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A Proof-of-Principle Dermal Decontamination Experiments: Swine Skin

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Defence R&D Canada – Ottawa

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Proof-of-Principle Dermal Decontamination Experiments: Swine Skin

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Abstract

A series of swine-skin decontamination trials were carried out to demonstrate a *proof-of-principle* for including a radiological detection and decontamination module in DRDC Suffield's Counter-Terrorism Technology Centre / First Responder Training Program (CTTC/FRTP). The radionuclides examined were ^{64}Cu, ^{42}K, ^{24}Na, and ^{99m}Tc and the decontamination agents evaluated included Water, Soap, Fuller's Earth paste, and both Active and Non-Active Reactive Skin Decontamination Lotion (RSDL). Skin coupons (2 x 2 inches) were prepared from fresh swine skin and then contaminated with 20µL spots in a 5 x 5 grid for each radionuclide. Initial decontamination attempts reduced the residual contamination levels to about 50%. The lowest residual contamination achieved after multiple decontamination cycles was 20%. Fuller's Earth paste proved to be the best decontamination agent with an average final residual contamination level of 20% for all radionuclides except ^{99m}Tc. With ^{99m}Tc, the lowest residual contamination level achieved was ~40% after six decontamination cycles. RSDL (Active and Non-Active) did not prove to be an effective radiological decontamination agent, as Water alone resulted in lower residual contamination levels. These experiments will be repeated using living human skin in tissue culture before presenting a proposal to implement a radiological detection and decontamination module to the DRDC Suffield training program.

Résumé

Ces essais ont été entrepris afin de réaliser une « démonstration de principe » pour l'ajout d'un module de détection et de décontamination radiologiques dans le programme de formation des premiers intervenants au Centre de technologie antiterroriste de RDDC Suffield. Les radionucléides testés sont le ^{64}Cu, le ^{42}K, le ^{24}Na et le ^{99m}Tc. Les agents de décontamination qui ont été évalués sont l'eau, le savon, la pâte d'argile à foulon et la lotion réactive de décontamination cutanée (active et non-active). Pour chaque radionucléide testé, des coupons de peau de porc fraîche (2 pouces x 2 pouces) ont été préparés, sur lesquels 20µL de radionucléide ont été appliqués sur une grille de 5 x 5. Les premières tentatives de décontamination ont réduit les niveaux de contamination résiduelle à 50%. Le niveau de contamination résiduelle le plus faible qui a pu être atteint après de multiples cycles de décontamination était de 20%. La pâte d'argile à foulon s'est avéré le meilleur agent de décontamination avec un niveau final de contamination résiduelle de 20% pour tous les radionucléides à l'exception du ^{99m}Tc. Dans le cas du ^{99m}Tc, le niveau de contamination résiduelle le plus faible qui a pu être atteint était d'environ 40% après six cycles de décontamination. La lotion réactive de décontamination cutanée (active et non-active) ne s'est pas avérée efficace comme agent de décontamination puisque l'eau à elle seule a donné des niveaux de contamination résiduelle encore plus bas. Ces expériences seront répétées sur de la peau humaine en culture de tissus et les résultats seront inclus dans une proposition visant à ajouter un module de détection et décontamination radiologiques au programme de formation de RDDC Suffield.

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Executive summary

Proof-of-Principle Dermal Decontamination Experiments: Swine Skin

Segura, T.M., Boulay, H.M., Jones, T., Cousins, T.; DRDC Ottawa TM 2007-063; Defence R&D Canada – Ottawa; April 2007.

Introduction

The Counter-Terrorism Technology Centre / First Responder Training Program (CTTC/FRTP) currently uses DRDC Suffield's Domestic Swine Model for training in both chemical and biological detection and decontamination. It has been proposed that, for a more complete training program, the addition of a radiological detection and decontamination module using this model would be beneficial. To examine this possibility, we investigated four short-lived radionuclides (^{64}Cu, ^{42}K, ^{24}Na, and ^{99m}Tc) applied to swine skin coupons to evaluate and identify a preferred detergent and washing method for radiological decontamination. Water, Soap, Fuller's Earth paste, and both Active and Non-active Reactive Skin Decontamination Lotion (RSDL) were studied to determine if certain methods are more effective for the radiological decontamination of skin.

Results

Each skin coupon underwent a minimum of three to a maximum of six cycles of decontamination. Initial decontamination attempts (i.e. the first cycle) reduced the residual contamination levels to about 50%. The lowest residual contamination achieved after multiple decontamination cycles was 20%. Overall Fuller's Earth paste proved to be the best decontamination agent with an average final residual contamination level of 20% for all radionuclides except ^{99m}Tc. With ^{99m}Tc, the lowest residual contamination level we could achieve was about 40% after six decontamination cycles. RSDL (Active and Non-Active) did not prove to be an effective radiological decontamination agent, as Water alone resulted in lower residual contamination levels.

Significance and Future Work

RSDL is the current Canadian Forces (CF) choice for chemical decontamination. This study was thus exploring the possibility of a "dual-use" for this product. This possibility was not realized. However, the CF's historical choice for chemical decontamination, Fuller's Earth, proved to be the best radiological decontamination agent that we tested making it the best choice as a "dual-use" product for the CF.

These short-lived radionuclides and the decontamination methods employed would make an excellent addition as a radiological detection and decontamination module for DRDC Suffield's CTTC/FRTP training program. The training would provide individuals with the knowledge of proper decontamination methods, as well as demonstrate the significant difficulty of removing

radiological contamination from skin. These experiments will be repeated using living human skin in tissue culture before presenting a proposal to implement a radiological detection and decontamination module to the DRDC Suffield training program.

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Proof-of-Principle Dermal Decontamination Experiments: Swine Skin

Segura, T.M., Boulay, H.M., Jones, T., Cousins, T.; DRDC Ottawa TM 2007-063; R & D pour la défense Canada – Ottawa; April 2007.

Introduction

A l'heure actuelle, le programme de formation des premiers intervenants au Centre de technologie antiterroriste de RDDC Suffield comprend l'utilisation d'un modèle de porc domestique pour la formation en détection et décontamination chimiques et biologiques. Afin de rendre le programme de formation plus complet, une proposition a été présentée pour l'ajout d'un module de détection et de décontamination radiologiques.

Durant cette étude, nous avons testé les radionucléides ^{64}Cu, ^{42}K, ^{24}Na et ^{99m}Tc sur des coupons de peau de porc afin d'évaluer et d'identifier les détergents et les méthodes de lavage les plus efficaces pour la décontamination radiologique. Nous avons évalué l'eau, le savon, la pâte d'argile à foulon et la lotion réactive de décontamination cutanée (active et non-active) afin de déterminer si certaines méthodes étaient plus efficaces que d'autres pour la décontamination radiologique de la peau. La lotion réactive de décontamination cutanée est le produit utilisé actuellement par les Forces canadiennes pour la décontamination chimique; par conséquent, dans cette étude nous avons donc exploré la possibilité d'en faire un produit à double usage.

Résultats

Chaque coupon de peau a subi un minimum de trois décontaminations, et dans certaines essais, jusqu'à six. Les premières tentatives de décontamination ont réduit les niveaux de contamination résiduelle à 50%. Le niveau de contamination résiduelle le plus faible qui a pu être atteint après de multiples cycles de décontamination était de 20%. La pâte d'argile à foulon s'est avéré le meilleur agent de décontamination avec un niveau final de contamination résiduelle de 20% pour tous les radionucléides à l'exception du ^{99m}Tc. Dans le cas du ^{99m}Tc, le niveau de contamination résiduelle le plus faible qui a pu être atteint était d'environ 40% après six cycles de décontamination. La lotion réactive de décontamination cutanée (active et non-active) ne s'est pas avérée efficace comme agent de décontamination puisque l'eau à elle seule a donné des niveaux de contamination résiduelle encore plus bas.

Importance et Recherches Futures

La lotion réactive de décontamination cutanée, actuellement utilisée par les Forces canadiennes comme agent de décontamination chimique, n'a pas rencontré nos attentes comme produit à double usage pour la décontamination radiologique ainsi que chimique. Ironiquement, le produit utilisé dans le passé par les Forces canadiennes comme agent de décontamination chimique, la

pâte d'argile à foulon, s'est avéré le meilleur agent de décontamination radiologique, ce qui en fait le meilleur choix comme produit à double usage pour les Forces canadiennes.

Ces radionucléides à période courte ainsi que les méthodes de décontamination utilisées constitueraient un excellent ajout comme module de détection et décontamination radiologiques au programme de formation des premiers intervenants du Centre de technologie antiterroriste de RDDC Suffield. Cette formation donnerait au personnel des connaissances sur les méthodes de décontamination et démontrerait la difficulté à éliminer la contamination radiologique sur la peau. Ces expériences seront répétées sur de la peau humaine en culture de tissus et les résultats seront inclus dans une proposition visant à ajouter un module de détection et décontamination radiologiques au programme de formation de RDDC Suffield.

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1. Introduction

The Counter-Terrorism Technology Centre / First Responder Training Program (CTTC/FRTP) currently includes the use of DRDC Suffield's Domestic Swine Model (DSM) for training in both chemical and biological detection and decontamination procedures. In order to make this training program more complete, the addition of a radiological detection and decontamination module using this model has been proposed. Due to the necessary animal research ethics approvals it was decided to first demonstrate the *proof-of-principle* of dermal decontamination for this model using swine skin samples *ex vivo*.

When people are exposed either deliberately or accidentally to hazardous Chemical, Biological, Radiological or Nuclear (CBRN) substances, these agents can become lodged on their clothing, skin and hair, thus presenting a continuing health risk for themselves and their immediate contacts. It is therefore important that safe and effective early detection and decontamination methods be undertaken to prevent further exposure of the contaminated individual and to minimize the spread of the contaminant. In contrast to chemical exposures, radiological exposures may not immediately demonstrate any apparent health effects that would trigger the action of first responders. This increases the significance and importance of both early detection and decontamination.

First responders routinely carry out decontamination procedures when dealing with incidents involving hazardous substances. In most instances this involves the first responders themselves having their protective clothing decontaminated using water, applied manually or through simple showering devices. In many cases, Emergency Services responders on the scene will have contact with contaminated casualties during their rescue, triage and treatment. The potential for intake of substances re-suspended from skin, hair or clothes is likely to persist, leading to possible internal contamination, and decontamination should not be delayed.

Radiological contamination of the skin is usually not immediately life threatening unless the contamination is from a very high dose rate gamma or beta emitter (i.e. Sieverts/hour). However, localized high-level radiation exposure can lead to serious skin and muscle injury. These can include rash, hair loss, redness, and atrophy. Cutaneous radiation injury progresses over time in various stages. The initial, prodromal stage occurs within hours of exposure, and often includes reddening of the skin with an accompanying burning and/or itching sensation that fades within hours to days [1, 2]. After a brief latent stage with no evidence of injury, the illness manifests itself with intense reddening of the skin. Acute radiation dermatitis soon follows and is characterized by desquamation, dyspigmentation, permanent hair loss, skin ulcers or blisters, hemorrhage and/or necrosis [3]. Radiation-induced ulcerations are difficult to cure and are susceptible to infections. Permanent thickening (fibrosis) and scarring of the skin may also occur. The treatment of radiation-induced skin changes is supportive and treated symptomatically. Skin grafting may sometimes be required to cover up non-healing skin ulcers.

Dermal radiation exposure implies exposure from a radioactive source placed in direct contact with skin surface. In general, depending on the specific physical properties of the radionuclide that may reside on the skin, the percutaneous absorption of radionuclides from particles is negligible, especially if the skin is thoroughly washed immediately after exposure and no open wounds exist. The long-term biological effects of dermally absorbed radionuclides are limited to the level of the epidermis, dermis and its vasculature. More soluble forms of the radionuclides may result in a small percentage of the nuclide being absorbed if it is not removed from the skin's surface. For example, tritium (in the form of tritiated water or vapour) is readily absorbed into the body through the skin. Generally, the skin is an effective barrier against absorption of radionuclides (except for tritiated water) into the body. The dermal exposure pathway is, therefore, a minor route of exposure; however, as previously stated, the greatest concerns for radionuclide-contaminated skin are dermal injury and the possible re-suspension and subsequent internal contamination of the individual and first responders.

Four short-lived radionuclides were studied as skin contaminants: ^{64}Cu, ^{42}K, ^{24}Na, and ^{99m}Tc. The degree of difficulty for decontamination was expected to be similar for these different radionuclides as none of them alone are known to be percutaneously absorbed. However, it was recognized that the chemical form of the contaminants (i.e. potassium nitrate for the ^{42}K) may possibly exacerbate dermal absorption since they are in a soluble form. These experiments employed swine skin, which has been previously shown to be a good model for skin studies [4], to evaluate and identify a preferred detergent and washing method for radiological decontamination. As a side benefit of this study, a protocol for the use of radioisotopes with the DSM could be developed to examine skin absorption.

Historically, decontamination usually proceeds from the least aggressive to more aggressive methods in order to prevent skin irritation and possible erythema. Commonly used methods include the removal of the individuals clothing, followed by washing or showering first with water alone, then using soap and water (pH neutral), then if needed using more aggressive methods. It has been reported that with the removal of clothing and showering of individuals, up to 95% of surface contamination can be removed [5]. For this work, water, soap, Fuller’s Earth paste and Reactive Skin Decontamination Lotion (RSDL) formulations were examined to determine if certain methods are more effective than others for the radiological decontamination of skin.

As above, the benefits of this research are three-fold:

1. To demonstrate the *proof-of-principle* for using the DSM for radiation training of first responders;

2. To establish standard operating procedures (SOPs) as guidelines for first responders in the decontamination of humans in a real event; and,

3. To begin establishment of radioisotope (and chemical compound) -specific contamination and decontamination factors for future expansion and realism.

2. Experiments and Equipment

2.1 Experimental Design Overview

Four radionuclides, ^{64}Cu, ^{42}K, ^{24}Na, and ^{99m}Tc, were examined as radiological skin contaminants. The efficacy of water, soap, Fuller's Earth paste, and RSDL (Active or Non-Active) as decontamination agents was measured. Preliminary experiments were performed to examine if the length of exposure and time for absorption (30 min, 1h, 2h) differentially effected the efficacy of decontamination and it was determined that there was no effect (data not shown). Further experiments were performed to determine how the decontamination agents performed against each radionuclide.

For each radionuclide experiment, the skin coupons were spotted in a 5 x 5 grid with 20µL of the aqueous radionuclide in each spot. Testing of each decontamination agent was performed in triplicate for each trial. The activity of the radionuclides used varied according to the "exempted quantities" (EQ) allowed for each radionuclide. From our preliminary timing experiments, we determined that ~1h was sufficient for absorption of the radionuclides and was not so long as to allow the skin to dry out.

Figure 1: A swine skin coupon spotted in a 5x5 grid with an aqueous radionuclide.

2.2 Radionuclides

Some general characteristics of the isotopes used for this study are shown in **Error! Reference source not found.**. Small quantities of the first three isotopes in the table were produced by the Royal Military College (RMC) SLOWPOKE facility. The fourth isotope, ^{99m}Tc diluted in saline, was directly procured by DRDC Ottawa from Bristol–Myers Squibb Imagerie Médicale. The RMC-produced isotopes were delivered to DRDC Ottawa by a commercial courier in powder form. Sources were shipped in accordance with established TDG procedures for shipment of radioactive sources and in accordance with both DGNS and CNSC requirements. Once the sources arrived at DRDC Ottawa, they were received by the DRDC Ottawa Radiation Safety Officer (RadSO) or qualified delegate. Procedures for the receipt of radioactive material at DRDC Ottawa were followed including inspection of the sources and confirming the integrity of the sources and packaging.

Table 1: Radionuclide Characteristics

Isotope	*Mass*	*Half-Life*	*Mode of Decay*	*Chemical Composition*
^{64}Cu	63.93	12.701 h	EC to ^{64}Ni; - to ^{64}Zn	Copper (II) Nitrate Hemipentahydrate $Cu(NO_3)_2$ $2.5H_2O$
^{42}K	41.96	12.360 h	- to ^{42}Ca	Potassium Nitrate KNO_3
^{24}Na	23.99	14.960 h	- to ^{24}Mg	Sodium Carbonate Na_2CO_3
^{99m}Tc	98.91	6.020 h	- to ^{99}Ru	Decay product of ^{99}Mo diluted in saline

The sources were then transferred to a secure and approved radioactive material storage facility, located in a fenced-off area of Compound-50. The key to the gate for this area is under control of the DRDC Ottawa RadSO. After the trial, the sources and remaining diluted solution were identified, returned to their storage container and placed in the secure and approved storage area. Contaminated materials remained in the trailer within Compound-50. For this trial the storage area of the sources was T-102 in Compound-50.

Each of the powdered sources was mixed with water prior to the trial, enabling more expeditious contamination. The sources (~ 1 g) were mixed in a volume of 5 mL of water. All such activities were carried out in accordance with established procedures and included the following:

1. All procedures for diluting the source were carried out in the trailer in Compound-50. The trailer was selected based on the activity of the sources (below EQ) and their physical form (liquid), reducing the chance of it becoming air borne.

2. All activities were conducted by trained individuals wearing appropriate individual protection equipment (IPE) and dosimetry.

3. All activities were monitored by the DRDC Ottawa RadSO.

4. The workstation (in the trailer) was lined with absorbent material before starting any transfer or dilution (Figure 2).

Figure 2: Typical experimental setup in the trailer in Compound-50 at DRDC Ottawa.

2.3 Detergents

A number of decontamination agent candidates were investigated for this study. Water was used as our base decontamination agent and control when comparing the relative effectiveness of the various agents. The pH neutral soap was chosen in order to prevent any interactions should the radionuclide, in an actual radiological release or accident, be in an acidic solution. We also investigated Fuller's Earth paste, a compound previously used by the Canadian Forces for the neutralization of Chemical agents. Finally, in hopes of discovering a "dual use" product, we examined the radiological decontamination effectiveness of RSDL, the Canadian Forces current choice for Chemical agent neutralization. To summarize, we investigated the following detergents:

1. Water alone
2. Dove (liquid) soap – neutral pH
3. Fuller's Earth paste
4. Active RSDL (Original Active Ingredient Formulation)
5. Non-Active RSDL (Training Formulation, lacks the active ingredient)

2.4 Model

Previous studies have shown that pig skin has similar physiological and histological properties to human skin and thus represents an ideal model for studying human skin permeability [4]. In this study, cuts of swine skin containing both the epidermal and dermal layers were used. The cuts were obtained from a local butcher, were fresh and had not been previously frozen. Once acquired, the skin was separated from the meat and cut into "skin coupons", squares measuring 2 x 2 inches.

2.5 Decontamination Procedures and Measurements

Background radiation measurements of the work area were measured and recorded. The radionuclide was then applied to the skin as described in section 2.1 and, after the absorption time had passed, the contamination levels of the radionuclides on the skin were measured. Measurements were made using an ADM 300C with the alpha-beta probe (ABP 100) attachment (Figure 3).

Figure 3: View of a swine skin sample being measured for radioactive contamination using an ADM-300C with the ABP 100 attachment.

The following decontamination procedures and measurements then followed:

2.5.1 Water Alone:

1. Rinse with 50 mL water and scrubbed gently for 2 minutes.
2. Dab dry with a Kimwipe.
3. Measure residual contamination with ADM-300C and ABP 100 attachment.
4. Repeat until measurement is within 2x background or until decontamination methods no longer decrease contamination levels.

2.5.2 Liquid Soap:

1. Apply 250 µL of 50% Liquid Dove soap (diluted in water), and scrub gently for 1 minute.
2. Rinse with 25 mL water and scrubbed gently for 1 minute.
3. Dab dry with a Kimwipe.
4. Measure residual contamination with ADM-300C and ABP 100 attachment.
5. Repeat until measurement is within 2x background or until decontamination methods no longer decrease contamination levels.

2.5.3 Fuller's Earth Paste:

1. Apply a thin, covering layer of Fuller's Earth paste to the contaminated area and allow the paste to sit for 20 minutes.

2. Rinse with 50 mL water and scrubbed gently for 2 minutes.

3. Dab dry with a Kimwipe.

4. Measure residual contamination with ADM-300C and ABP 100 attachment.

5. Repeat until measurement is within 2x background or until decontamination methods no longer decrease contamination levels.

2.5.4 RSDL (active agent):

1. Decontamination was performed as per manufacturer's instructions:

    a. Apply lotion liberally.

    b. Allow contact for 2 minutes.

    c. Rinse with water and scrubbed gently.

2. Measure residual contamination with ADM-300C and ABP 100 attachment.

3. Repeat until measurement is within 2x background or until decontamination methods no longer decrease contamination levels.

2.5.5 RSDL (training formula):

1. Decontamination was performed as per manufacturer's instructions:

    a. Apply lotion liberally.

    b. Allow contact for 2 minutes.

    c. Rinse with water and scrubbed gently.

2. Measure residual contamination with ADM-300C and ABP 100 attachment.

3. Repeat until measurement is within 2x background or until decontamination methods no longer decrease contamination levels.

The number of decontamination cycles and the measurements taken after each cycle were recorded. All water rinses were performed using tap water and applied using a gentle stream from a 60 mL syringe (Figure 4). The gentle scrubbing for all detergents was carried out using "soft" grade infant tooth brushes (Figure 5), except the RSDL detergents as the manufacturer provided the appropriate scrubbing pads for their protocol.

Figure 4: Gentle Rinsing with a 60 mL syringe.

Figure 5: "Soft" grade infant tooth brushes for gentle scrubbing.

2.6 Safety measures

All personnel wore gloves and goggles at all times while working with the radionuclides, as well as the necessary dosimetry. All personnel wore standard Health Canada issued thermo-luminescent dosimeters (TLDs). In addition, the individual manipulating the radionuclides also wore a Health Canada issued ring dosimeter.

2.7 Analysis

2.7.1 Data Analysis

Radiation measurements taken during the experiments were:

> Corrected for radioisotope decay so decontamination data could be compared to the initial contamination levels. Times of contamination, and measurements were recorded to ensure that the measurements could be referred back to the initial contamination levels.
>
> Corrected for background levels of radiation. Multiple readings were taken and the average was used as the background level and subtracted from all measurements.

Results presented in Figures 6 to 12 are expressed as a percentage of residual contamination, which is defined by the following formula:

$R = 100 – [(C_0 – C_t) / C_0 * 100]$

Where R = % residual contamination
C_0 = Measurement of the initial contamination counts
C_t = Measurement of counts following decontamination attempt

Evaluation of the efficacy of a particular agent for decontaminating a particular radionuclide is accomplished by determining the differential mean reduction of contamination from a radionuclide relative to the original contamination. Decontamination efficiency is expressed in terms of a percentage of the remaining contamination and is defined by the following formula:

$D = C_0\text{-}C_t/ C_o * 100$ or $D= 100\text{-}R$

where D = decontamination efficiency and the other variables are the same as noted above.

2.7.2 Statistical Analysis

As previously mentioned, decontamination trials for each agent against each of the four radionuclides were performed in triplicate. The mean for each data point was calculated from the three replicates and the error bars calculated from the standard deviations of the distributions. In each case, data are presented as mean ± standard deviation. Water served as the control when comparing the relative effectiveness of the various agents. Data were analyzed by two-way analysis of variance (ANOVA) with Bonferonni post-tests to assess the differences between experimental groups (PRISM 4.0, GraphPad Software Inc). Statistical significance was inferred at $P<0.05$.

3. Results

3.1 Sodium Carbonate (^{24}Na)

The residual contamination levels of ^{24}Na following decontamination attempts using either soap or Fuller's Earth are shown in Figure 6. The mean for each data point was calculated from three replicates and the error bars are standard deviations for the distributions. The ^{24}Na sample was received late from the supplier and was, as a result, at very low activity. For this reason we opted to only analyze two of the decontamination agents and did not include water. This was one of the first experiments performed and, we had not yet determined whether water or soap was to be designated as the control. No significant differences were observed between these methods after any of the decontamination attempts.

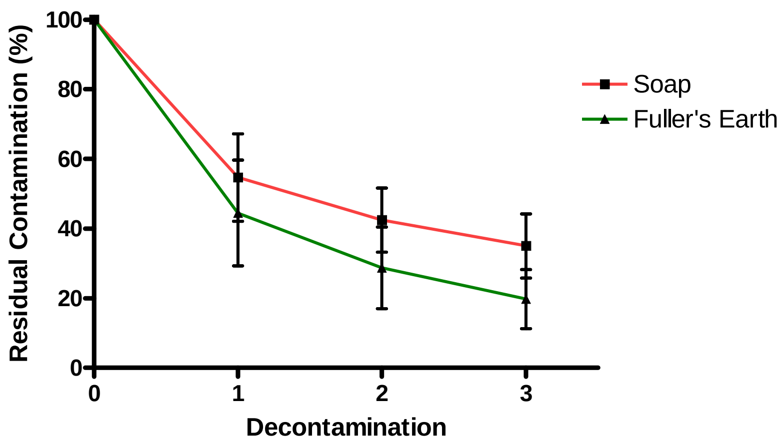

Figure 6: ^{24}Na decontamination with Soap or Fuller's Earth paste.

3.2 Potassium Nitrate (^{42}K)

The residual contamination levels of ^{42}K after decontamination attempts using water, soap or Fuller's Earth are shown in Figure 7. The mean and standard deviation for each data point was calculated as previously stated. Each of the decontamination agents was successful at significantly decreasing the ^{42}K contamination on each of the respective skin coupons over successive decontamination attempts ($p<0.0001$; Figure 7). Fuller's Earth paste proved to be the best agent for decontamination of ^{42}K, and resulted in significantly lower residual contamination levels after all decontamination attempts when compared to water. With respect to this radionuclide, soap was the least effective decontamination agent, as water alone was significantly better at 3 of the 4 time points. However, after 7 decontamination cycles, soap was able to reduce the residual decontamination level to ~50% (data not shown) which was comparable to the levels reached by the other agents.

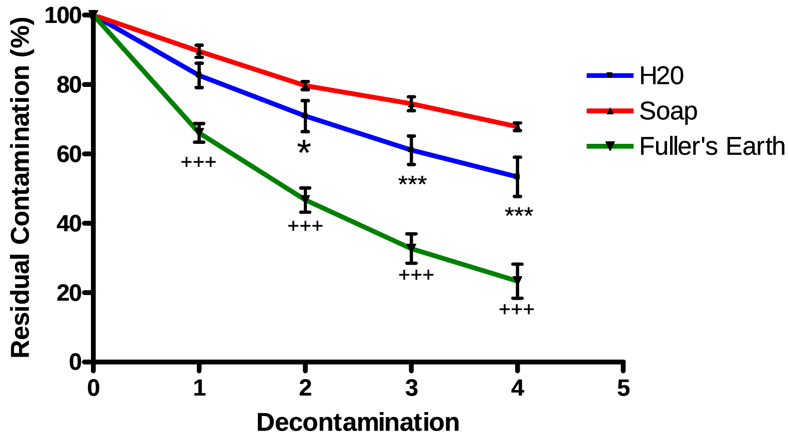

Figure 7: Residual contamination levels of ^{42}K after decontamination attempts using Water, Soap or Fuller's Earth paste.

Data represent mean ± SD. +++ $P<0.001$ (relative to water at each decontamination attempt) * $P<0.05$, *** $P<0.001$ (relative to soap at same decontamination attempt)

3.3 Copper (II) Nitrate Hemipentahydrate (^{64}Cu)

The biochemical properties of ^{64}Cu allow the decontamination results to be visualized. The copper compound stains the skin coupons a blue-green colour and it can be observed that the colour intensity is lessened with decontamination attempts (Figure 8). In this image the skin coupons in row 1 (Fuller's Earth samples) are considerably more "clean" than those in row 2 (soap samples) or row 3 (water samples)

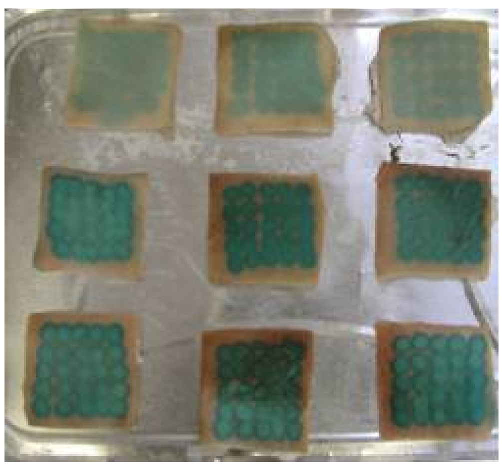

Figure 8: The ^{64}Cu swine skin coupons after final decontamination attempts.

The residual contamination levels of ^{64}Cu following decontamination attempts were determined for water, soap or Fuller's Earth paste (Figure 9). The mean and standard deviation for each data point was calculated as stated previously. The decontamination efficacy of water and soap for radioactive copper was very similar, with water being slightly more effective after the third and fourth attempts. These data indicate that Fuller's Earth paste was once again the most effective decontamination agent when compared to water or soap.

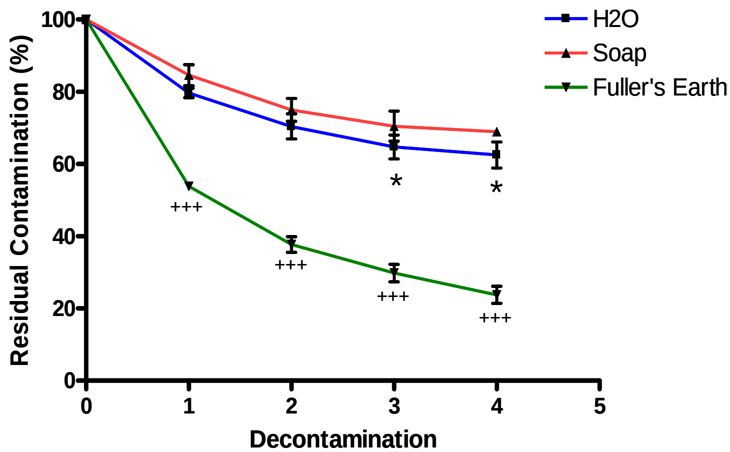

Figure 9: Residual contamination levels of ^{64}Cu after decontamination attempts using Water, Soap or Fuller's Earth paste.

Data represent mean ± SD. +++ P<0.001 (relative to water at each decontamination attempt) * P<0.05 (relative to soap at same decontamination attempt)

Similarly, the residual contamination levels of ^{64}Cu after decontamination attempts using the remaining detergents (Active RSDL and Non-active RSDL) are shown in Figure 10. The mean and standard deviation for each data point was calculated as stated previously. Contrary to our initial hypothesis, RSDL (the current agent used by the CF for chemical decontamination) was not very efficient at radiological decontamination of swine skin. Water alone was significantly more effective at removing ^{64}Cu contamination from the skin coupons than either the active or non-active formula of RSDL.

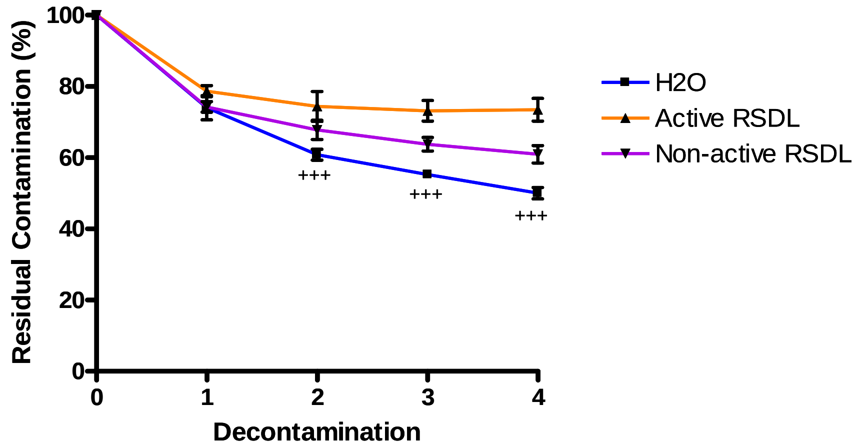

Figure 10: Residual contamination levels of ^{64}Cu after decontamination attempts using Active SDL or Non-active RSDL.

Data represent mean ± SD. +++ P<0.001 (relative to water at each decontamination attempt)

3.4 Technetium (^{99m}Tc)

The residual contamination levels of ^{99m}Tc after decontamination attempts using water, soap, or Fuller's Earth are shown in Figure 11. As seen previously, each of the decontamination agents was successful at significantly decreasing the technetium contamination on each of the respective skin coupons over successive decontamination attempts ($p<0.0001$; Figure 11). Taken together, these data indicate that soap was once again the least effective decontamination agent for ^{99m}Tc. Rinsing with water alone resulted in significantly lower residual contamination levels when compared to soap (*, $p<0.05$) after decontamination attempts 3 and 4. No significant differences were observed between water and Fuller's Earth paste.

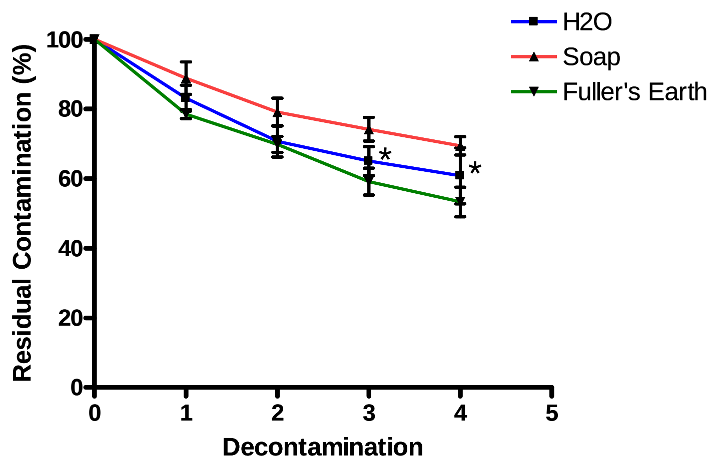

Figure 11: Residual contamination levels of ^{99m}Tc after decontamination attempts using water, soap, or Fuller's Earth.

The residual contamination levels of ^{99m}Tc after decontamination attempts using Active or Non-active RSDL are shown in Figure 12. Water was repeated in this experiment and included as a control. These experiments demonstrated that there were no significant differences between these three decontamination agents for removal of technetium.

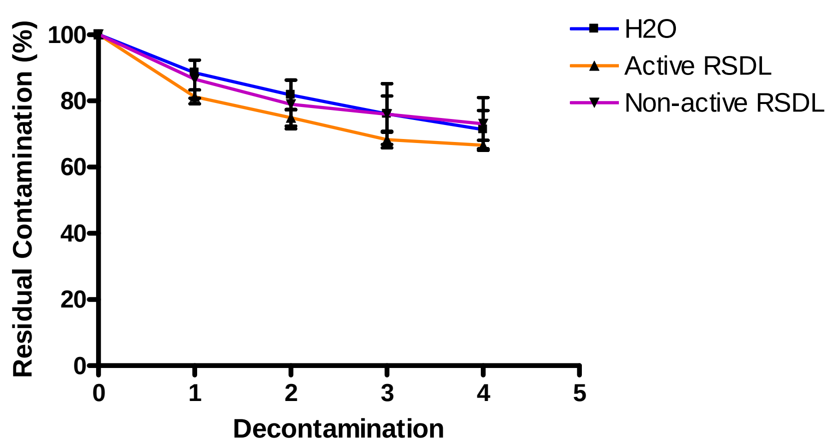

Figure 12: Residual contamination levels of ^{99m}Tc after decontamination attempts using Active or Non-active RSDL.

3.5 Comparative Results for Decontamination

A comparison of the efficacy of all decontamination agents for all radionuclides is shown in Table 2. The residual contamination levels following the first and last decontamination attempt are displayed. One can see that Fuller's Earth Paste was the most effective of all of the agents at radiological decontamination.

Table 2: Comparison of residual contamination levels for all agents and all radionuclides.

	^{24}Na		^{42}K		^{64}Cu		^{99m}Tc	
	Decon #1	**Decon #3**	**Decon #1**	**Decon #4**	**Decon #1**	**Decon #4**	**Decon #1**	**Decon #4**
Water	-	-	83%	53%	80%	62%	83%	60%
Soap	55%	35%	90%	68%	85%	70%	90%	70%
Fuller's Earth Paste	45%	20%	65%	23%	55%	25%	80%	53%
A RSDL	-	-	-	-	80%	73%	80%	67%
NA RSDL	-	-	-	-	74%	60%	86%	73%

3.5.1 Comparison of Soap and Fuller's Earth Paste

The decontamination effectiveness of soap and Fuller's Earth paste was calculated as described in Section 2.7.1. These were the only two agents tested against all of the radionuclides. The decontamination efficiency of soap for ^{24}Na, ^{42}K, ^{64}Cu, or ^{99m}Tc is shown in Figure 13. The effectiveness of soap as a decontamination agent was similar for all radionuclides except ^{24}Na, where soap was able to significantly decrease the residual contamination by almost 50% after the first decontamination attempt. For all other radionuclides, soap was able to remove approximately 30% of the contamination with successive decontamination attempts. The final residual contamination for ^{24}Na was approximately half that of the other radionuclides even after as many as 7 decontamination attempts (data not shown). This may be explained by the low initial activity of the sodium when it arrived.

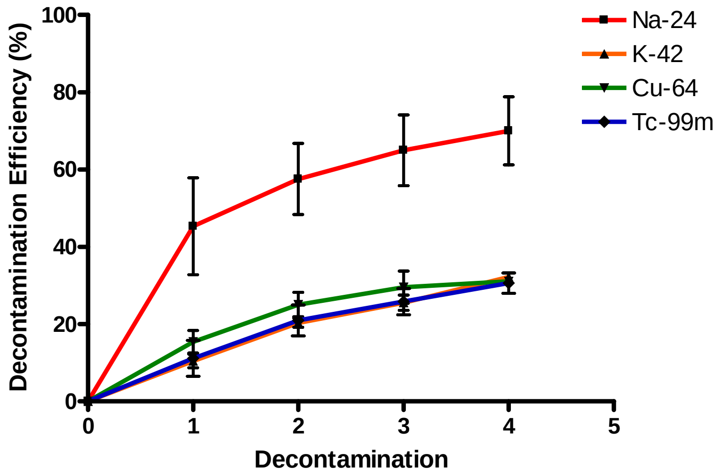

Figure 13: Decontamination efficiency of Soap for removal of ^{24}Na, ^{42}K, ^{64}Cu, or ^{99m}Tc.

The decontamination efficiency of Fuller's Earth paste for ^{24}Na, ^{42}K, ^{64}Cu, or ^{99m}Tc is depicted in Figure 14. Although the effectiveness of Fuller's Earth paste as a decontamination agent varied among the radionuclides tested it proved, overall, to be an effective agent, significantly lowering the contamination levels after the first decontamination attempt. With successive decontamination attempts, Fuller's Earth paste was successful in removing ~60% of the radionuclide contamination with the exception of ^{99m}Tc. The data clearly reveals that ^{99m}Tc proved to be the most difficult radionuclide to remove from the skin surface.

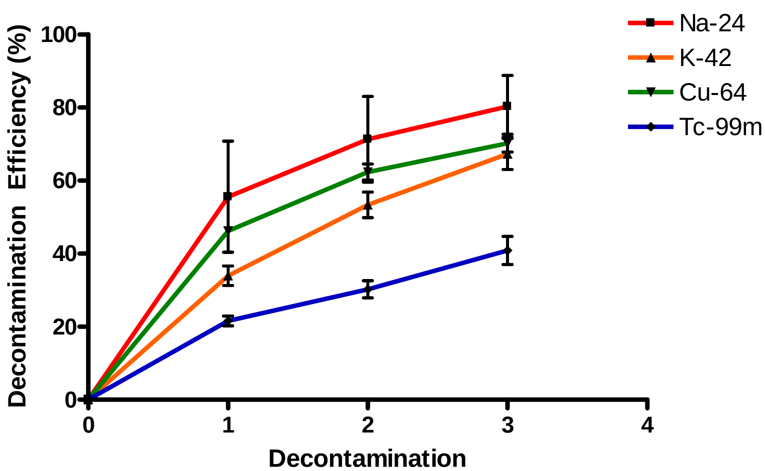

Figure 14: Decontamination efficiency of Fuller's Earth paste for the removal of ^{24}Na, ^{42}K, ^{64}Cu, or ^{99m}Tc.

3.5.2 Relative Efficacy of Decontamination Agents Compared to Water

Only two radionuclides, ^{64}Cu and ^{99m}Tc, were tested against all of the decontamination agents. The relative efficacy of the decontamination agent compared to water is thus shown only for these two radionuclides. The residual ^{64}Cu contamination after 4 cycles of decontamination using water, soap, Fuller's Earth paste, Active RSDL and Non-Active RSDL is depicted in Figure 15. The data are represented as normalized ratios where water was used as the control to normalize the values and is represented as 1. These data demonstrate that Fuller's Earth paste was the only decontamination agent more efficient than water for the removal of radioactive copper.

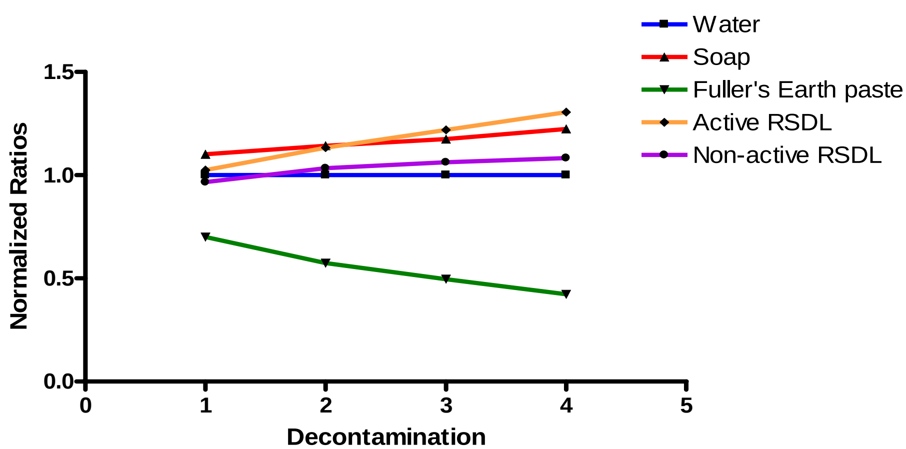

Figure 15: Residual ^{64}Cu contamination after 4 cycles of decontamination comparing soap, Fuller's Earth paste, Active and Non-Active RSDL.

The residual ^{99m}Tc contamination after 4 cycles of decontamination using water, soap, Fuller's Earth paste, Active RSDL and Non-Active RSDL is shown in Figure 16. Again, water was used as the control to normalize the values and is represented as 1 in this graph. These normalized data indicate that there is little difference in the effectiveness of these decontamination agents for removal of 99mTc contamination.

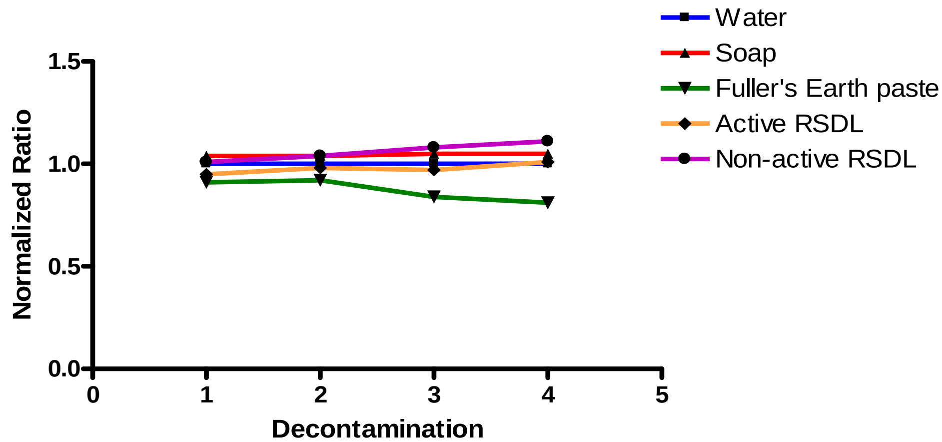

Figure 16: Residual ^{99m}Tc contamination after 4 cycles of decontamination comparing soap Fuller's Earth paste, Active and Non-Active RSDL.

4. Discussion and Conclusions

This work was effective in demonstrating the significant difficulty associated with radiological decontamination of exposed skin. After the first decontamination attempt, results varied from about 90% to 45% residual contamination (Figures 6-12, Table 2). After final decontamination attempts, the lowest residual contamination measurements were obtained from samples decontaminated with Fuller's Earth paste. With that agent, the lowest residual contamination achieved was approximately 20-30% for all radionuclides, with the exception of ^{99m}Tc, whose lowest achievable residual contamination was 60% (as shown in Figure 14). This finding correlates with the data for all other decontamination agents, which showed that ^{99m}Tc was the most challenging radionuclide to decontaminate (Figures 11, 12). Also noted was that ^{24}Na was the least challenging radionuclide to remove (Figures 13, 14). This might be explained by the low activity of the radionuclide upon arrival or the increased solubility associated with the carbonate compound making it readily dissolvable in water and rinsed off.

The decontamination efficacy of soap and water was comparable for all radionuclides, with water alone showing slightly better results (Figures 7, 9 and 11). This may have resulted from the slightly different decontamination techniques we employed for the different agents in these experiments. For decontamination with water, 50 mL of water was used during the washes, while decontamination with soap used only 25 mL of water. We originally made this decision because we wanted the total amount of scrubbing time to be equal for all samples. Scrubbing with 50 mL of water took 2 minutes, whereas the soap decontaminations required at least 1 minute of scrubbing with soap followed by 1 minute of scrubbing with water to rinse. With only 1 minute for the rinse we could only use 25 mL of water. Therefore, the more efficient results we see here from water alone may in fact be due to the increased volume of water that flushed the skin samples.

Our hope that RSDL, the CF's current choice for chemical decontamination, would prove to be a "dual-use" product for radiological decontamination was not realized. RSDL (both active and non-active) did not perform any better than water alone as a decontamination agent (Figures 10 and 12). Ironically, the CF's previous choice for chemical decontamination, Fuller's Earth paste, proved to be the best radiological decontamination agent that we tested, making it the best choice as a "dual-use" product for the CF.

These results indicate that radiological skin decontamination is very challenging, and that an ideal agent is not really known at this time. The need for more effective decontamination agents, evidenced by the results of this study, warrants further research into better agents and methods. It is important to realize that although 85-95% of an individual's skin would not be exposed due to clothing (highlighting the importance of removing clothing following exposure) , our data indicates that the uncovered areas of the skin that become contaminated could only be decontaminated to a mediocre extent. However, in cases where the dose rate of the contaminant is not too high, the natural skin renewal process will help to remove the remaining contaminates. Skin is a continuously renewing organ and this process occurs every 10-14 days with the old cells sloughing off and being repopulated by new underlying ones [3].

In regard to DRDC Suffield's CTTC/FRTP, the short lived radionuclides and the decontamination methods employed in this study would be an excellent radiological detection and decontamination module to add. The training would provide the individuals not only with the knowledge of proper decontamination methods, but also teach them just how difficult the removal of radionuclides from skin may be. We will conduct further experiments and then propose the addition of this module to the DRDC Suffield training program.

5. Future Work

This study examined the efficacy of radiological dermal decontamination using swine skin samples *ex vivo*. The obvious next step would be to examine the decontamination difficulties that might arise with using living skin, as would be the situation when working with the Domestic Swine Model. This follow-on work is important since living skin's natural barrier is more effective than that found in non-living skin [4], and thus one would hypothesize that it might be easier to remove radiological contamination however the opposite may also be true.

In order to examine this effect, we intend to repeat these experiments using human skin samples grown in tissue culture to be obtained from MatTek Corp. This company produces normal (non-transformed), human cell-derived, three-dimensional organotypic *in vitro* tissue models for use in product development and efficacy, claims substantiation, safety assessment, and target organ research applications. We have chosen to use the "full thickness" skin model (EpiDermFT Full Thickness Skin Model), which exhibits *in vivo*-like morphological and growth characteristics that are uniform and highly reproducible. EpiDermFT (EFT) consists of organized basal, spinous, granular, and cornified epidermal layers analogous to those found *in vivo*. The dermal compartment is composed of a collagen matrix containing viable normal human dermal fibroblasts (NHDF). EFT is mitotically and metabolically active.

We hope the results of these next *in vitro* experiments will provide insight for our plan to propose the radiological module for inclusion in DRDC Suffield's CTTC/FRTP. The in vitro experiments, if successful, would then be followed by an experimental assessment using the DSM. The future use of the DSM will move our experiments to the *in vivo* level and will provide the most accurate assessment of decontaminant functionality following a radiological incident (short of performing the experiments on human subjects).

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List of symbols/abbreviations/acronyms/initialisms

CBRN	Chemical, Biological, Radiological and Nuclear
CF	Canadian Forces
CNSC	Canadian Nuclear Safety Commission
CTTC	Counter-terrorism Technology Centre
Cu	Copper
DRDC	Defence Research & Development Canada
DSM	Domestic Swine Model
EFT	EpiDerm Full Thickness
EQ	Exempt Quantities
FRTP	First Responder Training Program
IPE	Individual Protection Equipment
K	Potassium
mL	millilitre
Na	Sodium
NHDF	Normal Human Dermal Fibroblasts
RadSO	Radiation Safety Officer
RMC	Royal Military College
RSDL	Reactive Skin Decontamination Lotion
Tc	Technetium
TDG	Transportation of Dangerous Goods
TLD	Thermal Luminescent Detector
µL	microlitre

Glossary

Atrophy

A wasting or decrease in size of a body organ, tissue, or part owing to disease, injury, or lack of use.

Cutaneous

Of, relating to, or affecting the skin.

Dermis

The sensitive connective tissue layer of the skin located below the epidermis, containing nerve endings, sweat and sebaceous glands, and blood and lymph vessels.

Dermatitis

Inflammation of the skin.

Desquamation

The shedding or peeling of the epidermis in scales; sloughing off.

Epidermis

The outer, protective, nonvascular layer of the skin of vertebrates, covering the dermis.

Fibroblast

A cell that gives rise to connective tissue.

Half-Life

The time required for half the nuclei in a sample of a specific isotopic species to undergo radioactive decay.

In vitro

(Experiments performed) In an artificial environment outside the living organism.

In vivo

(Experiments performed) Within a living organism.

Metabolically Active

The cells are growing and using nutrients.

Mitotically Active

The cells are actively growing and dividing.

Organotypic

Resembling an organ *in vivo* in three dimensional form or function or both.

Percutaneous Absorption

Passed, or effected through the unbroken skin. Transdermal.

Transformed

Eukaryotic cells obtained in a stationary phase which undergo a conversion to a state of unregulated growth in culture, resembling an *in vitro* tumour.

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A series of swine-skin decontamination trials were carried out to demonstrate a *proof-of-principle* for including a radiological detection and decontamination module in DRDC Suffield's Counter-Terrorism Technology Centre / First Responder Training Program (CTTC/FRTP). The radionuclides examined were ^{64}Cu, ^{42}K, ^{24}Na, and ^{99m}Tc and the decontamination agents evaluated included Water, Soap, Fuller's Earth paste, and both Active and Non-Active Reactive Skin Decontamination Lotion (RSDL). Skin coupons (2 x 2 inches) were prepared from fresh swine skin and then contaminated with 20µL spots in a 5 x 5 grid for each radionuclide. Initial decontamination attempts reduced the residual contamination levels to about 50%. The lowest residual contamination achieved after multiple decontamination cycles was 20%. Fuller's Earth paste proved to be the best decontamination agent with an average final residual contamination level of 20% for all radionuclides except ^{99m}Tc. With ^{99m}Tc, the lowest residual contamination level achieved was ~40% after six decontamination cycles. RSDL (Active and Non-Active) did not prove to be an effective radiological decontamination agent, as Water alone resulted in lower residual contamination levels. These experiments will be repeated using living human skin in tissue culture before presenting a proposal to implement a radiological detection and decontamination module to the DRDC Suffield training program.

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