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Personnel Decontamination Using Zirconium Hydroxide

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Numerous challenges are associated with decontamination of a military or civilian population that has been exposed to chemical agent contamination. One critical step in mitigating adverse health effects is preventing the absorption of chemical warfare agents into human skin. There has been recent interest in the development of a low-cost, U.S. Food and Drug Administration-cleared, toxic chemical-neutralizing countermeasure for use on unbroken skin. We aimed to meet this goal by exploring the use of zirconium hydroxide as a skin decontaminant. This study characterized the efficacy of $Zr(OH)_4$ in vitro and demonstrated the decontaminant provides similar or better agent removal compared to other established skin decontamination methods.

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O-Ethyl *S*-(2-diisopropylaminoethyl) methylphosphonothiolate (VX)
Sulphur mustard (HD)
Soman (GD)
Panel test
Percutaneous adsorption
Excised pig skin
Zirconium hydroxide
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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.

U.S. Army Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC; Aberdeen Proving Ground, MD) was previously known as U.S. Army Edgewood Chemical Biological Center (ECBC).

This report has been approved for public release.

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PERSONNEL DECONTAMINATION USING ZIRCONIUM HYDROXIDE

1. INTRODUCTION

Many challenges are associated with decontamination of a military or civilian population that has been exposed to chemical agent contamination. After a mass casualty, live-person decontamination event, one of the most critical steps in mitigating adverse health effects is preventing the absorption of chemical warfare agents (CWAs) into human skin. Skin decontamination methods used by the military have included the use of Skin Exposure Reduction Paste Against Chemical Warfare Agents as a barrier skin cream, the M291 Skin Decontamination Kit, 0.5% hypochlorite solution (household bleach diluted 1 to 10), and 1% soapy water solution, as well as Reactive Skin Decontamination Lotion (RSDL).[1,2]

There has been recent interest in the development of a low-cost, U.S. Food and Drug Administration (FDA)-cleared, toxic chemical-neutralizing countermeasure for use on unbroken skin. The current effort has aimed to meet this goal by exploring the use of zirconium hydroxide ($Zr(OH)_4$) as a skin decontaminant. This metal oxide has utility as a decontamination or filtration element[3] and has been shown to effectively neutralize CWAs. Using NMR, the half-lives of 3,3-dimethylbutan-2-yl methylphosphonofluoridate (soman or GD), sulphur mustard (HD), and *O*-ethyl *S*-(2-diisopropylaminoethyl) methylphosphonothioate (VX) when reacted with $Zr(OH)_4$ were shown to be 8.7, 138, and 1 min, respectively.[4] The neutralization ability of $Zr(OH)_4$ is critical, as other sorbent decontamination technologies such as Fuller's earth only provide physical removal of contamination from skin.[5] $Zr(OH)_4$ has also been developed as a component in a sprayable slurry for decontamination scenarios.[6] The current study aims to characterize the efficacy of the product in vitro and determine whether its use as a skin decontaminant provides similar or better agent removal compared to other established skin decontamination methods. A modified version of the remaining agent (RA) test procedure[7] using excised pig skin was developed to support the efficacy determination of different skin decontaminants, including $Zr(OH)_4$.

2. EXPERIMENTAL DETAILS

2.1 Experimental Approach

A two-phased approach was implemented for the assessment of $Zr(OH)_4$ skin decontaminant formulations. Initially, many formulations were screened against HD, GD, and VX on the Strat-M skin surrogate (MilliporeSigma; Billerica, MA) diffusion model. Those formulations showing the best efficacy were then tested against HD and GD and alongside other decontaminants on excised pig skin. For the studies described herein, the decontamination treatments with the best efficacy were those that resulted in the lowest RA.

2.2 Material Selection

The Strat-M diffusion model panel (product no. SKBM02560) is a synthetic two-layer system designed to mimic the interaction of a wide range of chemical compounds with human skin. Previous work has demonstrated that chemicals exhibit similar diffusion and partition parameters for Strat-M substrate compared to excised human and rat skin.[8] The Strat-M model has shown potential as an initial screening tool for the down-selection of formulations related to skin absorption.[9] Therefore, the model was chosen as the substrate to initially down-select promising skin decontamination formulations.

Once $Zr(OH)_4$ formulations were down-selected, further testing on the products was conducted on full-thickness excised pig skin. Historically, pig skin has proven to be an appropriate surrogate in vitro model for human skin absorption of a xenobiotic such as a CWA.[10–13] Details regarding the acquisition and handling of the pig skin are provided in Table 1. The skin was shipped to U.S. Army Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC; Aberdeen Proving Ground, MD) under dry ice and immediately stored in a freezer at –20 °C or lower for a maximum of 6 months prior to use.

Table 1. Pig Skin Information

Category	Description
Abattoir	Lampire Biological Laboratories
Breed	Yorkshire mix (white)
Gender	Female
Skin condition	Unscalded pig skin from the dorsal section of the pig
Age	5 months old
Handling	Hides were washed to remove debris, blood, and fecal matter. Hair was removed with an electric clipper against the grain. Subcutaneous fat was removed via hand trimming. Hides were cut into 1 × 1 in. square pieces and wrapped in aluminum foil.

2.3 Contamination

The HD, GD, and VX evaluations were completed using procedures modified from the *Chemical Contaminant and Decontaminant Test Methodology Source Document, Second Edition* (SD2ED).[7] Chemical Agent Standard Analytical Reference Material or high-purity agent was used. The purity on record for each agent was obtained from either NMR or gas chromatography–mass spectrometry (GC–MS) analyses. All purity documentation was maintained by the DEVCOM CBC Decontamination Sciences Branch. Each agent used was determined to be >85% pure. Chemical contaminants were used only in properly certified surety facilities capable of handling such materials safely. Personnel handling the chemical contaminants were fully trained and certified for such operations.

The Strat-M and pig skin substrate contaminations were performed in accordance with SD2ED contamination options for the test panels.[7] The chemical agent was removed from

cold storage and allowed to equilibrate to room temperature in the chemical surety hood prior to testing. The Strat-M panels were used as-received from the manufacturer. The pig skin was removed from the freezer and allowed to equilibrate to room temperature for approximately 1 h before testing. The impact of thawing time prior to the start of testing is explored in Section 3.2.2. The agent was applied using an Eppendorf Repeater plus pipette (part no. 2026020–1; Eppendorf; Hamburg, Germany). Each Strat-M panel received a 4 g/m^2 starting challenge applied as a 2 µL droplet on a 1 in. diameter panel. Each piece of pig skin received a 3.1 g/m^2 starting challenge applied as a 2 µL droplet on a 1 in. square panel. During the contamination–material interaction time, (i.e., time that deposited agent is permitted to interact with the material before any other treatment) contaminated panels were covered with a polystyrene petri dish prior to the application of the decontamination treatment.

2.4 Decontamination

The different decontamination techniques discussed throughout this report are described in the following subsections. A common rinse-only reference condition was executed throughout the test campaign. The rinse-only condition consisted of the test panel contaminated with agent for different agent–material interaction times, after which the substrate was rinsed with 120 mL of deionized (DI) water.

2.4.1 $Zr(OH)_4$ Description

Two types of $Zr(OH)_4$ in the form of powder (labeled B and C) were selected for the initial Strat-M screening. Differences between the selected $Zr(OH)_4$ powders are detailed in Table 2. Type B consisted of very small crystallites that form larger agglomerates, whereas type C consisted of much larger, spherical particles.[14] Scanning electron microscopy (SEM) images of the two types are shown in Figure 1.

Table 2. $Zr(OH)_4$ Characteristics as a Function of Type

Parameter	Type B	Type C
Micropore volume (mL/g)	0.17	0.20
Total pore volume (mL/g)	0.38	0.48
Hydroxyl ratio, O/Zr	3.4	3.6
Hydroxyl ratio, % terminal	21	35

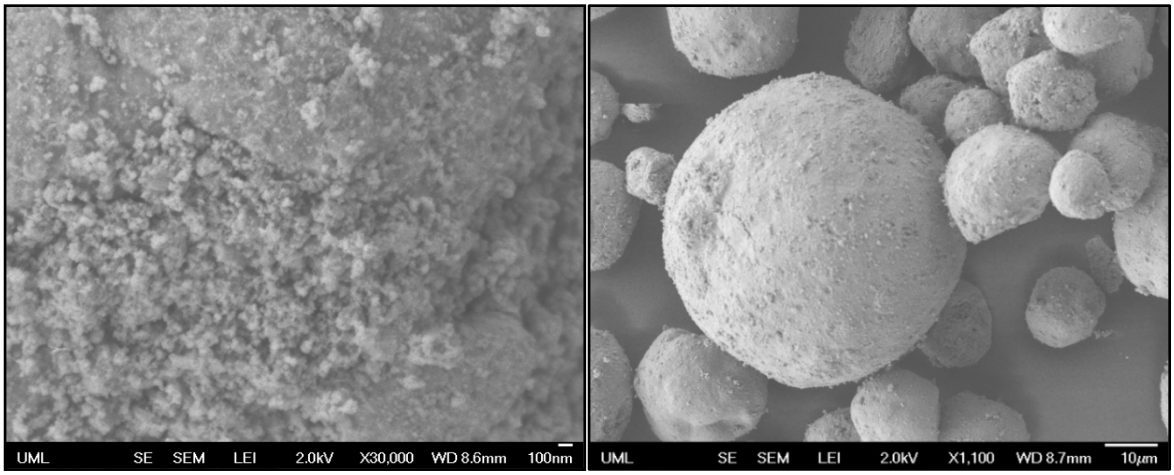

Figure 1. SEM images of type B (left) and type C (right) $Zr(OH)_4$.

2.4.2 Strat-M Substrate Screening Formulations

The formulations evaluated included type B and C $Zr(OH)_4$ powders mixed in different carrier liquids. The formulations are provided in Table 3. DI water was chosen as it is safe on skin and can increase the reactivity of $Zr(OH)_4$. Isopropanol was selected because of its ability to extract CWAs from materials; also, it is the main component of rubbing alcohol, a product routinely used on human skin. The water-and-isopropanol blends are safer alternatives to isopropanol alone and better represent the composition of rubbing alcohol. Another carrier liquid selected because it is regularly used in fragrances and as a food flavoring agent was 1-nonanol. It meets the criteria of the U.S. Environmental Protection Agency's Safer Choice Standard for human health and is acceptable for use on skin in a decontamination scenario. The compound has an octanol–water partition coefficient of 4.3 and is miscible with other alcohols that may also help solubilize hydrophobic agents such as HD. A rinse-only condition was also evaluated throughout the formulation screenings. Contaminated panels were rinsed with 120 mL of DI water after a 5 min agent–material interaction period. The rinse-only treatment was used as a reference condition, as various forms of water washing or rinsing are typical for skin cleaning.

Table 3. Formulations Used for Strat-M Substrate Evaluations

Formulation	$Zr(OH)_4$ Mass Used (g)	Comments
$Zr(OH)_4$ type B powder	3.7	Applied as powder alone
$Zr(OH)_4$ type C powder		Applied as powder alone
$Zr(OH)_4$ type B in 1-nonanol		100 wt %
$Zr(OH)_4$ type C in 1-nonanol		53 wt %
$Zr(OH)_4$ type B in DI water		100 wt %
$Zr(OH)_4$ type C in DI water		53 wt %
$Zr(OH)_4$ type B in isopropanol		100 wt %
$Zr(OH)_4$ type C in isopropanol		53 wt %
$Zr(OH)_4$ type C in 30/70 v/v isopropanol/DI water	1.25	25 wt %
$Zr(OH)_4$ type C in 50/50 v/v isopropanol/DI water		25 wt %
$Zr(OH)_4$ type C in 70/30 v/v isopropanol/DI water		25 wt %

After a 5 min agent–material interaction period, 250 µL of the liquid decontaminant formulation was applied to the contaminated panel using a positive-displacement pipette. The decontaminant covered the entire contaminated surface area of the panel. For the powder decontaminants, the allotted amount was sprinkled by hand over the contaminated area of the panel. After a 10 min decontaminant dwell time, the panels were rinsed with 120 mL of DI water to remove any excess decontaminant. Then the panels were extracted in agent-specific solvent to determine the RA on or in the panel after the decontamination process.

2.4.3 Excised Pig Skin Decontamination Products

Decontaminants that showed the best efficacy on Strat-M substrate were selected for further evaluation on contaminated pig skin. The chosen products are listed in Table 4. These decontaminants include the down-selected $Zr(OH)_4$ (described further in Section 3.1) and other field-relevant products. Unless otherwise described, the decontaminant was applied to the pig skin for 10 min, and the decontaminant was rinsed away from the skin using 120 mL of DI water.

Table 4. Decontaminants Used for Pig Skin Evaluations

Formulation	Decontaminant State	Mass or Volume Used	Justification for Evaluation
$Zr(OH)_4$ type C powder	Solid	Varies	Down-selected from Strat-M studies
RSDL	Liquid	0.25 mL	Currently fielded skin decontaminant

2.5 Remaining Contaminant Evaluation

Decontaminated Strat-M or pig skin panels were extracted to determine the mass of agent in the panel after the decontamination treatment. The Strat-M panels were placed in 20 mL clear scintillation vials with Teflon-lined polypropylene lids (product no. 170808; Scientific Specialties Service; Hanover, MD). Twenty milliliters of the appropriate solvent were added to the vials using a bottle-top organic solvent dispenser (part no. 4701351; BrandTech; New York, NY). The pig skin panels were placed in 250 mL glass jars with Teflon-lined polypropylene lids (product no. 170808; Scientific Specialties Service) and 40 mL of the appropriate solvent was added to the jars.

Several solvents could have been appropriate for use with chemical agent analytes. Prior method development activities involved selection of extraction solvents based on compatibility with the agents, the ability of the solvents to extract the agents from the test materials, and the chromatography analysis performances.[15] The solvents used for each agent are listed in Table 5.

Table 5. Extraction Solvent Selection per Agent

Agent	Solvent	Sigma Aldrich* Product Information
VX	Isopropanol	Product no. 650447-4L
GD	Acetonitrile	Product no. 34998-4L
HD	Chloroform	Product no. 650498-4L

*Sigma Aldrich; St. Louis, MO

The test panels remained in the extraction solvents for 60 min. At the end of the extraction period, each container was swirled to homogenize the extraction solution. A Pasteur transfer pipette (part no. 13–678–8C; Thermo Fisher Scientific; Waltham, MA) was used to place a sample into an autosampler vial for chromatography analysis. The details of these analytical techniques are described in previous reports.[15]

2.6 Interference Evaluations for Chromatography

Analysis of extraction samples was performed on instrumentation such as GC–MS or liquid chromatography–mass spectrometry. Confidence in a measured value depends on the ability of the analytical instrument to selectively detect and quantify the analyte of interest. The interference evaluation assesses all program matrices and defines sample preparation requirements to ensure accurate measurements of the analyte of interest without bias from interfering compounds

Analytical interference evaluations were performed using the format recommended in the SD2ED.[7] Matrices generated for interference testing were evaluated with and without the analyte of interest. Each representative matrix was generated without the presence of agent as a matrix blank. The matrix blank was evaluated directly for interferences such as false positives (i.e., detecting analyte when there was none). The sample matrix was also post-spiked to a known concentration of agent to determine if the known concentration was

accurately detected. Deviations from the known concentration indicate that the matrix was inducing bias in the result (i.e., the matrix was suppressing or enhancing the analyte signal). Multiple levels of post-spiking standard (PSS) solutions were prepared to known analyte concentrations. The PSS solutions were then spiked into aliquots of the matrix solution for analysis. Evaluating the matrix at multiple concentration levels allowed the determination of analytical confidence across a method's dynamic range.

Each unique matrix (i.e., each agent–material combination) was evaluated visually and analytically via chromatography methods for interference. Prior to analysis, visual inspection of the matrix sample determined suitability for analysis. A matrix that showed visible signs of interference (e.g., turbid or colored solutions) was not directly analyzed and required additional sample preparation before analysis (e.g., dilution). Interference evaluation was conducted in agreement with established acceptance criteria. For example, acceptable results required that the recovery value for the post-spiked matrix samples be 1.00 ± 0.2 (or $100 \pm 20\%$) when compared with the corresponding dose-confirmation sample reference concentration. Further interference evaluation was performed for any matrices not meeting acceptance criteria. Standard analytical techniques such as matrix dilution were used to minimize interference effects noted upon analytical quantitation of the analyte. Matrices were diluted prior to initial analysis based on visual interferences or observations from previous studies.

The output of interference evaluations resulted in sample preparation requirements that ensured the sample did not interfere with the analytical analysis. Sample preparation requirements entailed a minimum recommended dilution factor (DF). A minimum recommended DF is the minimum dilution at which no analytical interferences are noted. For example, a minimum recommended DF of 1 indicates that the sample matrix can be analyzed directly, with confident detection and quantification of the analyte and without bias from matrix interference. A minimum recommended DF of 10 indicates that the sample matrix may pose interference challenges at a DF lower than 10; therefore, all samples must be diluted by at least a factor of 10 for confident analysis. Matrix dilution may mitigate the interference; however, it may reduce the sensitivity for determining decontaminant efficacy. Matrix dilution is a balance between interference mitigation and required sensitivity.

Testing of all agent–material combinations indicated that a DF of 1 met the acceptance criteria of sample recovery within 1.00 ± 0.2 (i.e., there was no sample interference).

2.7 RA Data Analysis: Tukey–Kramer Test

The RA results for each agent–decontaminant combination were suitable for comparison using a Tukey–Kramer honestly significant difference analysis. There are many ways the mean value of data sets can differ. The Tukey–Kramer test indicates when one data set is different from the others. The Tukey–Kramer test controls the type 1 error (i.e., the probability of rejecting the null hypothesis even though it is true). This test is a single-step, multiple-comparison procedure that simultaneously considers all pair-wise comparisons. The goal is to compare the average effects of three or more data sets to decide which data sets are different from each other and by how much. The Tukey–Kramer test calculates a critical value that is used to evaluate whether differences between any two pairs of means are significant. The critical

value is determined using a studentized range statistic, the mean square error from the overall F-test, and the sample size for each group. The Tukey–Kramer test was used throughout this report to establish whether different test conditions resulted in statistically significant differences in RA.

3. RESULTS

3.1 Phase 1 Screening $Zr(OH)_4$ Decontaminants Using Strat-M Substrate

$Zr(OH)_4$ formulation down-selection screening was performed on the Strat-M substrate. The formulations (shown in Table 3) and their solvent controls were screened against HD, GD, and VX. The results are provided in Figures 2, 3, and 4, respectively. 1-Nonanol was not evaluated against VX.

The retention of HD was greater than that of GD or VX in the Strat-M substrate. In most cases, agent removal was improved when the active ingredient was present as compared to the results obtained for the carrier liquid alone. For HD and GD, the powder forms of $Zr(OH)_4$ were the top performers, as indicated by the lowest average mass of HD and GD remaining in the Strat-M substrate. $Zr(OH)_4$ type B in DI water was the top performer for VX, as indicated by the lowest average mass of VX remaining in the Strat-M substrate.

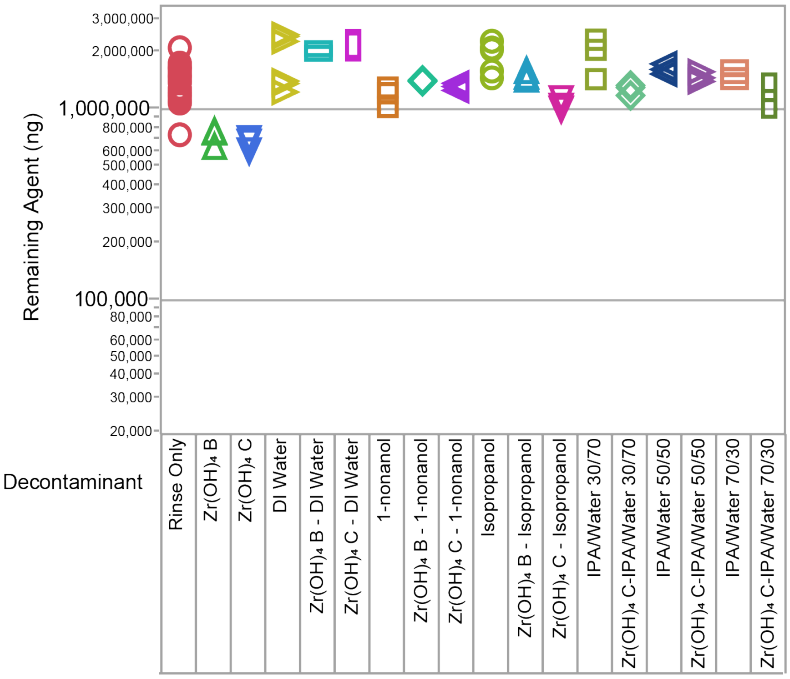

Figure 2. Results of HD on Strat-M substrate.

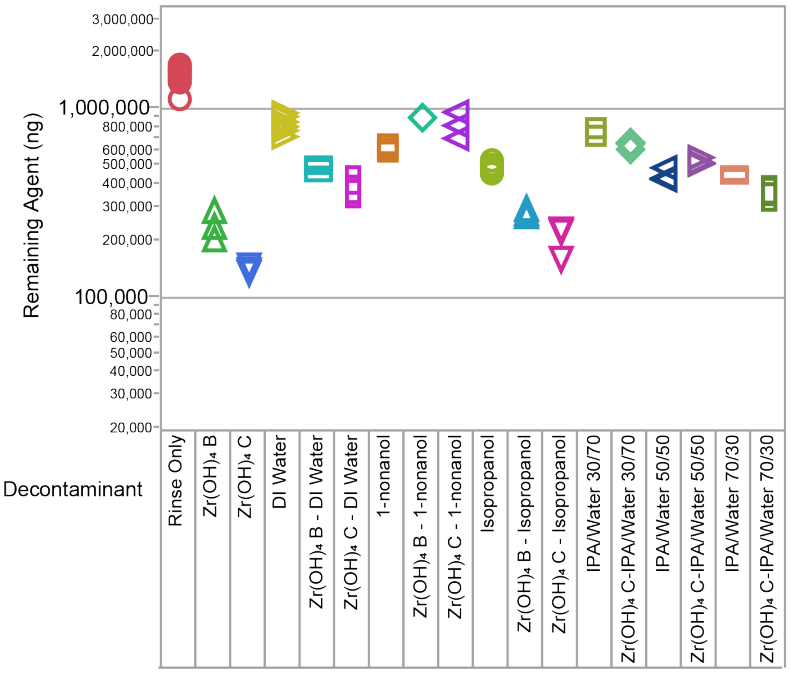

Figure 3. Results of GD on Strat-M substrate.

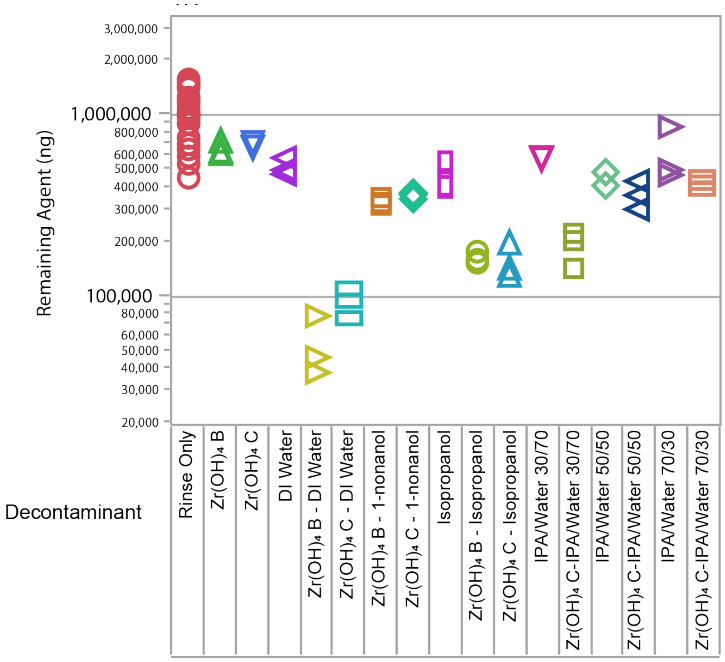

Figure 4. Results of VX on Strat-M substrate.

The Strat-M substrate evaluation was completed to down-select promising decontamination formulations and move forward into pig skin evaluations. The powders with no carrier liquid demonstrated the highest efficacy for GD and HD, whereas each powder in DI water was the top performer for VX. Because a dry decontaminant is advantageous for the

battlefield and logistically favorable (because no water is needed for use), the decision was made to move forward with $Zr(OH)_4$ type C powder. The differences in efficacy for the type B and type C powders were minimal; however, type C was chosen due to the improved efficacy observed with GD removal. Type C also had increased terminal hydroxyls that provided increased reactivity sites for acid and base hydrolysis of the agents.

3.2 Phase 2 Pig Skin Pre-Studies

3.2.1 Extraction Efficiency of Agents in Pig Skin

Decontaminant efficacy was measured via the RA test method throughout this study.[7] The RA test is a measurement of the mass of RA in and on a test material after a decontamination treatment. A pretest was necessary to determine whether the solvent extraction methods for each agent of interest would measure the true amount of agent left after a decontamination treatment.

Pig skin panels were contaminated with a known amount of each agent, and after set periods of time (age time), the skin was extracted. The amount of extracted agent mass was compared to delivered agent mass as measured by dose-confirmation samples collected during each test day. For ideal extraction efficiency, these values would be similar. The results of the study are provided in Figure 5. Recovery of 94% or greater was found for all conditions, apart from GD at the 60 and 90 min age times. The loss of GD was attributed to evaporation over the age time and not a deficiency in the ability to extract GD from the skin. The likely evaporation of GD was also reinforced by a set of stainless-steel control panels that were treated in the same manner as the pig skin. Stainless steel is an impermeable material; therefore, all present GD remains on the surface of the material and is readily removed via solvent extraction. It was assumed that any GD losses observed with this condition were due to agent evaporation. After a 90 min age time, the average percentage of the original mass applied of GD extracted from the stainless steel was 71.31 ± 8.23, similar to the pig skin at the same conditions. The results indicate that agent can be successfully extracted from pig skin using current techniques.

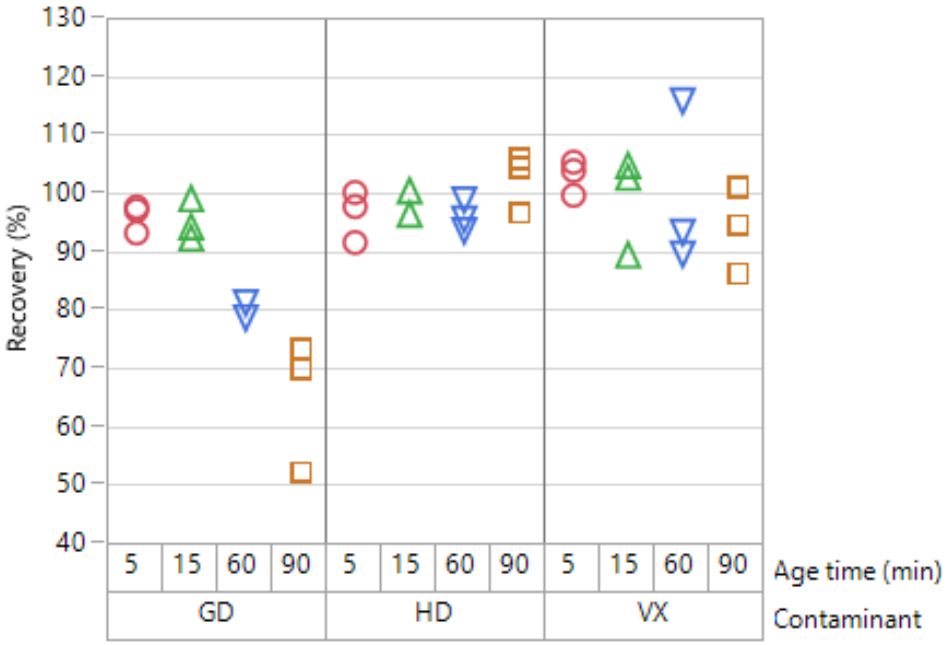

Figure 5. Extraction efficiency results for pig skin.

3.2.2 Pig Skin Thaw-Time Evaluation

For the decontamination evaluations detailed in this report, it was necessary that the agent spread across and absorbed into excised pig skin in the same way as for live pig skin. It was important that each decontaminant was assessed against the same agent presentation on the skin. Consistent agent spread and absorption into the skin are critical characteristics when assessing decontaminant performance. The excised skin was frozen after collection to maintain the integrity of the skin. It was brought to room temperature at the time of the test to ensure the physiology of the skin was not negatively impacted.

The Decontamination Sciences Branch laboratories are equipped to test up to 90 individual test panels in a single test session. The timing of each action applied to a test panel, such as contamination and decontamination, was specifically planned so that each panel was treated in the same manner. The test panels were placed in a temperature- and humidity-controlled chamber prior to the start of the test. Test panels were contaminated every 30 s to 1 min. Because up to 90 panels were tested in each session, this corresponded to a 45–90 min delay between contamination of the first and last test panels. For inert test substrates (such as a metal or polymeric material), the time elapsed from the start of the test until agent application does not affect the agent interaction with the material. This may not be the case for a tissue such as pig skin, given it was originally a living system that was maintained by the underlying blood flow of the animal.[16] Once excised, the skin is lacking in functioning physiological and metabolic systems, which can limit tissue integrity. Therefore, it was critical to assess whether variability in agent–pig skin interactions was observed at different thaw times. Thaw in this context indicates the time that elapsed between the pig skin removal from a –20 °C freezer and when agent was applied.

To determine whether changes in the pig skin thawing period prior to contamination influenced RA results, $Zr(OH)_4$ type C was applied to an identical starting challenge of HD, GD, and VX on pig skin. It was assumed that if changes in agent–pig skin interactions were changing with thaw time, the decontaminant performance would also change. The pig skin was removed from the freezer and contaminated after 30, 60, or 120 min post-removal. A 2 μL droplet of agent was applied to the pig skin. After a 5 min age time, the solid decontaminant mass of 0.125 g was applied to the contaminated area. After 10 min, the decontaminant was rinsed away with 120 mL of DI water. The substrate was then extracted to determine the amount of RA after the decontamination treatment.

Figure 6 shows the RA mass for each skin thaw time evaluated. The overlapping circle visualization of the Tukey–Kramer analyses for each agent indicated that there was no significant difference between the RA results across the evaluated thaw times. With the exception of HD at the 30 min thaw time, the $Zr(OH)_4$ decontamination treatment resulted in greater than 90% removal of agent from the pig skin, with many cases exceeding 95% agent removal. The results indicate that the mass of RA by the pig skin is not strongly influenced by thaw times ranging from 30 to 120 min.

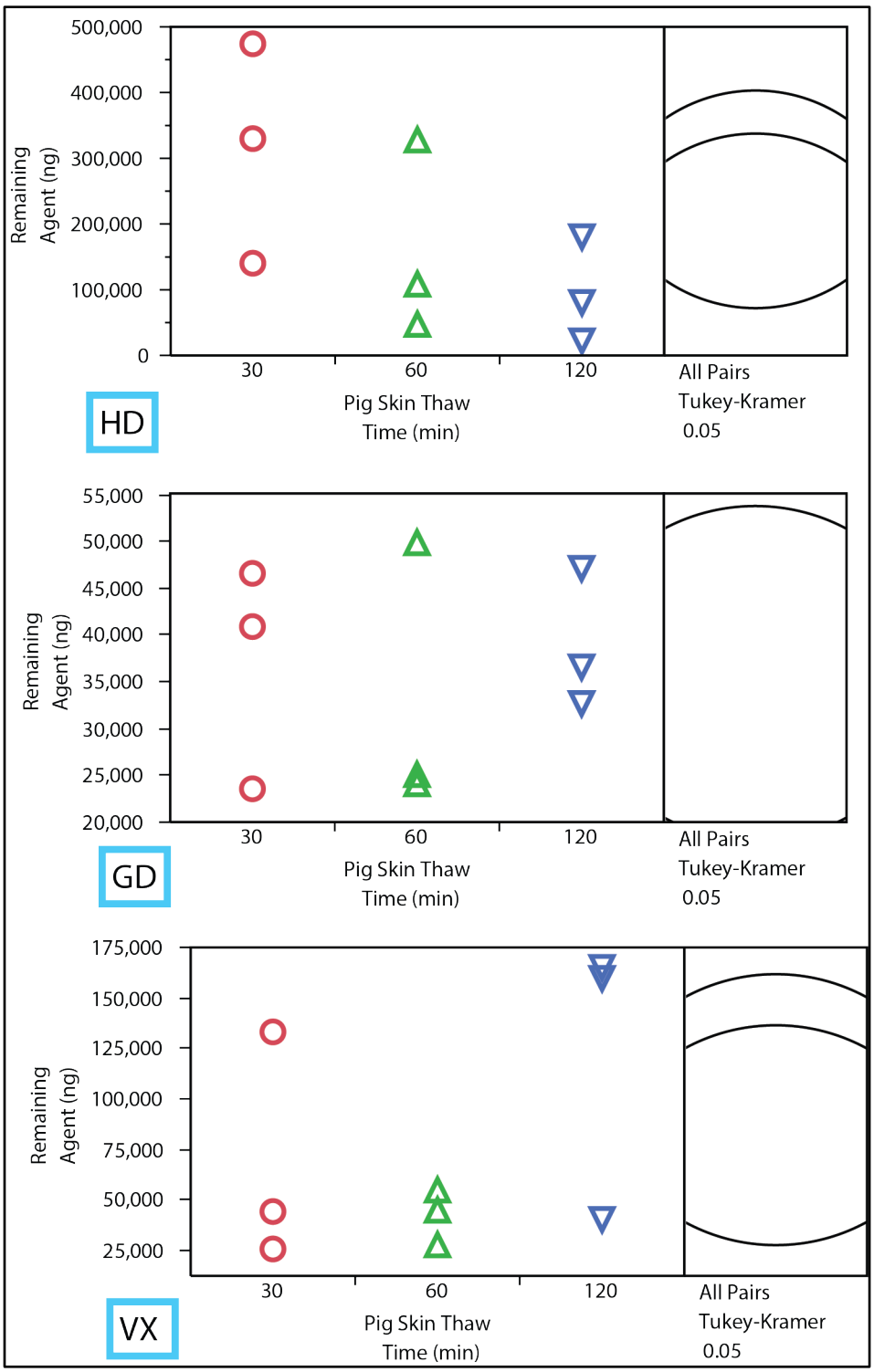

Figure 6. RA results across pig skin thaw durations.

3.3 Phase 2 Pig Skin Efficacy Results

$Zr(OH)_4$ type C was evaluated against HD-, GD-, and VX-contaminated pig skin in a variety of configurations to better understand the performance envelope of the technology. Efficacy, in these cases represented by lower RA results, was examined under an immediate decontamination scenario as well as when parameters such as decontaminant mass and decontaminant dwell time were varied.

3.3.1 Immediate Decontamination of Agent on Pig Skin Results

The $Zr(OH)_4$ type C powder was evaluated along with the fielded decontaminant RSDL. The decontamination efficacy results are provided in Figure 7. Each decontaminant was applied in two variations. The liquid RSDL was applied to the contaminated panel as liquid alone or rubbed into the skin with the sponge provided in the RSDL packet. The $Zr(OH)_4$ type C was applied as a powder that sat on the surface or was rubbed into the skin clockwise for three full rotations.

Control panels rinsed with water (i.e., rinse only) were included to track the variability of agent absorption and retention in the pig skin panels. The current data set was collected across seven individual test sessions. Generally, the rinse-only results spanned an order of magnitude for each agent. The results for a given decontaminant were typically more reproducible than those for the rinse-only panels.

The efficacy results for the $Zr(OH)_4$ type C treatments resulted in similar or greater performance than the RSDL treatments, as demonstrated by the similar or lower RA results. Rubbing the RSDL into the skin resulted in better performance for each agent. Rubbing the $Zr(OH)_4$ into the skin potentially increased efficacy for GD and VX; however, the efficacy did not appear to be increased when rubbing the powder for HD. The $Zr(OH)_4$ treatments resulted in similar or decreased RA for contaminated pig skin when compared to the RSDL treatments for each agent evaluated.

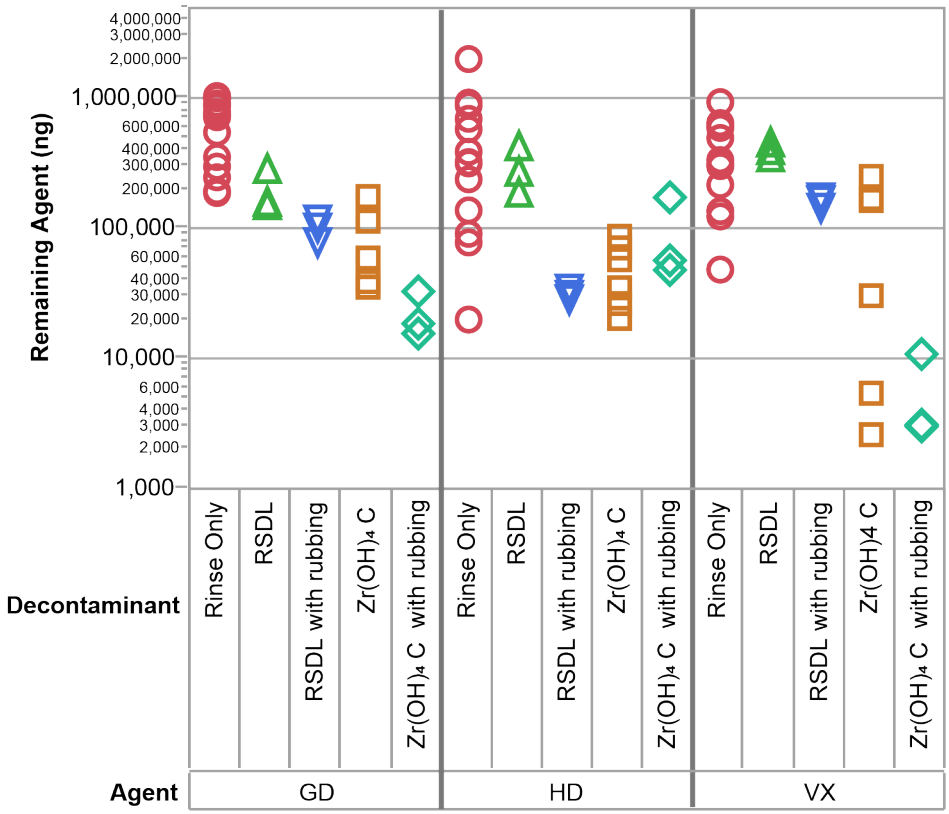

Figure 7. $Zr(OH)_4$ type C and RSDL on pig skin results.

3.3.2 $Zr(OH)_4$ Type C Decontaminant Mass Comparison Results

The mass of $Zr(OH)_4$ powder applied was varied for similar starting challenges of HD, GD, and VX on pig skin to determine if the decontaminant mass affected decontamination performance. The smallest mass of $Zr(OH)_4$ evaluated was approximately 12.5× more decontaminant than applied agent. The powder was applied directly to the contaminated panel and was not rubbed in any manner.

Figure 8 presents the results of the study with corresponding Tukey–Kramer analysis visualizations. The overlapping circles of the Tukey–Kramer analyses show there was no significant difference in the RA for HD and GD for the different masses of $Zr(OH)_4$ applied, but there was a significant difference in remaining VX between 0.065 and 0.025 g of $Zr(OH)_4$ applied. Surprisingly, the smaller mass of $Zr(OH)_4$ resulted in the lower mean remaining VX on the pig skin. In all cases investigated, more than 88% of agent was removed from the pig skin; in many cases, agent removal exceeded 95%. The results suggest that a small mass of $Zr(OH)_4$ type C powder is sufficient to absorb and remove agent from pig skin.

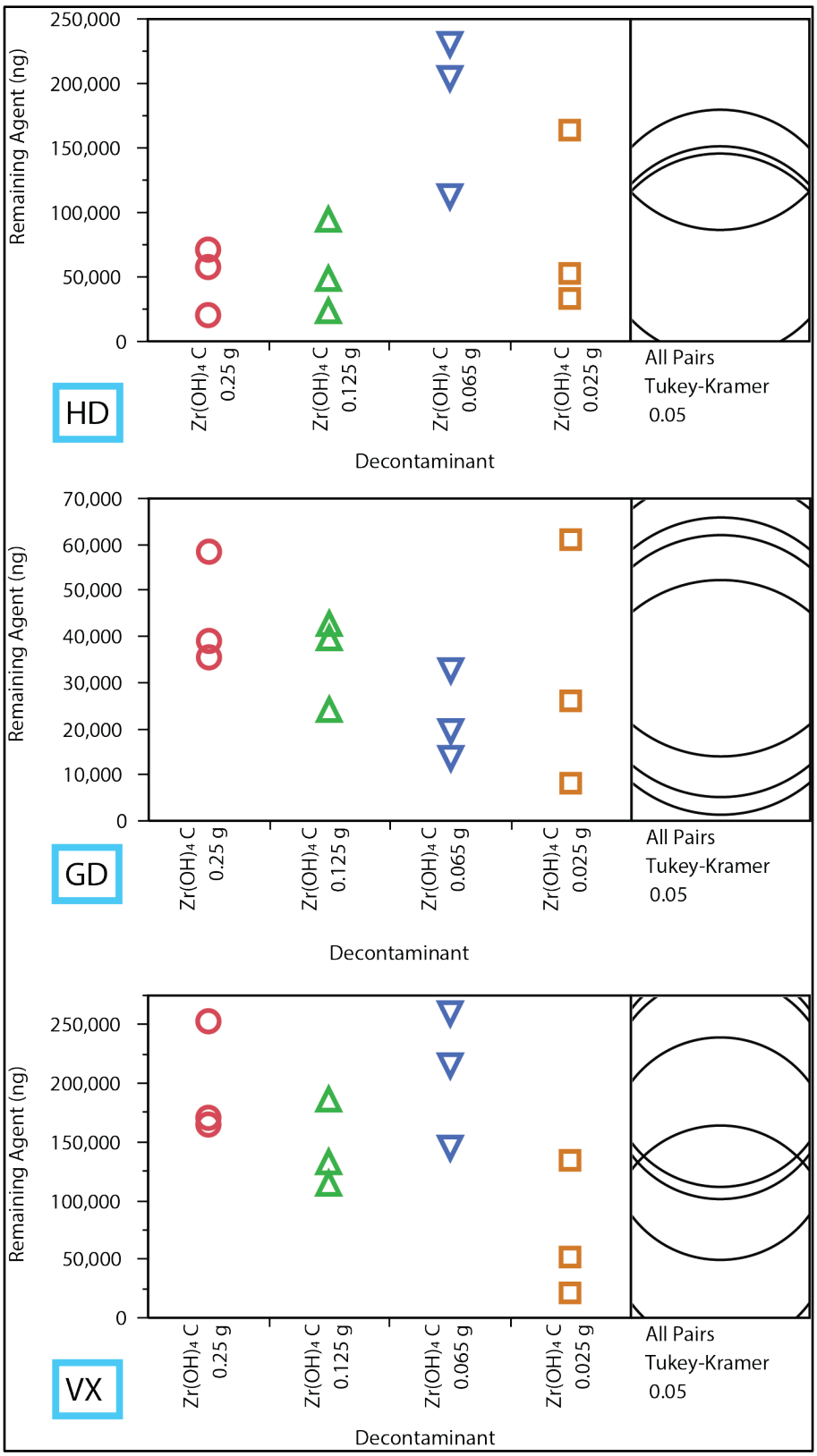

Figure 8. Decontaminant mass results.

4. CONCLUSIONS

There are advantages to developing a novel dry personnel decontaminant (i.e., not requiring water for decontaminant preparation or use). Water is a scarce commodity in certain environments and, as such, it is useful to provide efficacious products to the warfighter that do not require water. A dry decontaminant would also be useful in colder climates where any available water is likely frozen. The results from the pig skin studies provide a basis for $Zr(OH)_4$ to be considered for maturation as a novel skin decontaminant. The $Zr(OH)_4$ agent removal from CWA-contaminated, full-thickness pig skin is similar or better than that of the currently fielded RSDL in vitro, and its use does not require water. When applied soon after contamination, small amounts of the powder may provide sufficient agent removal from skin.

Further work is necessary to enable the acceptance of the $Zr(OH)_4$ product as an FDA-approved product. The tests described in this study were executed on full-thickness pig skin. The RA measurements obtained from full-thickness skin do not identify where the agent has been retained (i.e., whether RA was in the stratum corneum and potentially available for decontamination or if it was absorbed into the lower levels of the skin and underlying vascular system). Franz diffusion cell studies would be appropriate to better understand the absorption dynamics of agent in skin with and without decontamination. Matar et al. have completed similar appropriate studies against CWAs on pig skin.[13] Additional studies to understand the mode of action for the powder would also be useful, including assessment of the interactions of $Zr(OH)_4$ with the CWAs along with the interactions of $Zr(OH)_4$ with human skin (e.g., skin irritation potential). In vivo testing on an appropriate animal model would also be useful to further determine the efficacy of the powder decontaminant as an immediate personnel decontamination product.

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ACRONYMS AND ABBREVIATIONS

CWA	chemical warfare agent
DEVCOM CBC	U.S. Army Combat Capabilities Development Command Chemical Biological Center
DF	dilution factor
DI	deionized
FDA	U.S. Food and Drug Administration
GC–MS	gas chromatography–mass spectrometry
GD	soman; 3,3-dimethylbutan-2-yl methylphosphonofluoridate
HD	sulphur mustard
PSS	post-spiking standard
RA	remaining agent
RSDL	Reactive Skin Decontamination Lotion
SD2ED	*Chemical Contaminant and Decontaminant Test Methodology Source Document, Second Edition*
SEM	scanning electron microscopy
VX	*O*-ethyl *S*-(2-diisopropylaminoethyl) methylphosphonothioate

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