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Efficacy of DECON Green against VX Nerve and HD Mustard Simulants at Subfreezing Temperatures

Charles M. Reynolds, David B. Ringelberg, and Lawrence B. Perry

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Prepared for Edgewood Biological Chemical Center, U.S. Army RDECOM

Abstract: The objective of these studies was to quantify the efficacy of DECON Green against the VX nerve agent simulant bis (2-ethyl hexyl) phosphite and the HD mustard agent simulant 2-chloroethyl phenyl sulfide when used below 0°C relative to DECON Green use above 0°C. The efficacy of the DECON Green formulations was tested at 4°, –5° and –15°C using both dermal transfer and mass balance approaches. Dermal transfer measurements simulated the transfer of agent to skin. The mass balance approach addressed the fate of simulant by quantifying simulant recovery following each step of a decontamination process. Simulant that could not be accounted for in the mass balance was attributed to simulant degradation, and the effect of DECON Green was separated from other effects. Two formulations of DECON Green were investigated: the "standard" formulation, New DECON Green, and the "cold weather" formulation, CA^2WT. At controlled temperatures, simulants were spread on aluminum disks or "coupons" that were treated with Chemical Agent Resistant Coating (CARC). The CARC coupons were subsequently decontaminated using standard U.S. Army testing procedures. At all temperatures investigated, sequential dermal contact transfers of the simulant were three (on the HD mustard-agent simulant) to four (on the VX nerve-agent simulant) times lower following the application of DECON Green and washing than without DECON Green or without washing. The mass balance data showed that washing with a propylene glycol:H_2O solution was an important part of the decontamination process. DECON Green both degraded the simulant and improved simulant removal by washing. These findings indicate that at both –5° and –15°C, conditions where water-based procedures would be problematic, DECON Green and washing with propylene glycol:H_2O can be effective at reducing surface contact hazards from chemical agent simulants.

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Preface

This report was prepared by Dr. Charles M. Reynolds, David B. Ringelberg, and Lawrence B. Perry, Environmental Sciences Branch, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC), Hanover, New Hampshire. This project was supported by Dr. George Wagner of the U.S. Army Edgewood Chemical Biological Center at the Aberdeen Proving Ground, Maryland. The CRREL Product Delivery Team included Susan E. Hardy, Environmental Sciences Branch; Dale R. Hill, Office of the Technical Director; and the report authors.

This report was prepared under the general supervision of Dr. Terry Sobecki, Chief, Environmental Sciences Branch; Dr. Lance Hansen, Deputy Director; and James L. Wuebben, Acting Director, CRREL.

The Commander and Executive Director of ERDC is COL James R. Rowan. The Director is Dr. James R. Houston.

1 Introduction

DECON Green is an environmentally benign decontaminant developed by the U.S. Army. Compared to existing decontamination agents, DECON Green is less corrosive and does not leave behind heavy or toxic residues (Wagner and Yang 2002). DECON Green is a solution containing hydrogen peroxide, potassium carbonate, potassium molybdate, other activators, propylene carbonate, and Triton® X-100, a nonionic surfactant. In use, the carbonate and molybdate components activate the peroxide component to produce highly reactive peroxy anions (OOH^-). Hydrolysis of nerve agents VX and GD (Soman) and oxidation of the mustard agent HD to non-toxic byproducts have been previously demonstrated (Wagner and Yang 2002). Two formulations of DECON Green were investigated: the "standard" formulation, New DECON Green, and the "cold weather" formulation, CA^2WT.

The U.S. Army has developed standard operating procedures for decontaminating surfaces exposed to chemical warfare agents. An exposed surface is initially washed with water to remove dirt and soil, a decontaminant is then applied (with scrubbing, if needed), and the surface is given a final rinse with water. From a practical standpoint, freezing temperatures can adversely affect the decontamination process by impeding the application of water-based detergents, decontamination agents, and rinse water. Below 0°C, a glycol-based antifreeze rinse solution without an initial detergent wash may be needed to avoid freezing problems. Equipment can also malfunction in the cold. Application spray nozzles, often metal, can rapidly freeze closed (Parker and Walsh 1991). Metering valves can also be temperature dependent and sensitive to cold (Reynolds et al. 2006).

Temperatures below 0°C can also alter the chemical state of a decontaminant, causing an increase in viscosity. This may enhance contact times with the contaminated surface, especially if the surface is vertical, but it may also limit the flow of decontaminating solution to less accessible areas. Additionally, colder temperatures usually result in slower chemical reactions, including those involved in the decontamination of chemical warfare agents. Rates of hydroxy radical formation can vary by two orders of magnitude in a temperature range of –50° to 50°C. (The active ingredi-

ent of DECON Green is the free radical peroxy anion.) The effects of low-temperature on the efficacy of DECON Green are unknown.

The objective of these studies was to quantify the efficacy of the cold-weather formulation CA^2WT at two subfreezing temperatures, –5° and –15°C, relative to standard New DECON Green at 4°C using the nerve agent simulant bis (2-ethyl hexyl) phosphite (BIS) and the HD mustard agent simulant 2-chloroethyl phenyl sulfide (CEPS).

2 Materials and Methods

Test Facilities

All tests were performed at the U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). Tests were performed in controlled-temperature coldrooms maintained within 2°C of 4°, –5°, or –15°C.

Experimental Approach

The efficacy of the DECON Green formulations was tested using a dermal-contact transfer protocol and a mass balance approach. In brief, aluminum disks or "coupons" treated with a chemical agent resistant coating (CARC) were exposed to the nerve agent simulant BIS and the HD mustard agent simulant CEPS and then decontaminated using a laboratory-scale version of current U.S. Army decontamination standard operating procedures. Dermal transfer measurements were made to quantify the amount of simulant that may transfer from a CARC surface to skin. Mass balance data were assessed to determine both the percent removal of simulant from the CARC coupon and the extent of simulant degradation that occurred.

Two formulations of DECON Green were investigated; the "standard" formulation, New DECON Green, and the "cold weather" formulation, CA^2WT DECON Green. The freezing point of CA^2WT is significantly lower than that of New DECON Green.

CARC Preparation and Experimental Design

Five-cm- (2-in.-) diameter aluminum CARC coupons were prepared at the U.S. Army Aberdeen Proving Ground to specifications typical of the coating used on military vehicles. A completely random design was used to evaluate DECON Green efficacy against the two simulants. The U.S. Army standard operating procedure of an initial water wash, followed by decontamination, and then a final water rinse was modified for cold temperatures. The decontamination procedure tested here consisted of decontamination with DECON green followed by a wash with propylene glycol:H_2O (1:1, v:v). A no-DECON/no-wash control and a no-DECON/wash control

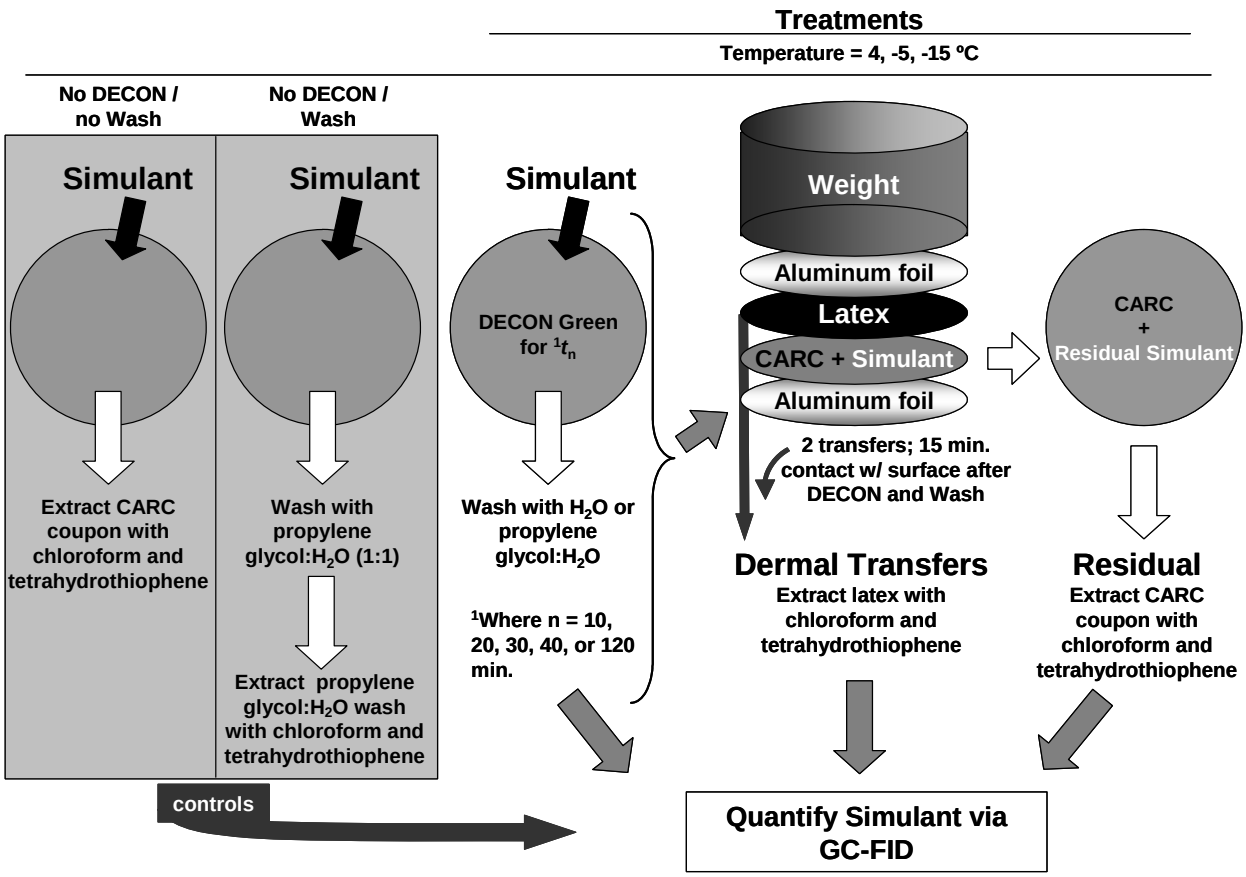

Figure 1. Experimental protocol.

were included to aid in delineating temperature effects on decontaminant efficacy from other mechanisms of decontamination.

Definitions of terms follow, and a summary description of the experimental protocol is provided in Figure 1.

Treatment denotes the temperature and formulation of DECON Green used.

DECON time refers to the amount of time that DECON Green reacted with the simulant on the coupon surface. DECON time ranged from 10 to 120 minutes.

Wash refers to the use of propylene glycol:H_2O (1:1, v:v) to remove unreacted simulant and DECON Green from the coupon surface prior to initiation of dermal transfer. Wash was collected and analyzed for the simulants. These data were also used in the mass balance. For the no-

DECON/wash control treatments, the wash contained stimulant removed from the coupon by propylene glycol:H_2O.

Dermal transfer refers to the use of latex patches to mimic the transfer of simulant from the CARC surface to skin. Two dermal transfers were done sequentially for each coupon. Dermal transfers lasted for 15 minutes, and they were made from 0 to 15 minutes and from 30 to 45 minutes following decontaminating and washing of simulant-treated coupons.

Residual simulant refers to simulant that remained on the coupon following decontamination, wash, and dermal transfers as specified. Residual indicates the simulant that was neither washed off by propylene glycol:H_2O, degraded by DECON Green, nor transferred during the dermal transfer process. Residual simulant was determined by GC following chloroform extraction of the coupon.

No-DECON control/no-wash refers to the addition of simulant to the coupon, followed by neither a wash nor decontamination with DECON Green.

No-DECON control/wash refers to coupons that received simulant, were not decontaminated with DECON Green, but were washed with propylene glycol:H_2O. Here we measured for the effect of washing alone.

Simulant Application

CARC coupons were allowed to equilibrate to test temperatures of –15°, –5°, or 4°C prior to simulant application. At each temperature, CARC coupons received ten 2-µL drops of 1 mg μL^{-1} of one simulant (98% CEPS or 96% BIS, Sigma-Aldrich, Milwaukee, WI) to achieve a simulant surface coating of 10 g m^{-2}. The simulant was spread evenly on the CARC coupon using a Teflon cell scraper, then covered with a glass petri dish (60 × 15 mm) and allowed to equilibrate for 1 hour. Sufficient coupons were used to provide six replicates for both controls and DECON time intervals of 10, 20, 30, 40, and 120 minutes.

Decontamination

After simulant application and 1 hour of equilibration, 1.0-mL aliquots of CA^2WT DECON Green for –15° and –5°C or New DECON Green for 4°C were evenly spread on each of six replicate CARC coupons for each of the DECON time intervals. DECON Green was spread onto the coupons using

a Teflon cell scraper, and each coupon was then covered with a glass petri dish to minimize DECON Green evaporation.

DECON times on the CARCs were 10, 20, 30, 40, and 120 minutes. Following the DECON time, coupons were placed vertically over a collection beaker and washed with two 20-mL aliquots of propylene glycol:H_2O (1:1, v:v) on the front side and one 20-mL aliquot on the back side to remove DECON Green and simulant. The entire 60 mL of propylene glycol:H_2O wash was collected and then extracted with 20 mL of chloroform (99.9+% capillary GC/GC-MS grade, Burdick and Jackson, Muskegon, MI) for 1 hour by rotary shaking at 150 rpm at 28°C. Tetrahydrothiophene (99%, Sigma-Aldrich, Milwaukee, WI) was added to the chloroform extracting solution at 0.1% (v:v) to quench residual oxidation. The propylene glycol:H_2O and chloroform phases were allowed to separate fully before 1 mL of the chloroform phase was transferred to a 2-mL sample vial for analysis by gas chromatography with flame ionization detection (GC-FID). The coupons remained vertical and then were air dried for 15 minutes, followed by further drying with a jet of compressed air for approximately 5 seconds to remove any residual propylene glycol:H_2O wash.

Dermal Transfer Protocols

The potential for dermal transfer of simulant using latex patches was determined at each test temperature. Dermal transfers were simulated by placing the CARC coupon on aluminum foil, overlaying the coupon with a 5-cm-diameter piece of latex (Dental Dam, natural rubber latex, Henry Schein Inc., no. 101-3751), covering the latex with another 5-cm-diameter circle of aluminum foil, and topping it with a 1-kg weight (Fig. 1), providing a contact pressure of approximately 50 g cm^{-2}. After 15 minutes, the weight was removed and both the latex and aluminum foil were placed in a vial containing 20 mL chloroform.

This process was then repeated to obtain two sequential dermal transfers. The first dermal transfer occurred from 0 to 15 minutes following decontamination and wash protocols, and the second dermal transfer occurred from 30 to 45 minutes following decontamination and wash protocols.

The foil and CARC coupon for each dermal transfer at each temperature were then extracted for 1 hour by rotary shaking at 150 rpm at 28°C.

Following extraction, an undiluted aliquot of chloroform was transferred to a 2-mL sample vial for analysis by GC-FID.

Recovery of Residual Simulant from CARC Coupons

Following decontamination with DECON Green, washing with propylene glycol:H_2O (1:1, v:v), and dermal transfers to latex patches, we measured the residual simulant on the CARC coupons by extracting each coupon in 20 mL of chloroform with rotary shaking at 150 rpm at 28°C for 1 hour. An undiluted aliquot of chloroform was then transferred to a 2-mL sample vial for analysis by GC-FID.

Chemical Analysis

The recovered simulant mass was determined in the following fractions: (1) propylene glycol:H_2O wash, (2) each of two sequential dermal transfers, and (3) the residual simulant remaining on each CARC coupon.

A Hewlett Packard 6890 GC-FID and a 7683 series autoinjector were used to quantify the simulant mass in each sample fraction. For GC-FID analysis, five or more calibration standards of simulant ranging from 50 to 1000 ng μL^{-1}, were analyzed at the beginning of each day's analyses. The GC was recalibrated if the correlation coefficient of signal to concentration was less than 0.990. Six replicate standards, 1000 ng μL^{-1}, were analyzed subsequent to each group of samples.

Definition of Dependent Variables and Statistical Analysis

The percent of simulant recovered in the various fractions, the percent removed from the CARC coupon surface, and the percent unaccounted for were calculated as described below. Percentages were based on the mass of simulant detected by GC-FID in the respective sample fractions relative to the mass added to each coupon.

Percent simulant recovered was calculated as the sum of the mass of simulant detected in (1) the wash, (2) the two dermal transfers, and (3) the residual on the coupon surface, divided by the total mass added to the coupon, and is expressed as a percentage.

Percent simulant removed was calculated as the difference between the amount applied to the CARC coupon minus the sum of the masses of

simulant detected in (1) the two dermal transfers and (2) the residual on the coupon surface. This difference was expressed as a percentage of the total mass of simulant added.

Percent simulant unaccounted for is the difference between the mass of simulant recovered and the mass of simulant added, expressed as a percentage of the total mass of simulant added.

Tests for significant differences among sample means were by analysis of variance (ANOVA). The Brown-Forsythe test was used to evaluate variance homogeneity. Where homogeneity of variance was not met, the Kruskal-Wallis one-way analysis of variance was applied. Significant differences among individual means were determined by a Tukey-Kramer HSD. In all cases, significance was determined at $p < 0.05$. All statistics were performed using the software packages JMP 5.1.1 (SAS Institute Inc., Cary, NC) and Statistica 7.0 (Statsoft, Inc., Tulsa, OK).

3 Results and Discussion

Percent Removal of Simulant from CARC Coupons

Dermal Transfers

The total percentages of CEPS and BIS removed by both dermal transfers with and without the DECON Green application are provided in Table 1. In general, the first dermal transfer resulted in a contact-hazard exposure approximately twice that of the second transfer (Fig. 2 and 3). Washing

Table 1. Mean percentages of CEPS and BIS transferred by both dermal transfers from the CARC coupon to the latex dermal patch. Means were compared using Tukey HSD.

	CEPS			BIS		
	+4°C	–5°C	–15°C	+4°C	–5°C	–15°C
No wash/no DECON	A* 44 A†	A 43 A	A 97 A	A 89 A	A 81 A	A 69 A
Wash/no DECON	B 37 B	A 40 C	B 27 A	B 55 B	B 50 AB	B 48 A
DECON 10 min	D 4.6 A	n.d.**	C 11 B	C 1.7 A	C 4.9 C	C 6.0 B
DECON 20 min	D 4.2 A	B 13 B	D 6.7 A	C 1.2 A	C 6.3 B	C 3.0 A
DECON 30 min	C 8.2 B	D 3.3 A	n.d.	C 1.2 A	C 11 B	C 3.6 A
DECON 40 min	DE 3.8 B	CD 7.2 C	E 1.6 A	C 0.6 A	C 8.1 C	C 2.9 B
DECON 120 min	E 0.9 A	BC 11 B	DE 4.1 A	C 0.5 A	C 8.3 C	C 6.5 B
Mean††	4.3 A	8.6 B	5.9 A	1.0 A	7.7 C	4.4 B

* Comparison of means across DECON treatments by temperature values connected by the same letter are not significantly different (α = 0.05, n = 6).

† Comparison of means across temperature by DECON treatment values connected by the same letter are not significantly different (α = 0.05, n = 6).

** Not determined.

†† Mean across all DECON times (n = 30).

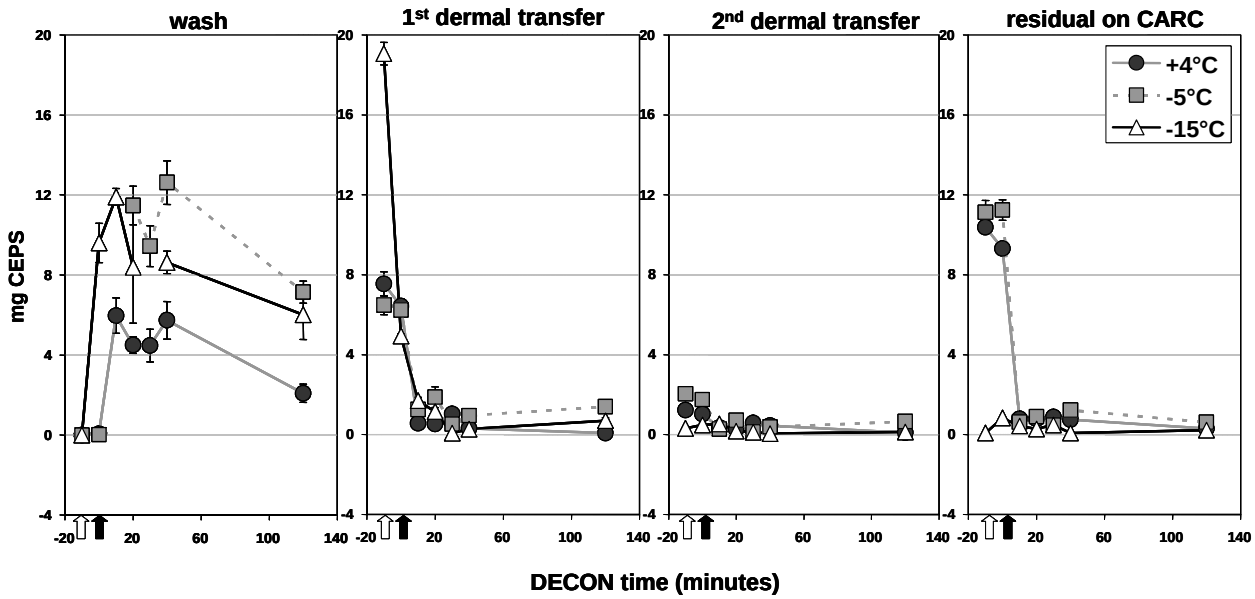

Figure 2. Mass of 2-chloroethyl phenyl sulfide (CEPS) in each analysis compartment at each temperature. Approximately 20 mg of CEPS was loaded onto each CARC coupon, resulting in a density of 10 g m^{-2}. Measurements were recorded after no propylene glycol:H_2O wash and no DECON (⇧), propylene glycol:H_2O wash but no DECON (⬆), and propylene glycol:H_2O wash and DECON for 10–120 minutes (10, 20, 30, 40, 120). Each graph represents the mass of CEPS recovered (left to right) in the wash, from the 1st dermal transfer, from the 2nd dermal transfer, and as a residual on the CARC (see Figure 1).

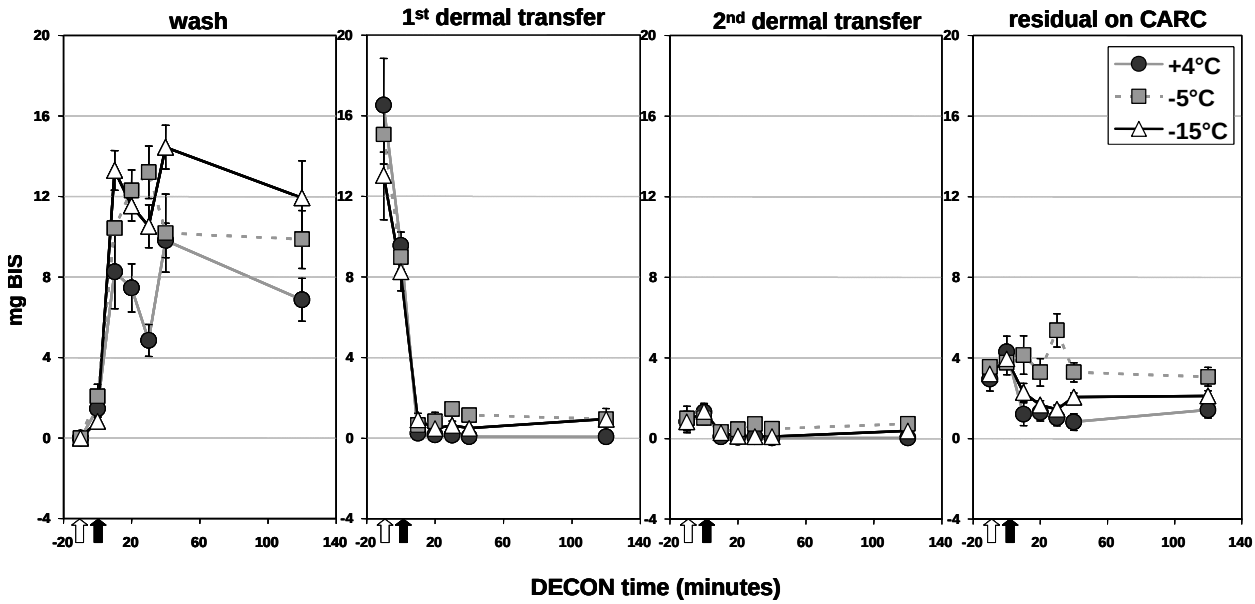

Figure 3. Mass of bis (2-ethyl hexyl) phosphite (BIS) in each analysis compartment at each temperature. Approximately 20 mg of BIS was loaded onto each coupon, resulting in a density of 10 g m^{-2}. Measurements were recorded after no propylene glycol:H_2O wash and no DECON (⇧), propylene glycol:H_2O wash but no DECON (⬆), and propylene glycol:H_2O wash and DECON for 10–120 minutes (10, 20, 30, 40, 120). Each graph represents the mass of BIS recovered (left to right) in the wash, from the 1st dermal transfer, from the 2nd dermal transfer, and as a residual on the CARC (see Figure 1).

significantly reduced the amount of simulant transferred to the latex patches by 2.7–70% for CEPS and 21–34% for BIS (Table 1). The large disparity in values seen with CEPS is attributable to the large amount of simulant transferred to the latex patch in the first transfer at –15°C (Fig. 2). The reason for this disparity is currently unknown. Nevertheless, these results further indicate that washing is an important component of the decontamination process.

Decontamination with DECON Green significantly reduced contact hazards for both CEPS and BIS (Table 1). Relative to no DECON, 10 minutes of DECON time resulted in 33% less CEPS transferred at 4°C and 16% less at –15°C. Relative to no DECON, 20 minutes of DECON time resulted in 27% less at –5°C. The 10-minute DECON time resulted in a greater reduction in BIS transfer to the latex patches. When BIS was decontaminated for 10 minutes with DECON green, 53% less simulant at 4°C, 45% less at –5°C, and 42% less at –15°C was transferred to the latex patches when compared to the washing alone. The mean percentages provided in Table 1 indicate that DECON green was more effective at minimizing the dermal transfer of BIS versus CEPS at each test temperature examined.

Similar to the percentage removal data (described below), the length of DECON time was significant only for CEPS, with a longer DECON time resulting in a lessening of the contact hazard. However, the 40-minute and 120-minute DECON times did not show a significant advantage over the 30-minute DECON time. These results indicate that the application of DECON Green for short periods of time, 10–30 minutes, can significantly reduce the hazards associated with dermal contact at 4°C to –15°C.

Wash Effect

The percentage removal of the two simulants at each of the three temperatures are provided in Table 2 and illustrated in Figures 2 and 3. Washing alone significantly enhanced the removal of CEPS and BIS from the coupon surfaces. With only one exception, simulant percentage removals were found to be significantly greater following washing with propylene glycol:H_2O than without. The exception occurred at –5°C with CEPS. The efficacy of the wash in removing simulants from the coupon surfaces also increased significantly with decreasing temperature. The use of propylene glycol:H_2O prevented freezing of the wash on the coupon surface at the low temperatures, thereby enhancing contact and removal of the simulant

from the coupon surface. There is no clear mechanism to explain the wash being more effective at –15°C than at 4°C. We suggest that at the lower temperature the slowed ability of the simulant to penetrate/soften the coupon surface resulted in enhanced removal.

Table 2. Mean percentage removals of CEPS and BIS from CARC coupons. The means were compared using Tukey HSD.

	CEPS			BIS		
	+4°C	–5°C	–15°C	+4°C	–5°C	–15°C
No DECON/no wash	E* 4.2 A†	C 1.5 A	E 2.6 A	C –2.6 A	D 1.6 A	C 15 A
No DECON/wash	D 16 B	C 3.8 C	D 69 A	B 23 B	C 31 AB	B 32 A
DECON 10 min	B 91 A	n.d.**	C 87 B	A 92 A	A 74 C	A 82 B
DECON 20 min	B 92 A	B 82 B	B 92 A	A 92 A	A 77 B	A 89 A
DECON 30 min	C 87 B	A 94 A	n.d.	A 93 A	B 62 B	A 89 A
DECON 40 min	B 92 B	B 86 C	A 98 A	A 95 A	A 75 C	A 87 B
DECON 120 min	A 98 A	B 86 B	AB 95 A	A 92 A	A 76 C	A 83 B
Mean††	92 A	87 B	93 A	93 A	73 C	86 B

* Comparison of means across DECON treatments by temperature values connected by the same letter are not significantly different (α = 0.05, n = 6).

† Comparison of means across temperature by DECON treatment values connected by the same letter are not significantly different (α = 0.05, n = 6).

** Not determined.

†† Mean across all DECON times (n = 30).

DECON Green Effect

The use of DECON Green significantly enhanced the percentage removals of both simulants from the coupon surfaces. Application of DECON Green for only 10 minutes increased the removal of CEPS by 18–75% and BIS by 43–69% compared to washing alone (Table 2). This finding is similar to that obtained by Friel et al. (1988), who concluded that spray rinsing alone

was only marginally effective against VX when used in the absence of the decontaminant DS2. For CEPS, in general, longer DECON times resulted in greater percentage removals (Fig. 4). One exception occurred at –5°C, where the percentage removal was greatest following 30 minutes of DECON time. The percentage of CEPS removed between 10 and 120 minutes or 20 and 120 minutes for the –5°C treatment was 6.2% at 4°C, 3.6% at –5°C, and 8.0% at –15°C. These results suggest that, for CEPS, longer decontamination times appear to impart a small advantage in terms of total percentage removal of the simulant from a painted surface. In terms of a mean efficiency for DECON Green against CEPS (10–120 minutes), values were calculated as 92% ± 4% for 4°C, 87% ± 6% for –5°C, and 93% ± 5% for –15°C, with no significant difference between the means at 4° and –15°C. These values are comparable to those obtained by Wagner and Yang (2002), who found DECON Green to be 90% effective and DS2 to be 86.7% effective in removing HD from a CARC panel at room temperature.

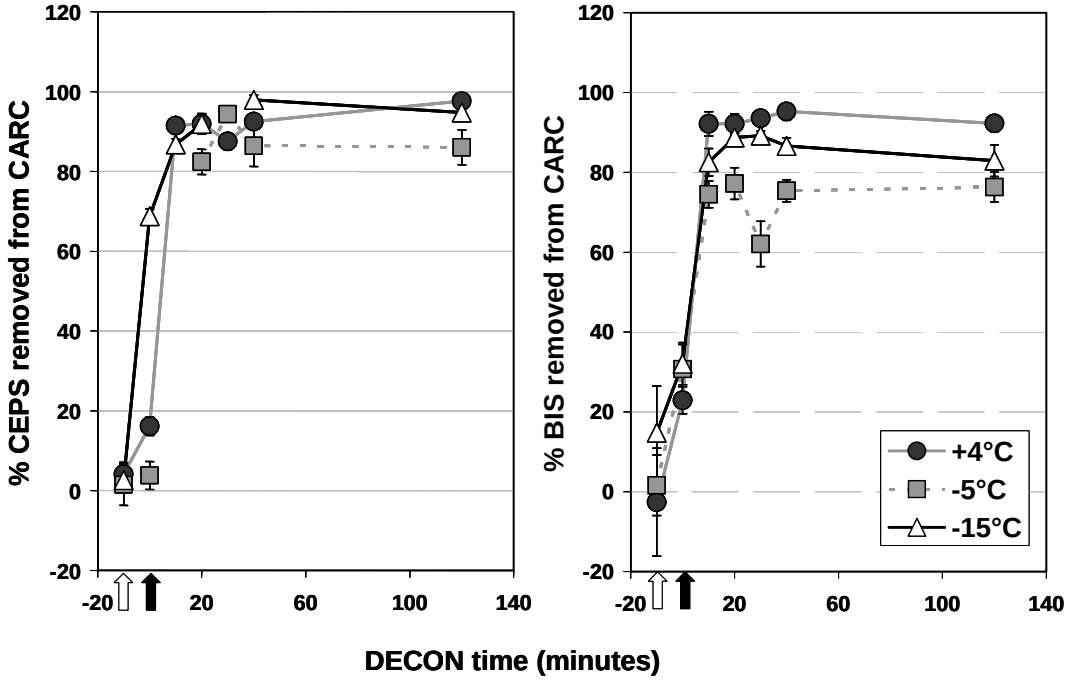

Figure 4. Percent removal of 2-chloroethyl phenyl sulfide (CEPS) and bis (2-ethyl hexyl) phosphite (BIS) from CARC coupons. Each coupon (n = 6) was loaded with CEPS or BIS to a density of 10 g m^{-2}. Measurements were recorded after no propylene glycol:H_2O wash and no DECON Green (⇧), propylene glycol:H_2O wash but no DECON Green (⬆), and propylene glycol:H_2O wash and DECON Green for 10–120 minutes.

In contrast and with one exception, an analysis of variance (ANOVA) indicated that there was no significant difference between means for BIS at any of the five decontamination times evaluated (Table 2). The exception

occurred at –5°C following 30 minutes of DECON time, where the percentage removal of BIS was significantly less than at either 4° or –15°C. As with CEPS, the discrepancies occurring with percentage removals at –5°C are currently not understood. In terms of a mean efficiency for DECON Green against BIS (10–120 minutes), values were calculated as 93% ± 3% for 4°C, 73% ± 7% for –5°C, and 86% ± 4% for –15°C, with a significant difference occurring between the means at 4° and –15°C. The effect of temperature on BIS decontamination is discussed in more detail below. These values are also comparable to those obtained by Wagner and Yang (2002), who found DECON Green to be 87% effective and DS2 to be 72% effective in removing VX from a CARC panel at room temperature.

Effect of Temperature on DECON Green Efficacy

Temperature was found to have a significant effect on the recovery of CEPS and BIS (Table 3). For both simulants, the greatest recoveries occurred at –5°C. This finding corresponded with the detection of greater amounts, on a mass basis, of the two simulants in the wash, in the dermal

Table 3. Results of a means comparison (Tukey HSD) for the mass balance of simulant added to the CARCs following decontamination with DECON Green. The values represent the total percentage of CEPS and BIS recovered, the percentage recovered from the CARC and the two dermal transfers (residual), the percentage recovered in the wash, and the percentage of simulant unaccounted for. Means were compared across test temperatures by decontamination time (average of 10–40 minutes decontamination times only).

	CEPS			BIS		
	+4°C	–5°C	–15°C	+4°C	–5°C	–15°C
Total % simulant recovered	36 (1.4)*	69 (3.6)	56 (3.4)	46 (2.3)	86 (2.7)	76 (2.4)
	C†	*A*	*B*	*C*	*A*	*B*
% simulant in wash	26 (1.4)	56 (2.4)	48 (2.7)	39 (2.2)	58 (1.9)	63 (2.1)
	B	*A*	*AB*	*B*	*A*	*A*
% simulant in dermal transfers	5.2 (0.4)	7.9 (1.2)	6.5 (1.0)	1.1 (0.1)	7.6 (0.6)	3.8 (0.3)
	A	*A*	*A*	*C*	*A*	*B*
% simulant as residual	*9.2 (0.5)*	*12 (6.1)*	*7.8 (1.2)*	*6.7 (0.5)*	*28 (1.5)*	*13 (0.7)*
	AB	*A*	*B*	*C*	*A*	*B*
% simulant unaccounted for	64 (1.4)	31 (3.6)	44 (3.4)	54 (2.3)	14 (2.7)	24 (2.4)
	A	*C*	*B*	*A*	*C*	*B*

* Values expressed as percentages with standard errors in parentheses.

† Values connected by the same letter are not significantly different (α = 0.05, n = 30) comparison of means (10–40 minutes DECON time) by temperature.

transfers, and as residual on the CARC coupon surfaces (Fig. 2 and 3). In contrast, the 4°C treatment resulted in significantly more of either contaminant being unaccounted for, presumably due to oxidation, other chemical reaction, or simulant volatilization. Correspondingly, less mass of either simulant was detected in the wash, in the dermal transfers, and as a residual on the CARC coupon.

The efficacy of decontamination typically declines as temperatures decrease. Yet in this study, the –15°C treatment resulted in greater percentage removals of simulants (Table 2) and a greater percentage of unaccounted-for simulant (Table 3) than observed at –5°C. This phenomenon may be a result of differential temperature effects on simulant binding to the CARC coupon. The coupons incubated at 4°C received the standard formula of DECON Green, whereas those incubated at –5° and –15°C received the cold-weather formulation. The results showed that the mass of residual CEPS and BIS detected on the coupons at –5°C was nearly twice that observed at –15°C following 40 minutes of DECON time (Fig. 2 and 3). A similar result was observed with both dermal transfers. Wagner and Yang (2002) showed that the standard formula of DECON Green is less efficient at colder temperatures. This study suggests that the cold-weather formula may also be temperature dependent, but in terms of a lower efficiency at higher temperatures. A more precise determination of the temperature threshold at which a benefit can be gained by applying the cold-weather formula instead of the standard formula cannot be made from these data.

The efficacy of DECON Green was not the same for both simulants at the temperatures tested (Table 3). Temperature had a greater effect on the simulant BIS in terms of percentage simulant in the wash, in the dermal transfers, and as a residual on the CARC coupon surface (Table 3). Significant differences in each sample fraction were identified for BIS between 4° and –15°C, with lower percentages occurring at 4°C. The same was not observed for CEPS, for which means did not differ significantly at the 95% confidence level for any of the three sample fractions.

The percentage of BIS unaccounted for was always less than the percentage of CEPS. In contrast, the percentage of BIS ending up in the wash or as a residue on the CARC coupon surface was nearly always greater for BIS, with the greatest percentages occurring at the coldest temperature, –15°C. This result suggests that although percentage removal of either simulant

was comparable at all three temperatures (Table 2), DECON Green appeared to be more effective against CEPS than BIS. However, percent dermal transfer or contact hazards were greater for CEPS at each temperature tested. These data suggest that chemical interactions between the simulant and the decontaminat may result in greater contact hazards as well as in greater simulant degradation if the decontamination process is not allowed to continue through completion. In the case of CEPS, at least 120 minutes of DECON time were required to bring the percentage of simulant transferred to the latex patch below 1% (Table 1). Even longer decontamination times may be required at the lower temperatures.

4 Conclusion

Cold-formula DECON Green (CA^2WT) was found to be effective in removing the VX nerve agent simulant bis (2-ethylhexyl) phosphite and the HD mustard gas simulant 2-chlorophenyl sulfide from a CARC on a metal surface. At –5° and –15°C, appropriately formulated and used DECON Green was found to be 87% and 93% effective against CEPS and 73% and 86% effective against BIS, respectively. Results indicated that:

- Washing was an important component of the decontamination process.
- Applying DECON Green for 10–30 minutes significantly reduced the hazards associated with dermal contact.
- For the HD simulant, longer decontamination times appeared to impart a small advantage in terms of total percentage of simulant removed from the CARC coupon.
- DECON Green was more effective at minimizing the dermal transfer of BIS at each test temperature examined than it was for CEPS.
- DECON Green appeared to be more effective at chemically altering the simulant CEPS than the simulant BIS.

5 References

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14. ABSTRACT

The objective of these studies was to quantify the efficacy of DECON Green against the VX nerve agent simulant bis (2-ethyl hexyl) phosphite and the HD mustard agent simulant 2-chloroethyl phenyl sulfide when used below 0°C relative to DECON Green use above 0°C. The efficacy of the DECON Green formulations was tested at 4°, –5° and –15°C using both dermal transfer and mass balance approaches. Dermal transfer measurements simulated the transfer of agent to skin. The mass balance approach addressed the fate of simulant by quantifying simulant recovery following each step of a decontamination process. Simulant that could not be accounted for in the mass balance was attributed to simulant degradation, and the effect of DECON Green was separated from other effects. Two formulations of DECON Green were investigated: the "standard" formulation, New DECON Green, and the "cold weather" formulation, CA^2WT. At controlled temperatures, simulants were spread on aluminum disks or "coupons" that were treated with Chemical Agent Resistant Coating (CARC). The CARC coupons were subsequently decontaminated using standard U.S. Army testing procedures. At all temperatures investigated, sequential dermal contact transfers of the simulant were three (on the HD mustard-agent simulant) to four (on the VX nerve-agent simulant) times lower following the application of DECON Green and washing than without DECON Green or without washing. The mass balance data showed that washing with a propylene glycol:H_2O solution was an important part of the decontamination process. DECON Green both degraded the simulant and improved simulant removal by washing. These findings indicate that at both –5° and –15°C, conditions where water-based procedures would be problematic, DECON Green and washing with propylene glycol:H_2O can be effective at reducing surface contact hazards from chemical agent simulants.

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