMS AND ABBREVIATIONS

CI	confidence interval
COTS	commercial off-the-shelf
CWA	chemical warfare agent
DEVCOM CBC	U.S. Army Combat Capabilities Development Command Chemical Biological Center
DSB	Decontamination Sciences Branch
GD	soman
HD	distilled mustard
LD	log difference
LD50	median lethal dose
LDP	log-difference panel
RSDL	Reactive Skin Decontamination Lotion
SD2ED	*Chemical Contaminant and Decontaminant Test Methodology Source Document, Second Edition*
VX	*O*-ethyl *S*-(2-diisoproylaminoethyl) methylphosphonothiolate

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