THESIS

DECONTAMINATING COBALT-60 FROM WOUNDS

Submitted by

Daniel Mannis

Department of Environmental and Radiological Health Sciences

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2013

Master's Committee:

Advisor: Alexander Brandl

Thomas Johnson
James Lindsay

ABSTRACT

DECONTAMINATING COBALT-60 FROM WOUNDS

Removing radionuclide contamination from wounds in tissue is essential to minimizing incorporation and dose to an individual. This experiment compared the effectiveness of decontaminating wounds inflicted in pig tissue that were contaminated with cobalt-60. The process was established to compare three decontamination methods consisting of: commercially available, non-prescription, surfactant based, non-ionic wound cleanser spray; physiologic saline solution spray; physiologic saline solution pour. Three wound types were used: smooth incision, jagged cut, and blunt force trauma wounds. The cleanser spray and the saline spray were more effective at decontaminating all three wounds than the saline pour. The difference between the cleanser spray and saline spray was not statistically significant, but the cleanser spray did decontaminate the wound to a lower mean value. The spray pressure used for the saline and cleanser sprays produced the most noticeable impact in the decontamination process.

ACKNOWLEDGEMENTS

I must start by expressing my deep and sincere gratitude to my loving wife of over 20 years, Chris, for her unwavering support, encouragement and faith in me. She has been an amazing companion and mother. Chris, I love you with all my heart. I also want to thank my daughters, Javon and Rachel, for all my career and educational endeavors has required them to endure, they are truly wonderful and understanding ladies. My parent, Jerry and LaLoni, have encouraged me throughout my entire life and have never doubted my abilities. They are wonderful parents and I have been blessed by their presence and guidance in my life. Dad and mom, I love you very much. I must proclaim my thanks to my Lord, Jesus Christ, who is my source of strength.

I am grateful for my advisor, Alex Brandl, and committee members, Thomas Johnson (TJ) and James Lindsay. They have challenged me resulting in a better research project and thesis, and they have helped me through this entire master's degree process.

Finally, there are some folks who are behind the scenes and have a tremendous impact in ensuring things run smoothly. I want to thank Jeanne Brockway, she made the process of being accepted extremely smooth and easy. I want to thank Julie Asmus also. She has been the one I can always go to when I have a question or need, and she always comes through. You two ladies are amazing and I thank you for all you do, the department is lucky to have you. The last quiet person I want to express my thanks to is Dr. John Pinder. He has been my go-to-guy for all things statistical, and this master's degree would have been a lot more difficult without his guidance. Thank you John.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

The guiding principle and regulatory requirement in the field of ionizing radiation protection is as low as reasonably achievable, ALARA, which means minimizing exposure to ionizing radiation to the lowest levels possible taking into account economic and societal factors for occupational workers and members of the public. The concept of ALARA is based on dose, energy deposited per unit of mass, versus effect, cancer, from the Linear-Non-Threshold Dose-response model, which assumes that even low-dose exposures to ionizing radiation proportionally increase the likelihood of cancer and/or an inheritable disease. While there are other dose-response models, the Linear-Non-Threshold Dose-response model is judged to provide "the most reasonable description of the relation between low-dose exposure to ionizing radiation and the incidence of solid cancers that are induced by ionizing radiation" by the National Academy of Sciences Biological Effects of Ionizing Radiation Committee and is used for this research.[1,3,10,13,20]

Exposure to radiation can be via external or internal pathways. External exposure most often is not due to source contact with the individual, except in the case of skin contamination, and ceases when the person is removed from the radiation field. Since the radiation field is external to the person it typically can be easily characterized, allowing for a rather simple and accurate radiation dose assignment to the individual. We use the concepts of time, distance, and shielding to minimize exposure. Time, if the amount of time an individual spends in the radiation field is minimized the accumulated dose will be reduced. Distance, as a person increases the distance between himself and the source the radiation fluence will decrease and the radiation dose will decrease also. Shielding, a material is placed around the source in which the radiation field will interact resulting in reduced radiation fluence outside of the shielding and a decreased radiation dose to the individual.

Internal exposure is a more complex problem since the radioactive material is deposited within the body. Internal exposure can be from inhalation, ingestion, or absorption of radioactive material. The dose to the individual must be determined by calculations using external measurements (of penetrating radiations deposited in the body) and/or from physical observations including urine and fecal samples, which can be unpleasant to collect. Since the radioactive material is inside the body, the irradiation continues depositing energy in tissues after the person leaves the area containing the radioactive material. The radioactive material is eliminated from the body based on the biological half-life, the amount of time required for the body to remove one half of the radioactive material through its normal functions, and the radiological half-life, the time for half the radioactive nuclei in any sample to undergo radioactive decay. The committed effective dose to the individual may result in the dose being delivered over decades; ICRP Publication No. 103[3], The 2007 Recommendations of the International Commission on Radiological Protection, guidance is to integrate dose over 50 years for adults and to the age of 70 years for children. An incorporated radioisotope, having both a long radiological half-life and a long biological half-life, can result in an accumulated dose from the time of incorporation until death, which may be in excess of the standardized 50 years or 70 years of age cutoff.[3]

Controls have been developed to prevent internal exposure. The principles behind these controls are to block the body's portals of entry and to interrupt transmission of radioactive materials to the worker. At the source, the goal is to confine or enclose the source. Confining the radioactive materials refers to limiting the area the material can occupy, which can be accomplished by actions such as using a glove box or a vent hood. Enclosing the radioactive material refers to placing the material into a sealed container. Even with these levels of control, personnel contamination may occur during handling of the material.

Radioactive materials can, depending on the chemical compound, be absorbed through intact skin and incorporated in the body. More typically, internal contamination results from broken skin, i.e. a wound. The open tissue provides a path for contamination to make contact with muscle, fluids, and underlying tissue layers allowing a rapid rate of absorption and incorporation into the body. Due to this increased absorption rate and the potential for incorporation in the surrounding tissue, wound decontamination is an important aspect of health physics.[12]

A large number of studies on wound decontamination focus on plutonium contamination. In these studies, the primary methodology for wound decontamination utilizes the process of chelation.[19] Chelation is a particular way in which ions or molecules form two or more separate coordinate bonds between an organic multi-bonded ligand, chelating agent, and a single metal ion. The chelating agent increases the solubility of the metal ion, which helps to increase mobility of the ion to accelerate removal from the body. Chelating agents can be administered orally to remove contaminates entering the body or sprayed directly onto the wound to assist with the decontamination process. As a result, the internal exposure from the radioisotope is reduced since it is in the body for a shorter period of time. This research is designed to help fill the void of available information on non-transuranic radioisotope wound decontamination due to the shortage of studies addressing this area of personnel decontamination.[11]

The National Council on Radiation Protection and Measurements recommends to copiously irrigate a radioactively contaminated wound with physiologic saline solution for several minutes.[11] A medical prescription is required to purchase physiologic saline solution, increasing the difficulty of having the decontaminating agent at the site of the injury and contaminating event. Quickly decontaminating the wound provides the best hope to minimize the absorption and incorporation of the radioactive contaminates into the body and minimizing the dose. There are several commercial wound cleansing products available without a medical prescription. A comparison of

the efficacy of physiologic saline solution's decontamination ability to that of a commercially available, non-prescription, surfactant based, non-ionic wound cleanser was conducted.

CHAPTER 2: MATERIALS AND METHODS

Experiments were performed by inflicting three types of wounds into samples of excised pig skin. An aqueous solution of cobalt-60 was used as a radioactive wound contaminant. Three different methods of decontamination were performed in a glove box to prevent the spread of contamination.

2.1 MATERIALS

2.1.1 TISSUE

The use of excised pig skin for the project was approved by the Colorado State University Institutional Animal Care and Use Committee. Excised pig skin was used as the tissue for the wound decontamination in this experiment even though there are differences between pig and human skin.

One of the major differences is the sweat glands, of which there are two types: eccrine and apocrine. Eccrine sweat glands are smaller and more shallow than apocrine sweat glands; and they discharge water, in liquid form, directly onto the surface of the skin as a cooling mechanism. Apocrine sweat glands, on the other hand, discharge a milky, oily substance into the canals of hair follicles; and they are associated with pheromones and odors. Humans have eccrine sweat glands over their entire bodies and apocrine sweat glands limited to specific areas of the body such as the armpits and eyelids. However, pigs do not have eccrine sweat glands at all as they are limited to apocrine sweat glands. The variance in sweat glands between humans and pig may pose a difference as to how the radioactive contaminate is absorbed by the surrounding tissues. [4,9,14]

An evaluation of the similarities reveals that humans and pigs have a sparse pelage, but pigs have a higher density of hair which is also more course than the human counterpart. The dermis of both skins is thick and shares a well-defined papillary body and a large population of elastic fibers. The epidermis of the pig is relatively thick, which resembles the human epidermis well.[9] However, the pig's dermis is poorly vascularized when compared to the vascularization of human dermis.[9] Vascularization is important in characterizing the impact of blood flushing the contamination from a wound. However, since ex-vivo tissue was used, the effects of bleeding on the retention of radionuclides in the wound will not be analyzed in this experiment.

Pig skin, with all of its similarities and differences to human skin, was used for several reasons. As compared to other non-primate mammals it is a useful model of human skin. Since the pelage mimics that of humans, the results are expected to be relatively consistent with human skin. Finally, pig skin was readily available in sufficient quantities for the number of decontamination attempts performed.[4,9,14]

2.1.2 WOUNDS

The ex-vivo pig skin was segmented into 7.5 cm by 7.5 cm pieces in preparation for inflicting three wound types. After creating the wound in the ex-vivo tissue, the tissue was contaminated with radioactive material and then decontaminated utilizing multiple techniques. Three wound types were used to evaluate those most likely to be suffered by workers in an environment contaminated with radioactive material. The wounds were:

1. smooth cut inflicted with a scalpel, incision;
2. rough and jagged cut inflicted with the sharp tip of a nail, jagged wound;
3. blunt force trauma produced with a hammer and masonry chisel.

The incision wounds were achieved using a scalpel, blade size 12, held perpendicular to the surface of the tissue, with the handle in contact with the tissue to produce a consistent depth, 0.9 cm, 4.5 cm long smooth wound. This wound is similar to a wound that could be inflicted in the arm of a worker by a sharp cutting tool such as a knife or razor blade.

The jagged wounds were produced by dragging a six penny (6d) finish nail driven through the diameter of a 1.9 cm dowel. The dowel provided a handle, sufficiently solid, to firmly hold the nail perpendicular to the surface of the tissue and allowed a downward force great enough to cut through the surface of the skin. The wound inflicted by pulling the nail through the tissue once was of insufficient depth as compared to the incision wound and too small to confine the radioactive contamination. The nail needed to be pulled through the tissue three times to produce a wound of similar depth as the incision wound. The jagged wounds were designed to simulate an injury to a muscled area, such as the arm, of a worker with a rough piece of sheet metal or the tip of a screwdriver.

The blunt force trauma wounds were difficult to produce consistent wounds. The varying thickness and small size (7.5 cm × 7.5 cm) of the tissue samples proved challenging to position. Holding the tissue tight enough to open the surface tissue without causing significant damage to the underside of the tissue was the primary difficulty. Once the underside of the tissue was damaged, the surface would open, creating a complete penetration along a portion or the entire length of the wound.

The first attempt in imposing a blunt force trauma was performed by laying the tissue flat on a board. A masonry chisel with a 4.5 cm wide blade was placed directly on top and in contact with the tissue. The chisel was struck with a hammer to create the wound. The dermal layer of the tissue damaged more easily than the surface of the epidermis. Multiple blows from the hammer were required to damage the epidermis. Since the dermis was easier to damage, the skin received a

penetrating wound by the time the chisel damaged the epidermis. The penetration would allow the contamination to pass through the tissue onto the underlying material supporting the tissue. This method was unacceptable.

The second attempt to create a blunt force trauma wound was similar to the first; however, the tissue was stretched tight and nailed to a board at the four corners to hold the tissue in place. The same method for inflicting the wound as in the first attempt was repeated with very similar results. Once again, this method of inflicting a blunt force trauma was unacceptable.

A third attempt also did not produce a blunt force trauma wound acceptable for the experiment. A piece of 0.3 cm thick foam was rolled tightly to create a 2.5 cm diameter cylinder. The tissue was stretched over the foam cylinder and nailed to a base at the four corners to hold the tissue tight and secure. Again the masonry chisel was struck with a hammer with sufficient force to produce a wound. The foam cylinder absorbed too much of the force from the chisel except at the corners where it penetrated the tissue. Both ends of the chisel penetrated the tissue while leaving the area in between the two small wounds unaffected.

Attempt number four consisted of wrapping one layer of 0.3 cm foam around a 1.9 cm diameter wood dowel which was nailed to a base. A same size dowel 10 cm long was split along its length. The dowel halves were placed with the curved side down and nailed to the base to hold the tissue firmly in place as seen in Figure 2.1. A wound was inflicted following the same procedure as in each of the previous attempts. The surface of the tissue was difficult to damage and once enough force was used the chisel penetrated the tissue's entire thickness. Attempt number four, as all the previous attempts, was unacceptable in producing a suitable blunt force trauma wound.

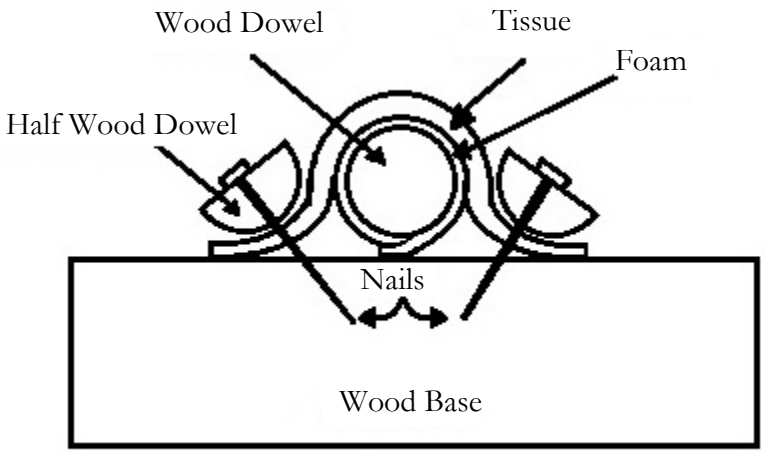

Figure 2.1: Blunt Force Trauma Stand

The final attempt to produce an acceptable blunt force trauma repeated the process of attempt four except a scalpel was used to start the wound to the surface of the skin. The area of the wound was very slightly abraded to help the tissue tear when the chisel was struck by the hammer. Inspection of the tissue revealed a wound 4.5 cm in length, depth comparable to that of the other types of wounds, and demonstrating much more tearing than the jagged wounds. The blunt force trauma wounds were less consistent in presentation than either of the other wound types. However, actual blunt force trauma from a work environment also has the potential for significant variation. This method of imposing blunt force trauma wounds was deemed acceptable for the purpose of this experiment.

2.1.3 RADIONUCLIDE

Cobalt-59 is a stable metal used to produce alloys that are useful because of their excellent wear resistance, corrosion resistance, and elevated temperature hardness. These cobalt alloys are used in the construction of nuclear power plants. As the normal process of corrosion progresses, cobalt-59 atoms are entrained in the reactor coolant which results in the cobalt-59 being exposed to

a neutron flux. The exposure to a neutron flux results in cobalt-59 absorbing a neutron to produce cobalt-60. Cobalt-60 is a radioactive isotope of cobalt which decays to nickel, demonstrated in equation 2.1.[6]

$$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co \rightarrow ^{60}_{28}Ni + e^{-} + \overline{\nu} + \gamma \qquad \text{Equation 2.1}$$

Experiments were conducted using aqueous cobalt-60 chloride (^{60}CoCl) since it offered several favorable traits. Cobalt-60, in an aqueous solution, is a concern for personnel contamination in nuclear power plants. The radiological half-life (T_r) of cobalt-60 is long enough, 5.27 years, to prevent a significant change in the activity (A_F/A_0), due to radiological decay during the decontamination process. Equation 2.2 is used to calculate the decay constant (λ) for cobalt-60 which is used in equation 2.3 to calculate the percentage of the initial activity remaining after 15 minutes (t), the time from the initial survey following the contamination process until the final survey following three decontamination attempts.

$$\lambda = \frac{\ln(2)}{T_r} = \frac{\ln(2)}{5.27\text{y}} = 0.1315\text{y}^{-1} = 1.50\times10^{-5}\text{h}^{-1} \qquad \text{Equation 2.2}$$

$$\frac{A_F}{A_0} = \text{e}^{-\lambda t} = \text{e}^{-1.50\times10^{-5}\text{h}^{-1}\cdot 0.25\text{h}} = 99.9996\% \qquad \text{Equation 2.3}$$

As demonstrated by equation 2.3, effectively 100% of the activity remains after the 15 minutes.[2,7,18]

Cobalt-60 decay yields a beta particle with an average energy of 95.77 keV in 99.9% of all transitions.[2] The beta energy is sufficient to penetrate and deposit energy in the sensitive volume of

a Geiger-Müller (G-M) pancake detector (see Appendix B).[15] The decay of cobalt-60 to stable nickel-60 also releases two gammas, 1.17 and 1.33 MeV, which have a minor contribution to the detected count rate since the gammas have a very low rate of interaction with the detector, approximately 1%.[2,15]

A calibrated (November 21, 2012 at 12:00 P.M. EST) 5 mL aqueous 185 kBq ± 1.2% ^{60}CoCl (0.1M HCl) source (Eckert and Ziegler, Atlanta, GA) was diluted with 245 mL ± 0.04% of deionized water resulting in an activity concentration (A_C) of 740 ± 8.9 Bq/mL.

$$A_C = \frac{\text{source activity}}{\text{total volume}} = \frac{185{,}000\ \text{Bq}}{5\ \text{mL} + 245\ \text{mL}} = 740\ {}^{\text{Bq}}\!/\!_{\text{mL}} \qquad \text{Equation 2.4}$$

$$\sigma_T = \sqrt{\sigma_S^2 + \sigma_W^2} = \sqrt{\left((0.012)^2 + (0.0004)^2\right)} = 0.012 \qquad \text{Equation 2.5}$$

$$A_{C_{Uncertainty}} = \sigma_T \cdot A_C = 0.012 \cdot 740\ {}^{\text{Bq}}\!/\!_{\text{mL}} = 8.9\ {}^{\text{Bq}}\!/\!_{\text{mL}} \qquad \text{Equation 2.6}$$

Table 2.1: Definition of Terms for Equations 2.4, 2.5, and 2.6

Term	Definition	Units
A_c	Activity Concentration	Bq/mL
σ_T	Total Uncertainty of A_C	
σ_S	Source Uncertainty	
σ_W	Water Volume Uncertainty	
$A_{CUncertainty}$	Activity Concentration Uncertainty	Bq/mL

The contamination was applied with a micropipette adjusted to 0.250 mL. To verify the precision and accuracy of the micropipette, deionized water was transferred into a tared 50 mL

beaker using a Fisher Scientific XL-400D scale (see Appendix B). The beaker's mass was recorded, Table 2.2, which resulted in an average of 0.250 ± 0.001 g per pipette transfer. Using equations 2.7 and 2.8, the ^{60}Co activity transferred in each pipette (A_P) was 185 ± 2.59 Bq.

Table 2.2: Pipette Trial Run

Number of Pipettes at 0.250 mL	First Trial Run Mass (g)	Second Trial Run Mass (g)
10	2.50	2.49
20	5.20	4.98
30	7.52	7.46

$$A_P = A_C \cdot V_P = 740\,{}^{\mathrm{Bq}}\!/_{\mathrm{mL}} \cdot 0.250\,\mathrm{mL} = 185\,\mathrm{Bq} \qquad \text{Equation 2.7}$$

$$\sigma_{A_P} = \sqrt{\sigma_P^2 + \sigma_S^2} = \sqrt{\left(\left(\frac{9.6}{740}\right)^2 + \left(\frac{0.001}{0.250}\right)^2\right)} = 0.014 \qquad \text{Equation 2.8}$$

$$\sigma_A = \sigma_{A_P} \cdot A_P = 0.014 \times 185\,\mathrm{Bq} = 2.59\,\mathrm{Bq} \qquad \text{Equation 2.9}$$

Table 2.3: Definition of Terms in Equations 2.7, 2.8, and 2.9

Term	Definition	Units
A_P	Activity in Pipette	Bq
A_c	Activity Concentration	Bq/mL
V_P	Pipette Volume	mL
σ_{AP}	Uncertainty of A_P	
σ_A	Uncertainty of Activity	Bq

2.1.4 DECONTAMINANTS

The National Council on Radiation Protection and Measurements, NCRP, recommends irrigating radioactively contaminated open wounds with copious amounts of physiologic saline solution, a sterile water solution which is isotonically equivalent to tissue fluids and blood, for several minutes to help minimize incorporation into the body.[11] The Agency for Health Care Policy and Research (AHCPR), now the Agency for Healthcare Research and Quality, identify 4 – 15 pounds per square inch (psi) as the safe and effective pressure range for wound cleansing. The AHCPR describes pressures less than 4 psi as inadequate for wound cleansing and pressures greater than 15 psi as having the potential to cause additional trauma to the wound. The commercial marketplace provides access to surfactant based non-ionic wound cleansers (a mild detergent which helps to clean the wound), some of which are in spray bottles designed to operate within the AHCPR recommended pressure range.[17] This experiment combines the recommendations of the NCRP and AHCPR to study decontamination of wounds. A comparison of cleansing radioactively contaminated wounds by flushing with saline solution, spraying with saline at a pressure within the AHCPR recommended pressure range and spraying with wound cleanser at a pressure within the ACHPR recommended pressure range was conducted.[16,17] The spray cleanser used for this research was found to deliver a spray pressure of 8.6 psi at a distance of 7.6 cm verified through testing by an independent laboratory.[5]

The same volume of cleanser or saline was used for each decontamination attempt to determine if the wound cleanser was more effective than saline. A practice decontamination attempt was performed using the cleanser spray to determine an appropriate number of sprays to sufficiently wet and clean the wound, which was found to be 10 pumps from the sprayer. The 10 sprays were found to be a volume of 8.93 ± 0.14 mL. For this experiment, the volume of fluid used was 10 pumps from the spray bottle for all decontamination attempts, not a measured volume of fluid.

One bottle of the cleanser was emptied and flushed with deionized water, water filtered by ion exchange to remove ions such as calcium and others, 10 times; then the sprayer was reinstalled; and pumped 50 times to flush out any cleanser residue. The empty spray bottle was filled with saline, the sprayer was flushed with 50 pumps, and the bottle was emptied to flush the deionized water from the bottle. The bottle was filled with saline for use in all of the saline decontamination experiments. For the saline pour decontamination method, 10 sprays from the saline spray bottle were collected in a 30 mL beaker and then poured through the wound site.

2.2 METHODS

The decontamination experiments were performed in three groups which included all skin samples of a particular wound type: incision, jagged, and blunt force trauma. The glovebox background radiation levels were characterized using a G-M pancake detector before the ^{60}CoCl was transferred into the glovebox. The wounded pieces of pig skin were transferred into a negative pressure glove box (see Appendix B) and placed on a sheet of plastic in a grid pattern. Three 0.250 mL applications of the diluted aqueous ^{60}CoCl were applied into each wound using an adjustable micropipette. The pipette was inserted into the bottom of the wound to apply the radioactive contamination. The three smaller applications of 0.250 mL, instead of one application of 0.750 mL, were used to prevent the radioactive contamination from saturating the wound and spilling out onto the surface of the skin. Following each application, the contamination was allowed to dry for three hours before the next application resulting in a total of nine hours of drying time.

The samples of contaminated pig tissue were transferred to a contaminated material holding area behind a lead shield inside the glovebox. The background radiation levels, in the glovebox, were measured to verify the contaminated tissue did not influence the background radiation level. The background radiation levels were also verified after the decontamination of each sample and

before the commencement of the decontamination of the next sample. Throughout the experiment, background was observed at a consistent rate of 50 counts per minute (CPM).

The decontamination methods were performed in the following order: saline pour, saline spray, and cleanser spray. Each sample of contaminated tissue was transferred from the contaminated material holding area to the main area of the glove box for decontamination. The initial count rate was observed and recorded by holding the probe of the G-M pancake detector approximately 0.6 cm from the surface of the hair on the skin, to prevent contamination of the probe face. The tissue was held at a 45° angle while the decontamination agent was applied. The saline pour was performed by pouring the saline starting at the highest end of the wound and lowering the beaker during the pour. Both of the spray decontamination methods were performed by initiating the spray at the highest end of the wound and lowering the spray nozzle to direct the spray evenly along the length of the wound. The spray decontamination technique was practiced repeatedly to develop the best rate of motion for even application of the spray. Following each decontamination attempt, the tissue was dried using hospital grade gauze (5 cm × 5 cm). A survey, performed after each decontamination attempt, was conducted to determine the new count rate. The decontamination attempt was repeated twice more, for a total of three decontamination attempts, on each piece of tissue.

Four tissue samples of each wound type were used for each decontamination method, see Table 2.4. Since there were three wound types; incision, jagged, and blunt force trauma; and three decontamination methods; saline pour, saline spray, and cleanser spray; 36 total samples of wounded tissue were required. However, after all preparations, wounding attempts, and practice decontamination attempts were conducted only 35 samples of tissue were available for the experiment. Only three samples of tissue, instead of four, were used for the saline pour method of decontamination of the blunt force trauma wound.

Table 2.4: Number of Wound Samples per Decontamination Method

Decontamination Method	Samples by Wound Type		
	Incision	Jagged	Blunt Force Trauma
Cleanser Spray	4	4	4
Saline Spray	4	4	4
Saline Pour	4	4	3

CHAPTER 3: RESULTS AND DISCUSSION

Upon completion of the contamination process, an application of the contamination and a three hour drying time which was repeated three times, the initial count rate was determined for each tissue sample. Following each decontamination attempt, the wound count rate was measured and recorded. The results from each decontamination attempt were corrected by subtracting the glovebox background count rate to provide the actual count rate of the contamination in the wound, the corrected count rate. Then a contamination retention factor (*CRF*) was calculated by comparing the count rate following each decontamination attempt to the initial count rate, indicating the fraction of contamination retained in the wound. The contamination retention factor was developed to provide a quantitative measure with a definite endpoint. The *CRF* was derived from the decontamination factor by inversion, indicating the fraction of the initial activity retained in the wound rather than the amount removed.[8] For the *CRF*, the values would range from 1, meaning all of the initial contamination is present, and eventually approach 0, indicating all of the contamination has been removed. The *CRF* at any point in the decontamination process quickly identifies the fraction of the initial contamination remaining at the site of concern, in this case within the wound.

Equation 3.1 provides an example calculation demonstrating the *CRF* for the data provided below.

Initial corrected count rate (R_I) = 1000 cpm

Corrected count rate following first decontamination attempt (R_{D1}) = 500 cpm

$$CRF = \frac{R_{D1}}{R_I} = \frac{500\ \text{cpm}}{1000\ \text{cpm}} = 0.5 \qquad \text{Equation 3.1}$$

The four tissue samples used to test each of the three decontamination methods produced four data points for each tissue sample consisting of the initial contamination retention factor, CRF_0 ($CRF_0 = 1.0$ for all samples), and the contamination retention factor following each decontamination attempt: CRF_1, CRF_2, and CRF_3 (displayed in Tables 3.1, 3.2 and 3.3). A two-way analysis of variance (ANOVA) test was used to determine how many decontamination attempts produced a statistically significant difference and a one-way ANOVA was used to determine if a statistically significant difference existed between the decontamination methods for each wound type.

The two-way ANOVA is the simplest and most robust method to conservatively compare two independent variables to determine if a statistically significant difference exists within a data set using a 95% confidence interval. Utilizing the Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA) application data analysis two-way ANOVA feature, the data were compared to determine if a difference existed from one decontamination attempt to the others for each tissue sample. The two-way ANOVA identifies if a statistically significant difference exists, but it does not distinguish which values are significantly different. The Tukey's Honestly Significant Difference (HSD), a single step – multiple comparison procedure, is used to identify which of the differences are statistically significant. Tukey's HSD was then used to compare the mean *CRF* values to determine which decontamination attempts were statistically effective. The one-way ANOVA was used with the Tukey's HSD to determine which decontamination methods produced a statistically significant difference as compared to the other decontamination methods.

3.1 INCISION WOUNDS

Table 3.1 displays the data obtained from the decontamination attempts for the tissue samples with incision wounds. The two-way ANOVA indicated a statistically significant difference between the decontamination attempts. The mean *CRF* and the standard deviation are recorded in

Table 3.1. Figure 3.1 graphically displays the mean *CRF* values for each decontamination method with error bars displaying one standard deviation.

Table 3.1: Incision Wound Decontamination Results

	Cleanser Spray			Saline Spray			Saline Pour		
	CRF_1	CRF_2	CRF_3	CRF_1	CRF_2	CRF_3	CRF_1	CRF_2	CRF_3
T_1	0.30	0.23	0.18	0.50	0.37	0.27	0.59	0.56	0.56
T_2	0.56	0.36	0.28	0.50	0.36	0.35	0.87	0.86	0.86
T_3	0.37	0.26	0.23	0.47	0.34	0.28	0.66	0.66	0.66
T_4	0.43	0.24	0.24	0.49	0.36	0.29	0.90	0.90	0.90
Mean *CRF*	0.41	0.27	0.23	0.49	0.36	0.30	0.73	0.72	0.72
Standard Dev	0.10	0.05	0.03	0.01	0.01	0.03	0.13	0.14	0.14

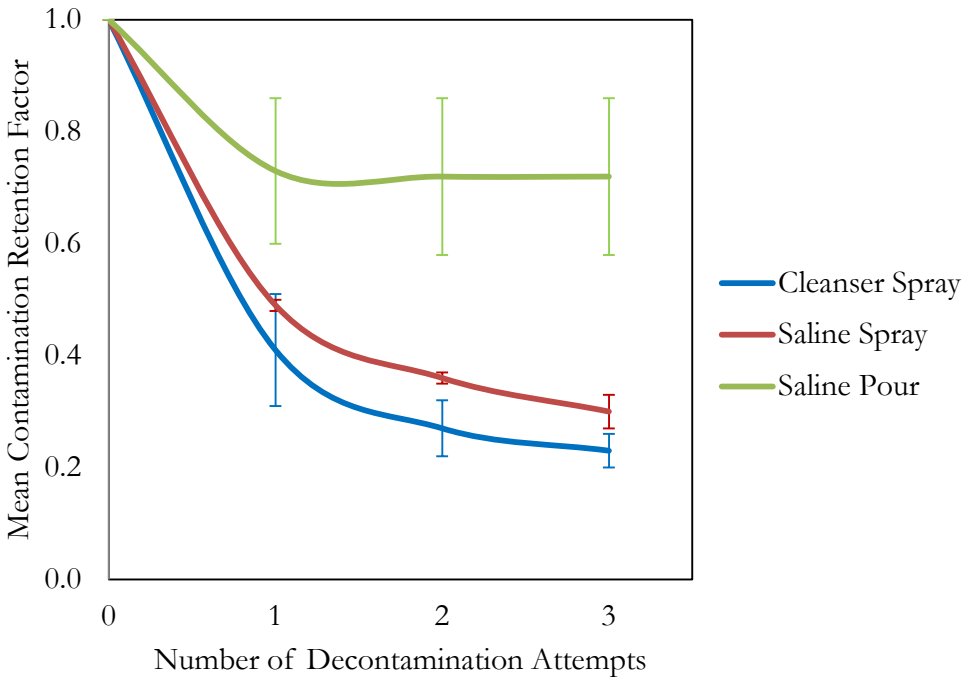

Figure 3.1: Incision Wound Mean *CRF* vs Number of Decontamination Attempts

3.1.1 CLEANSER SPRAY

The cleanser spray method of decontamination produced the lowest mean *CRF*, indicating removal of more contamination than either of the two other methods. The first two decontamination attempts were effective, and produced statistically significant differences in the mean *CRF*, while the third attempt was statistically ineffective.

The difference between the *CRF* of the saline spray and cleanser spray following three decontamination attempts was not statistically significant when compared using Tukey's HSD. Since the difference was not statistically significant, the saline spray and the cleanser spray are statistically equivalent decontamination methods.

The *CRF* of the cleanser spray was statistically significantly lower than the *CRF* of the saline pour, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the cleanser spray is a statistically more effective method of decontamination than the saline pour.

3.1.2 SALINE SPRAY

The saline spray method of decontamination produced a mean *CRF* between that of the cleanser spray and saline pour methods of decontamination. All three decontamination attempts were effective and produced statistically significant differences in the mean *CRF*.

The difference between the *CRF* of the saline spray and cleanser spray following three decontamination attempts was not statistically significant when compared using Tukey's HSD. Since the difference was not statistically significant, the saline spray and the cleanser spray are statistically equivalent decontamination methods.

The *CRF* of the saline spray was statistically significantly lower than the *CRF* of the saline pour, after three decontamination attempts, when compared using Tukey's HSD. Since the

difference was statistically significant, the saline spray is a statistically more effective method of decontamination than the saline pour.

3.1.3 SALINE POUR

The saline pour method of decontamination produced the highest mean *CRF* of all the decontamination methods, indicating it removed less contamination than either of the other two methods. Only the first decontamination attempt was effective, producing a statistically significant difference in the mean *CRF*, while the second and third attempts were not effective.

The *CRF* of the saline pour was statistically significantly higher than the *CRF* of the cleanser spray, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the saline pour is a statistically less effective method of decontamination than the cleanser spray.

The *CRF* of the saline pour was statistically significantly higher than the *CRF* of the saline spray, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the saline pour is a statistically less effective method of decontamination than the saline spray.

3.1.4 DISCUSSION

The mean saline pour endpoint *CRF* was 0.72, the mean saline spray endpoint *CRF* was 0.30, and the mean cleanser spray endpoint *CRF* was 0.23, see Table 3.1. The saline pour was a significantly less effective method of decontaminating incision wounds than either the saline spray or cleanser spray methods. Statistically, the saline spray method and the cleanser spray methods were identical, although the cleanser spray appeared to be somewhat more effective. Two decontamination attempts with the cleanser spray, *CRF* = 0.27, produced approximately the same

results as three decontamination attempts using the saline spray, *CRF* = 0.30, see Table 3.1. The mean *CRF*s of the cleanser spray and saline spray are both significantly lower than the saline pour mean *CRF*, which indicates the spray pressure has a significant contribution to the effectiveness of the cleansing agent in wound decontamination.

3.2 JAGGED WOUND

Table 3.2 displays the data obtained from the decontamination attempts for the tissue samples with jagged wounds. The two-way ANOVA indicated a difference between the decontamination attempts. The mean *CRF* and the standard deviation are recorded in Table 3.2. Figure 3.2 graphically displays the mean *CRF* values with error bars displaying one standard deviation.

Table 3.2: Jagged Wound Decontamination Results

Jagged	Cleanser Spray			Saline Spray			Saline Pour		
	CRF_1	CRF_2	CRF_3	CRF_1	CRF_2	CRF_3	CRF_1	CRF_2	CRF_3
T_1	0.43	0.19	0.16	0.46	0.30	0.29	0.80	0.79	0.79
T_2	0.47	0.22	0.21	0.46	0.42	0.41	0.79	0.69	0.69
T_3	0.44	0.31	0.24	0.51	0.40	0.32	0.47	0.43	0.39
T_4	0.49	0.32	0.25	0.44	0.26	0.25	0.72	0.71	0.71
Mean *CRF*	0.45	0.26	0.21	0.47	0.35	0.32	0.69	0.65	0.64
Standard Dev	0.02	0.06	0.04	0.03	0.07	0.06	0.13	0.13	0.15

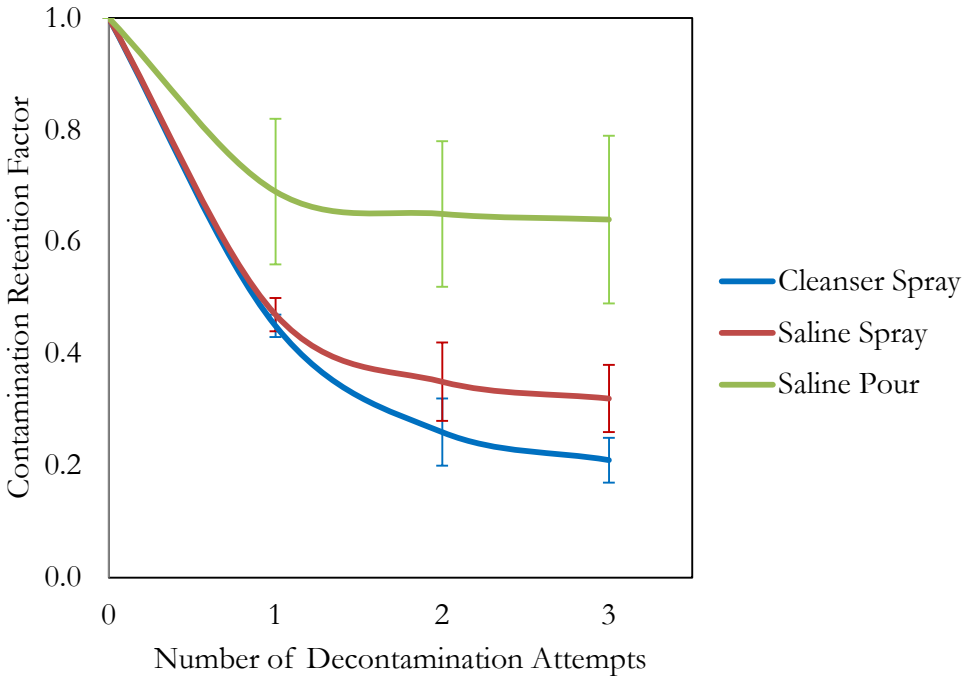

Figure 3.2: Jagged Wound Mean *CRF* vs Number of Decontamination Attempts

3.2.1 CLEANSER SPRAY

The cleanser spray method of decontamination produced the lowest mean *CRF*, indicating removal of more contamination than either of the two other methods. The first two decontamination attempts were effective, and produced statistically significant differences in the mean *CRF*, while the third attempt was statistically ineffective.

The difference between the *CRF* of the saline spray and cleanser spray following three decontamination attempts was not statistically significant when compared using Tukey's HSD. Since the difference was not statistically significant, the saline spray and the cleanser spray are statistically equivalent decontamination methods.

The *CRF* of the cleanser spray was statistically significantly lower than the *CRF* of the saline pour, after three decontamination attempts, when compared using Tukey's HSD. Since the

difference was statistically significant, the cleanser spray is a statistically more effective method of decontamination than the saline pour.

3.2.2 SALINE SPRAY

The saline spray method of decontamination produced a mean *CRF* between that of the cleanser spray and saline pour methods of decontamination. The first two decontamination attempts were effective, and produced statistically significant differences in the mean *CRF*, while the third attempt was statistically ineffective.

The difference between the *CRF* of the saline spray and cleanser spray following three decontamination attempts was not statistically significant when compared using Tukey's HSD. Since the difference was not statistically significant, the saline spray and the cleanser spray are statistically equivalent decontamination methods.

The *CRF* of the saline spray was statistically significantly lower than the *CRF* of the saline pour, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the saline spray is a statistically more effective method of decontamination than the saline pour.

3.2.3 SALINE POUR

The saline pour method of decontamination produced the highest mean *CRF* of all the decontamination methods, indicating it removed less contamination than either of the other two methods. Only the first decontamination attempt was effective, producing a statistically significant difference in the mean *CRF*, while the second and third attempts were not effective.

The *CRF* of the saline pour was statistically significantly higher than the *CRF* of the cleanser spray, after three decontamination attempts, when compared using Tukey's HSD. Since the

difference was statistically significant, the saline pour is a statistically less effective method of decontamination than the cleanser spray.

The *CRF* of the saline pour was statistically significantly higher than the *CRF* of the saline spray, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the saline pour is a statistically less effective method of decontamination than the saline spray.

3.2.4 DISCUSSION

The mean saline pour endpoint *CRF* was 0.64, the mean saline spray endpoint *CRF* was 0.32, and the mean cleanser spray endpoint *CRF* was 0.21, see Table 3.2. The results demonstrate that saline pour was significantly less effective than the saline spray or cleanser spray methods of decontamination. Comparing the results of the saline spray method and the cleanser spray method seems to indicate that the cleanser spray was more effective, but not significantly. The difference between the mean *CRF*s of the cleanser spray and saline spray are both significantly lower than the saline pour mean *CRF*, which indicates the spray pressure has a significant contribution to the effectiveness of the cleansing agent in wound decontamination.

3.3 BLUNT FORCE TRAUMA

Table 3.3 displays the data obtained from the decontamination attempts for the tissue samples with blunt force trauma wounds. The two-way ANOVA indicated a statistically significant difference between the decontamination attempts. The mean *CRF* and the standard deviation are recorded in Table 3.3. Figure 3.3 graphically displays the mean *CRF* values with error bars displaying one standard deviation.

Table 3.3: Blunt Force Trauma Decontamination Results

Blunt Force Trauma	Cleanser Spray			Saline Spray			Saline Pour		
	CRF_1	CRF_2	CRF_3	CRF_1	CRF_2	CRF_3	CRF_1	CRF_2	CRF_3
T_1	0.30	0.17	0.17	0.60	0.47	0.44	0.62	0.45	0.44
T_2	0.20	0.10	0.09	0.41	0.31	0.24	0.69	0.53	0.50
T_3	0.37	0.24	0.22	0.49	0.32	0.28	0.96	0.94	0.94
T_4	0.51	0.44	0.44	0.36	0.27	0.21			
Average *CRF*	0.31	0.20	0.19	0.47	0.34	0.29	0.75	0.63	0.61
Standard Dev	0.11	0.13	0.13	0.09	0.08	0.09	0.15	0.22	0.23

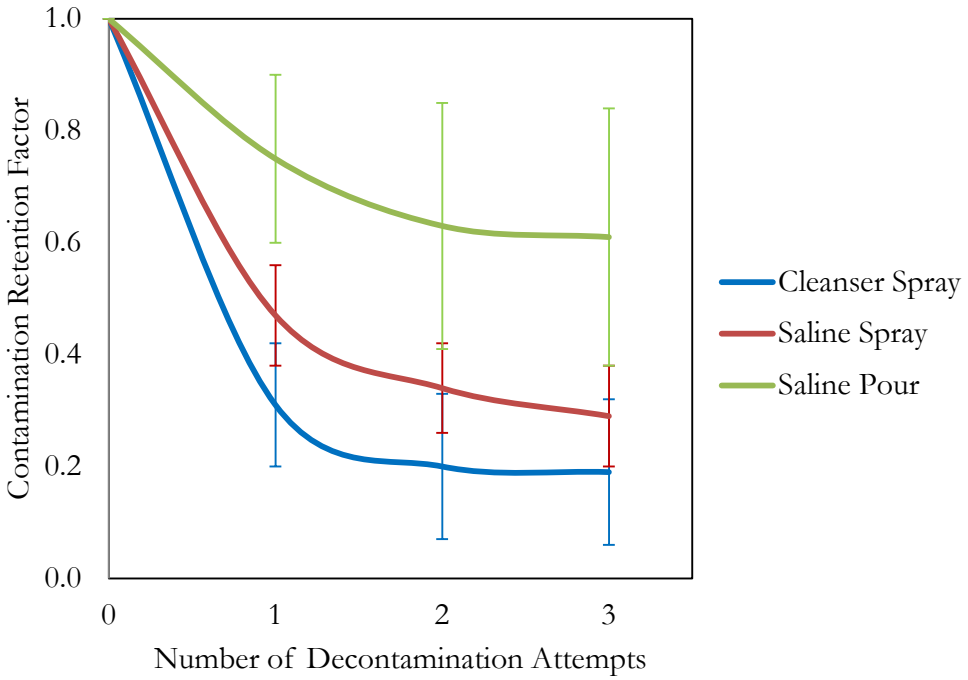

Figure 3.3: Blunt Force Trauma Average *CRF* vs Number of Decontamination Attempts

3.3.1 CLEANSER SPRAY

The cleanser spray method of decontamination produced the lowest mean *CRF*, indicating removal of more contamination than either of the two other methods. The first decontamination

attempt was effective, and produced statistically significant differences in the mean *CRF*, while the second and thirds attempt were statistically ineffective.

The difference between the *CRF* of the saline spray and cleanser spray following three decontamination attempts was not statistically significant when compared using Tukey's HSD. Since the difference was not statistically significant, the saline spray and the cleanser spray are statistically equivalent decontamination methods.

The *CRF* of the cleanser spray was statistically significantly lower than the *CRF* of the saline pour, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the cleanser spray is a statistically more effective method of decontamination than the saline pour.

3.3.2 SALINE SPRAY

The saline spray method of decontamination produced a mean *CRF* between that of the cleanser spray and saline pour methods of decontamination. All three decontamination attempts were effective, and produced statistically significant differences in the mean *CRF*.

The difference between the *CRF* of the saline spray and cleanser spray following three decontamination attempts was not statistically significant when compared using Tukey's HSD. Since the difference was not statistically significant, the saline spray and the cleanser spray are statistically equivalent decontamination methods.

The *CRF* of the saline spray was statistically significantly lower than the *CRF* of the saline pour, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the saline spray is a statistically more effective method of decontamination than the saline pour.

3.3.3 SALINE POUR

The saline pour method of decontamination produced the highest mean *CRF* of all the decontamination methods, indicating it removed less contamination than either of the other two methods. Only the first decontamination attempt was effective, producing a statistically significant difference in the mean *CRF*, while the second and third attempts were not effective.

The *CRF* of the saline pour was statistically significantly higher than the *CRF* of the cleanser spray, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the saline pour is a statistically less effective method of decontamination than the cleanser spray.

The *CRF* of the saline pour was statistically significantly higher than the *CRF* of the saline spray, after three decontamination attempts, when compared using Tukey's HSD. Since the difference was statistically significant, the saline pour is a statistically less effective method of decontamination than the saline spray.

3.3.4 DISCUSSION

The mean saline pour endpoint *CRF* was 0.61, the mean saline spray endpoint *CRF* was 0.29, and the mean cleanser spray endpoint *CRF* was 0.19, see Table 3.3. The uncertainty for the final *CRF*s was larger for the blunt force trauma than the uncertainty of the incision and jagged wounds for each decontamination method. However, the larger uncertainties were expected since the blunt force trauma wounds were less consistent than other wound types. The results demonstrate that the saline pour was significantly less effective than the saline spray or cleanser spray methods of decontamination. Comparing the results of the saline spray and cleanser spray methods seems to indicate that the cleanser spray was more effective. However, as there was no statistically significant difference between these two endpoints, this cannot be ascertained with

sufficient confidence. Since the spray cleanser and the saline spray decontaminated more effectively than the saline pour, we can conclude that the spray pressure has a significant contribution to the effectiveness of the cleansing agent in wound decontamination.

3.4 DECONTAMINATION DISCUSSION

The cleanser spray appears to be to best method for removing contamination from a wound. The spray cleanser decontaminated all of the wounds to a lower mean *CRF*. Cleanser spray can be purchased over the counter from drug stores while the saline solution requires a prescription to purchase. Cleanser spray is thus easier to obtain for facilities without a physician on-site. The cleanser spray is provided with a sprayer designed to provide pressure within the target range; and to utilize the saline as it was in this experiment would require a sprayer designed to deliver the saline at the target pressure. Ultimately, the cleanser spray can be obtained relatively easily, delivers the ideal wound cleaning pressure and cleans the wounds to the lowest mean *CRF* of all the decontamination techniques tested in the experiment.

From a statistical standpoint, the effectiveness of first two decontamination attempts of the cleanser spray provides valuable information from an operational perspective. If a mass casualty were to occur, and a substantial number of people have contaminated wounds, the decontamination process may be limited to only two attempts in order to quickly process all the injured individuals and to effectively use the decontamination agent inventory. However, if only a small number of people have contaminated wounds, the third attempt may be warranted to reduce the dose to the individual since processing time and inventory are not of such great concern.

CHAPTER 4: UNCERTAINTY

The processes of obtaining a source material, source dilution, wound creation, contamination application, and wound counting cannot, by their nature, be exact. Due to the limitations in making measurements, not shortcomings in measurements, there are uncertainties associated with all measurements. To have confidence in the results the impacts of these uncertainties must be considered.

4.1 CONTAMINATE UNCERTAINTY

4.1.1 COBALT-60 SOURCE

The NIST traceable cobalt-60 certified source activity was 185 kBq ± 1.2% on 12 November 2012 at 12:00 P.M. Eastern Standard Time. Since the uncertainty was ± 1.2%, the range of activity of the source was 182,780 to 187,220 Bq.

4.1.2 SOURCE DILUTION

The 5 mL source was diluted with 245 mL of deionized water. The deionized water was weighed on a Fisher Scientific XL-400D scale (see Appendix B) with a 400 g capacity and 0.01 g resolution. A resolution of 0.01 g indicates that the actual mass of the deionized water was between 244.09 to 245.01 g. An uncertainty of 0.04% was introduced by the dilution process..

4.1.3 MICROPIPETTE

The adjustable micropipette was set to deliver a volume of 0.250 mL with each application. The pipetting process was practiced repeatedly to develop familiarity with the pipette operation and

then multiple transfers were deposited into a tared beaker. The tared beaker was placed on a scale and 30 transfers were deposited into the beaker to determine the final mass of the water transferred; this entire process was repeated twice. The data from these two pipette processes were used to determine the uncertainty associated with the micropipette. The uncertainty of the micropipette was determined to be 1.4%

4.1.4 TOTAL CONTAMINATE UNCERTAINTY

The three uncertainties; source, dilution, and micropipette; combine to produce a total uncertainty of 1.8% (Equation 4.1).

$$\sigma_T = \sqrt{\sigma_S^2 + \sigma_W^2 + \sigma_P^2} = \sqrt{\left((0.012)^2 + (0.004)^2 + (0.014)^2\right)} \cdot 100\% = 1.8\% \qquad \text{Equation 4.1}$$

4.2: WOUND UNCERTAINTY

Great care was exercised to produce wounds as consistently as possible to allow the same decontamination experience with each attempt. Each wound type was practiced to develop a technique to produce a similar wound with each attempt, the blunt force trauma being the most difficult to develop and consistently repeat. Calculating an uncertainty value for the wounds would be quite difficult, if not impossible, so the uncertainty of the wounds was not calculated separately but is reflected in the total uncertainties from the decontamination process.

4.3 COUNTING UNCERTAINTY

The same G-M pancake detector used to count the background count rate, initial count rate of each sample, and count rate following each decontamination attempt to remove potential uncertainty contributions resulting from using multiple detectors. The range of the wound count

rates was in relatively small, 2600 to 180 counts per minute, which would minimize the uncertainty as compared to a process involving a much larger count rate range. The count rates were converted into the *CRF* by dividing the count rate after the decontamination attempt by the initial count rate, and the mean *CRF* was used to analyze the data. The standard deviation represents the uncertainty of the entire process which includes the uncertainty of the counting results.

4.4 OVERALL UNCERTAINTY

The contaminate uncertainties; source, dilution, and pipette; do not significantly impact the results since the actual activity within the wound is not a factor in determining the effectiveness of the decontamination techniques. The *CRF* sets all activity measurements to relative activity measurements based on each tissue sample's initial activity count rate. Since the *CRF* removes the concern for the uncertainties of the activity in the wound, the only remaining uncertainties of concern are those associated with the wounds and the detector. The overall uncertainty of the entire process is incorporated in the standard deviation and in the results of the two-way ANOVA and Tukey's HSD used to identify statistical significance within the results.

CHAPTER 5: CONCLUSION

This experiment compared the effectiveness of decontaminating wounds inflicted in ex-vivo pig tissue. The process was established to compare three decontamination methods consisting of: 1) commercially available, non-prescription, surfactant based, non-ionic wound cleanser spray; 2) physiologic saline solution spray; and 3) physiologic saline solution pour. Three wound types were used for the experiment: 1) incision, a smooth cut inflicted with a scalpel; 2) jagged wound, a rough wound inflicted with the sharp tip of a six penny nail; and 3) blunt force trauma, inflicted with a masonry chisel and a hammer. The experiment was developed to help fill a void of available literature on the most effective ways to decontaminate wounds contaminated with non-transuranic radionuclides.

The data from each of the wound types present a similar outcome: 1) the spray pressure of 8.6 psi, when used with either the cleanser or the saline, was significantly more effective in removing the contamination from the wound as compared to pouring saline to decontaminate the wound; 2) the cleanser spray did not decontaminate to a significantly lower lever than the saline spray on any of the wounds; 3) the cleanser spray decontaminated the wound to a lower mean *CRF* than the saline spray, by greater than one standard deviation when used on the incision and jagged wounds; 4) the cleanser spray decontaminated the blunt force trauma wound to a lower mean *CRF* than the saline spray, but not outside of one standard deviation; and 5) the first two decontamination attempts of the cleanser spray were more effective in reducing the mean *CRF* than three decontamination attempts using the saline spray method.

This experiment demonstrated that simply flushing a wound with physiological saline solution is not the best way to remove contamination from a wound. The decontamination data

clearly established that a wound cleansing pressure of 8.6 psi has a significant effect on the wound contamination removal effectiveness of the cleansing agent.

In each of the decontamination methods the surfactant based non-ionic wound cleanser spray removed the contamination to a lower mean *CRF* than the saline spray or saline pour. Two decontamination attempts with the cleanser spray reduced the mean *CRF* to a lower value than three decontamination attempts with either the saline spray or saline pour decontamination methods; and the third decontamination attempt with the cleanser spray did not produce a statistically significant difference in the *CRF*. The saline pour decontamination method was ineffective at wound decontamination when compared to either the saline or cleanser spray decontamination methods.

The experiments were performed on ex-vivo tissue, which prevented observing the effects of living tissue response to the decontamination process. The lack of blood flow prevented any potential flushing effect to carry the contamination out of the wound site before incorporation into the body. Also, the ex-vivo tissue may have different absorption characteristics than living tissue. Since only one specific radionuclide was used in this experiment, the results may not be applicable to all nuclides and all chemical forms. Additional research may be able to use living tissue and multiple radionuclides in various chemical forms to verify overall effectiveness. The testing was limited to a single cleanser spray; there are several wound cleanser sprays available on the commercial market. Additional studies may be able to determine if one of these commercially available cleansers is particularly more effective in radioactive wound decontamination.

REFERENCES

1. Annuals of the International Commission of Radiation Protection (ICRP), *ICRP Publication 22, Implications of Commission Recommendations that Doses be Kept as Low as Readily Achievable,* pp. 2-7, (1973).

2. Annuals of the International Commission of Radiation Protection (ICRP), *ICRP Publication 38, Radionuclide Transformations – Energy and Intensity of Emissions*, pp. 63, (1984).

3. Annuals of the International Commission of Radiation Protection (ICRP), *ICRP Publication 103, The 2007 Recommendations of the International Commission on Radiological Protection*, pp. 72-298, (2007).

4. Bartek, Methodius J.; Labudde, John A.; and Maibach, Howard I., *Skin Permeability In-vivo: Comparison in Rat, Rabbit, Pig and Man*, The Journal of Investigative Dermatology, The Williams and Wilkins Co, (1972).

5. Britton, Wayne E. AHCPR Guideline Compliance Test for Sprayer P.S.I. for SkinTegrity Wound Cleanser, CPM Laboratory, Study Number 3231A, (1996).

6. Campbell, Flake C., *Elements of Metallurgy and Engineering Alloys*, ASM International, pp. 557-558, (2008).

7. Cember, H. & Johnson, Thomas E., *Introduction to Health Physics*, 4th Edition, McGraw-Hill, (2009).

8. Johnson, Thomas E. and Birky, Brian K., *Health Physics and Radiological Health*, 4th Edition, Wolters Kluwer, Lippincott Williams and Wilkins, pp. 1203, (2012).

9. Montagna, William and Yun, Jeung S., *The Skin of the Domestic Pig*, Oregon Regional Primate Research Center, Publication No. 24, (1963).

10. National Council on Radiation Protection and Measurements (NCRP), *NCRP Report 136*, *Evaluation of the Linear-Non Threshold Dose-Response Model for Ionizing Radiation*, pp. 1-211, (2001).

11. National Council on Radiation Protection and Measurements (NCRP), *NCRP Report 156, Development of a Biokinetic Model for Radionuclide-Contaminated Wounds and Procedures for Their Assessment, Dosimetry and Treatment*, pp. 7-329, (2007).

12. National Council on Radiation Protection and Measurements (NCRP), *NCRP Report 161, Management of Persons Contaminated with Radioisotopes*, pp. 132-133, (2008).

13. National Research Council (U.S.*), Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII – Phase 2*, National Academy of Sciences, pp. 6, 9-10, (2006).

14. Rittié, Laura; Sachs, Dana L.; Orringer, Jeffrey S.; Voorhees, John J.; and Fisher, Gary J., *Eccrine Sweat Glands are Major Contributors to Reepithelialization of Human Wounds*, The American Journal of Pathology, American Society for Investigative Pathology, Vol. 182, No. 1, Elsevier Inc., (2013).

15. Steinmeyer, Paul R., *G-M Pancake Detectors: Everything You've Wanted to Know (But Were Afraid to Ask)*, RSO Magazine, Vol. 10, No. 5, RSA Publications, pp. 7-17, (2005).

16. Stevenson TR, Thacker JG, Rodeheaver GT, Bacchetta C, Edgerton MT, Edlich RF. *Cleansing the Traumatic Wound by High Pressure Syringe Irrigation*, Journal of the American College of Emergency Physicians, Volume 5, Issue 1, pp. 17-21, (1976).

17. Treatment of Pressure Ulcers Guideline Panel, *Treatment of Pressure Ulcers*, Rockville (MD): Agency for Health Care Policy and Research (AHCPR); 1994 Dec. (AHCPR Clinical Practice Guidelines, No. 15.) Available from: http://www.ncbi.nlm.nih.gov/books/NBK63898/

18. Turner, James E., *Atoms, Radiation, and Radiation Protection*, 7th Edition, WILEY-VCH Verlag GmbH & Co, (2007).

19. Tymen H., Gerasimo P., and Hoffschir D. *Contamination and Decontamination of Rat and Human Skin with Plutonium and Uranium, Studied with a Franz's Chamber*, International Journal of Radiation Biology, Volume 76, Number 10, pp 1417-1424, (2000).

20. United States Nuclear Regulatory Commission (NRC), *NRC Regulations Title 10 Code of Federal Regulations Part 20-Standards for Protection Against Radiation*: Subpart B, 20.1101 (2013).

APPENDIX A: DATA

Table A1: Cleanser Spray Decontamination Data

Cleanser Spray		Raw Data (CPM)				Corrected Count Rate (CPM)				Contamination Retention Factor			
Decontamination Attempt		0	1	2	3	0	1	2	3	0	1	2	3
Incision	1	975	330	260	220	925	280	210	170	1.00	0.30	0.23	0.18
	2	850	500	340	270	800	450	290	220	1.00	0.56	0.36	0.28
	3	1040	420	310	280	990	370	260	230	1.00	0.37	0.26	0.23
	4	800	370	230	230	750	320	180	180	1.00	0.43	0.24	0.24
Jagged	5	2300	1010	480	400	2250	960	430	350	1.00	0.43	0.19	0.16
	6	1980	950	470	450	1930	900	420	400	1.00	0.47	0.22	0.21
	7	2150	970	700	560	2100	920	650	510	1.00	0.44	0.31	0.24
	8	2250	1120	750	610	2200	1070	700	560	1.00	0.49	0.32	0.25
Blunt Force Trauma	9	1500	485	290	290	1450	435	240	240	1.00	0.30	0.17	0.17
	10	2230	490	265	250	2180	440	215	200	1.00	0.20	0.10	0.09
	11	1630	635	435	400	1580	585	385	350	1.00	0.37	0.24	0.22
	12	930	500	440	440	880	450	390	390	1.00	0.51	0.44	0.44
Average		1553	648	414	367	1503	598	364	317	1.00	0.41	0.26	0.23
Standard Deviation		584	270	162	125	584	270	162	125	0.00	0.10	0.09	0.08

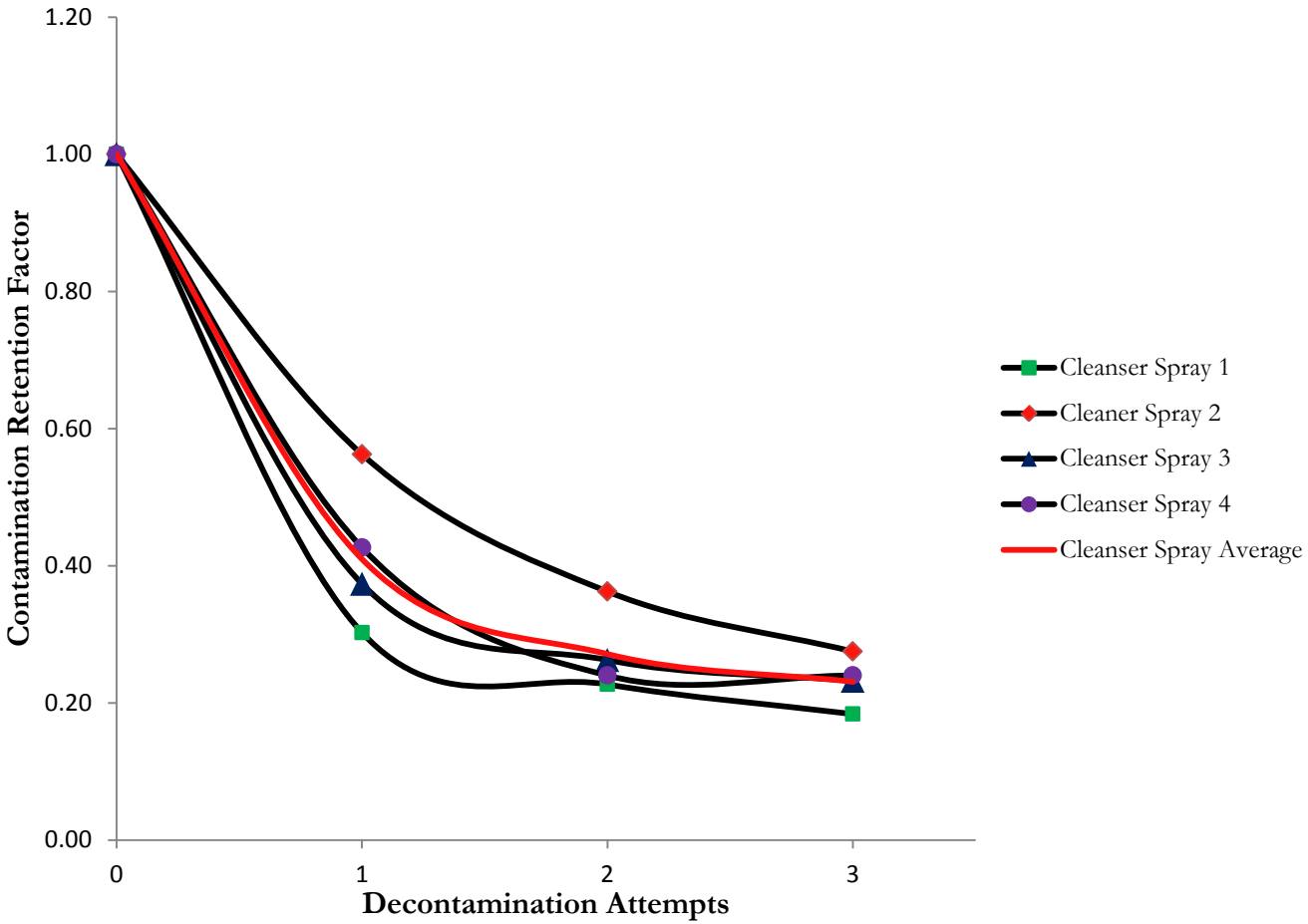

Figure A1: Incision Wound Decontaminated With Cleanser Spray

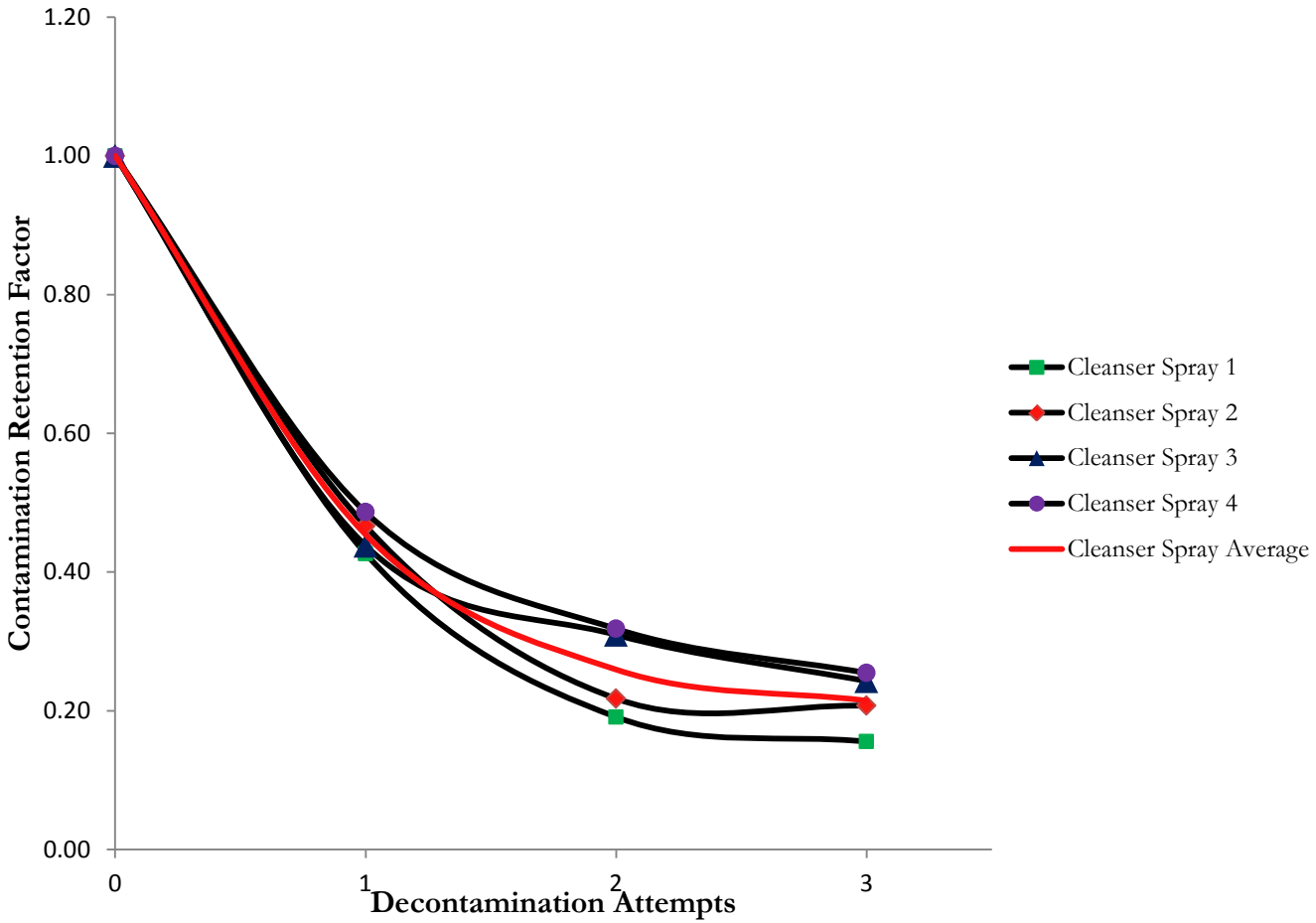

Figure A2: Jagged Wound Decontaminated With Cleanser Spray

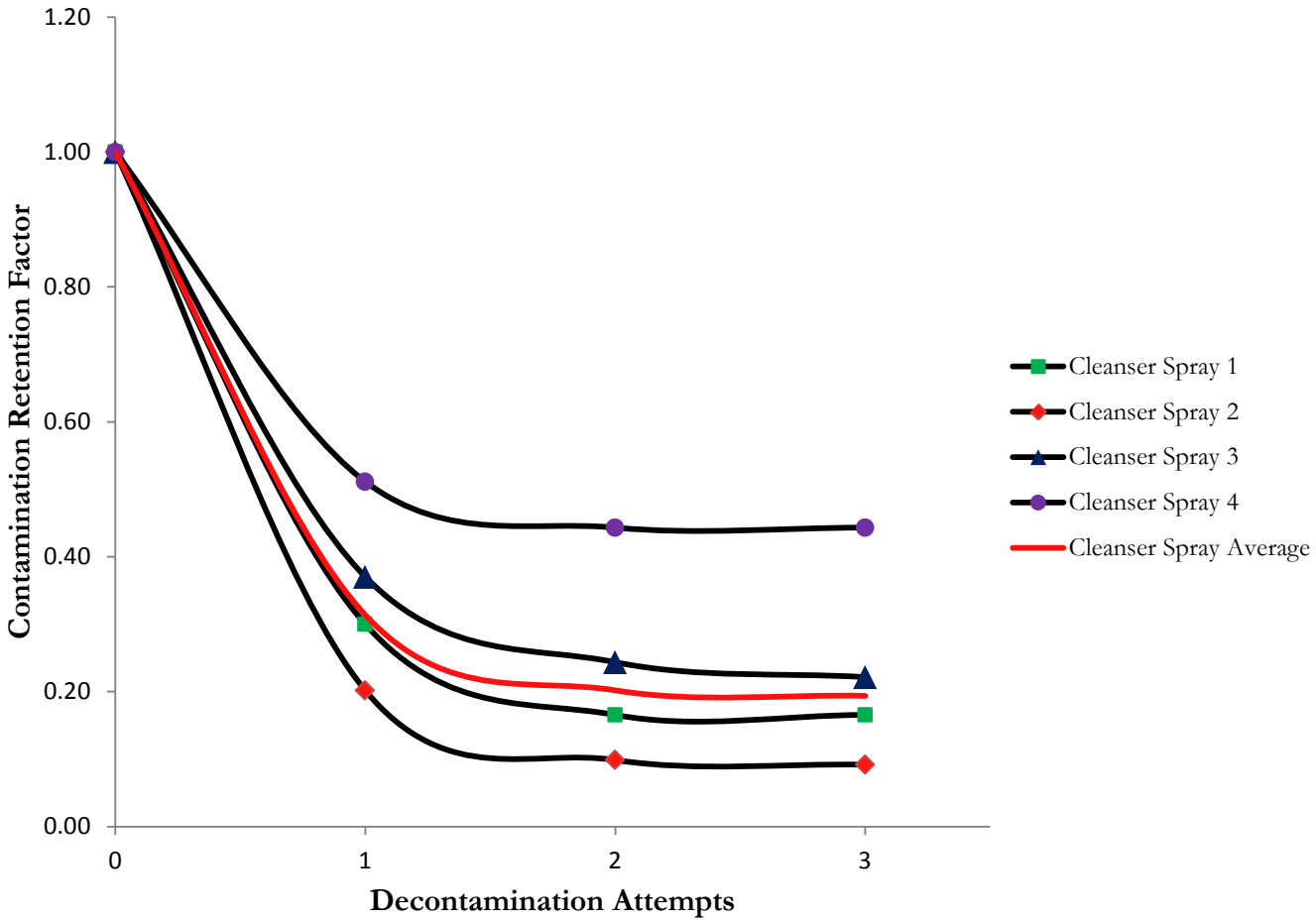

Figure A3: Blunt Force Trauma Wound Decontaminated With Cleanser Spray

Table A2: Saline Spray Decontamination Data

Saline Spray		Raw Data (CPM)				Corrected Count Rate (CPM)				Contamination Retention Factor			
Decontamination Attempt		0	1	2	3	0	1	2	3	0	1	2	3
Incision	1	970	510	390	300	920	460	340	250	1.00	0.50	0.37	0.27
	2	850	450	340	330	800	400	290	280	1.00	0.50	0.36	0.35
	3	840	420	320	270	790	370	270	220	1.00	0.47	0.34	0.28
	4	1060	540	410	340	1010	490	360	290	1.00	0.49	0.36	0.29
Jagged	5	2600	1220	810	790	2550	1170	760	740	1.00	0.46	0.30	0.29
	6	1840	870	805	780	1790	820	755	730	1.00	0.46	0.42	0.41
	7	1420	745	600	485	1370	695	550	435	1.00	0.51	0.40	0.32
	8	860	405	260	250	810	355	210	200	1.00	0.44	0.26	0.25
Blunt Force Trauma	9	1920	1170	920	880	1870	1120	870	830	1.00	0.60	0.47	0.44
	10	1720	735	560	450	1670	685	510	400	1.00	0.41	0.31	0.24
	11	1650	835	555	490	1600	785	505	440	1.00	0.49	0.32	0.28
	12	1970	750	560	450	1920	700	510	400	1.00	0.36	0.27	0.21
Average		1475	721	544	485	1425	671	494	435	1.00	0.47	0.35	0.30
Standard Deviation		543	263	204	208	543	263	204	208	0.00	0.06	0.06	0.07

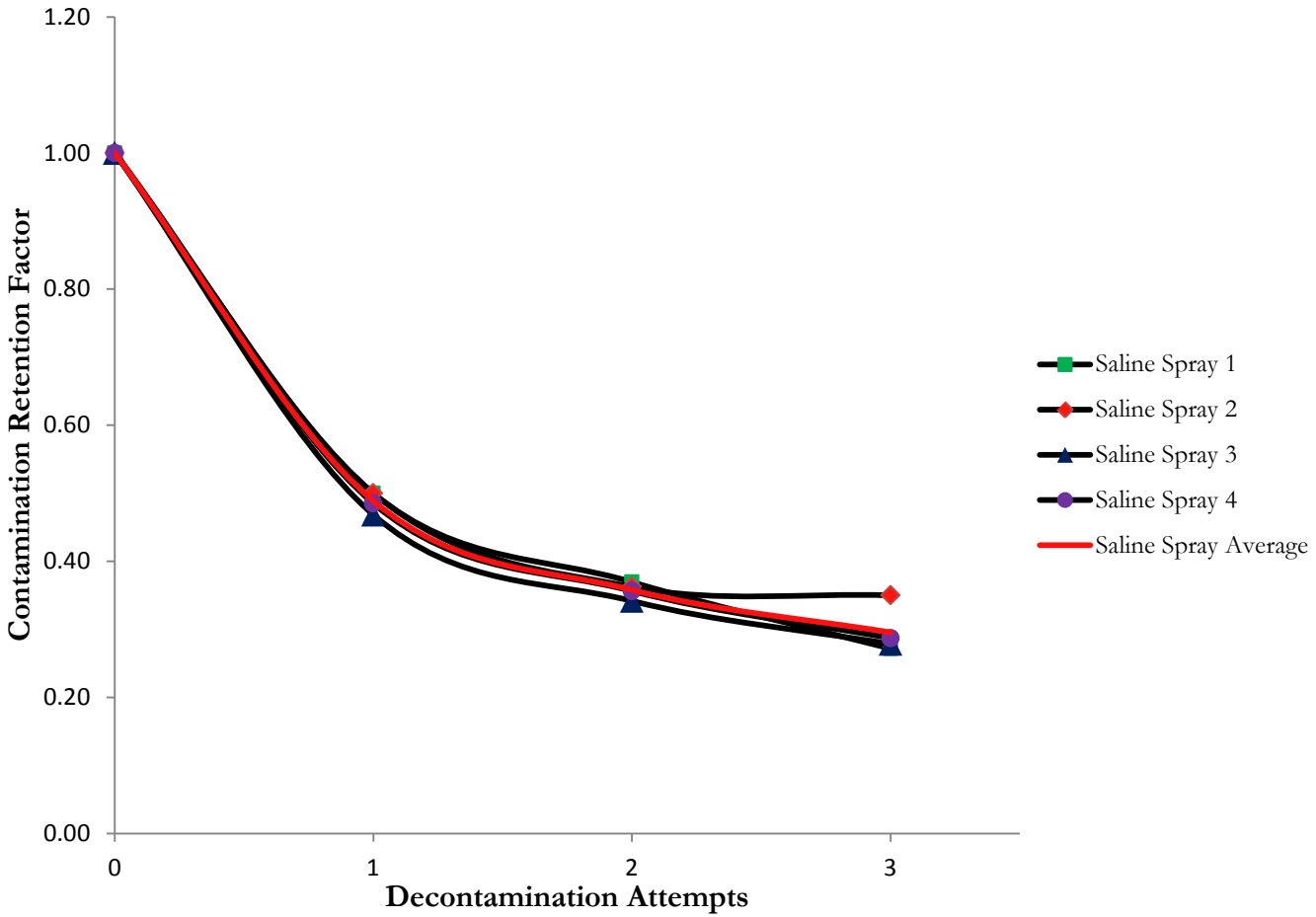

Figure A4: Incision Wound Decontaminated With Saline Spray

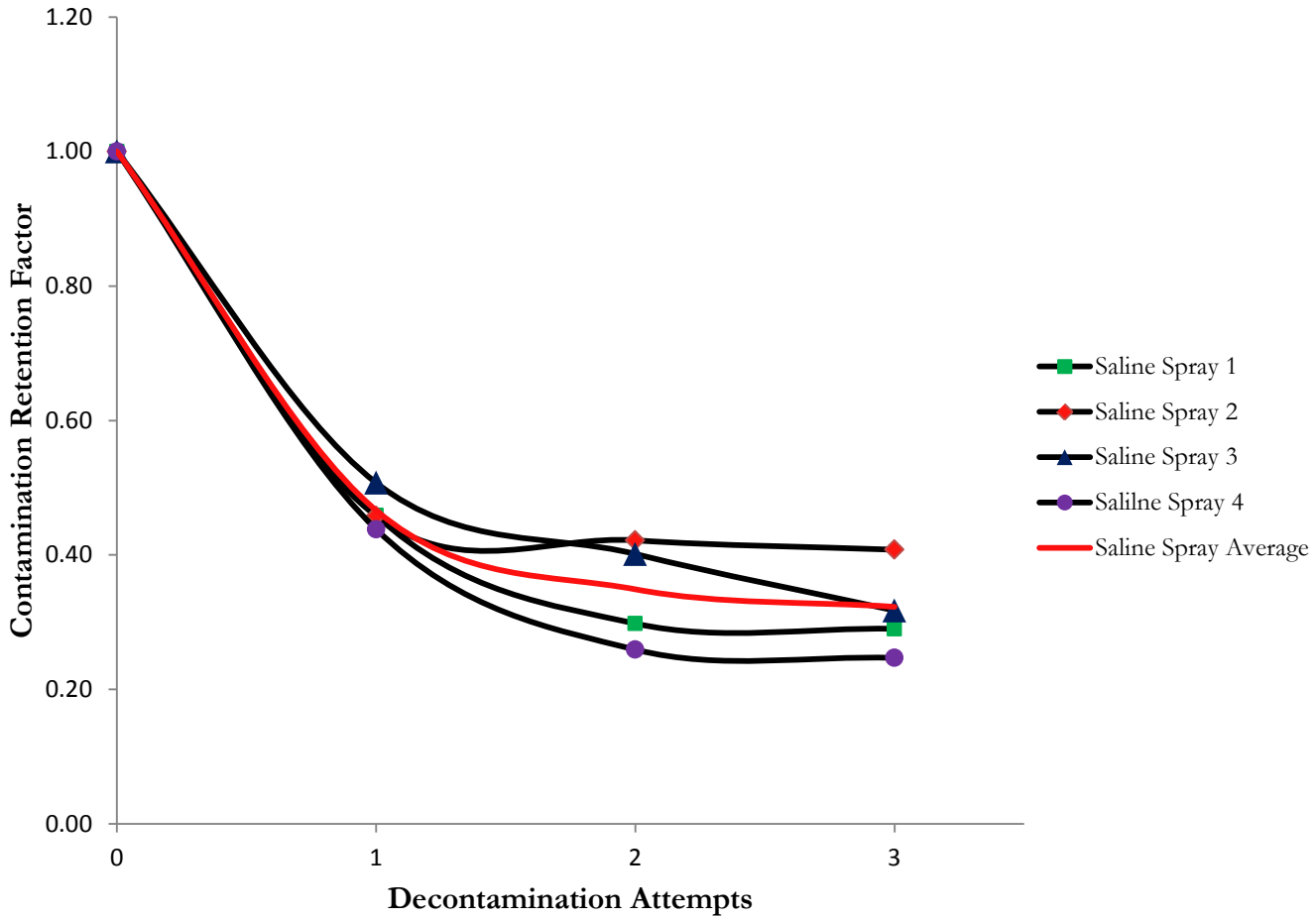

Figure A5: Jagged Wound Decontaminated With Saline Spray

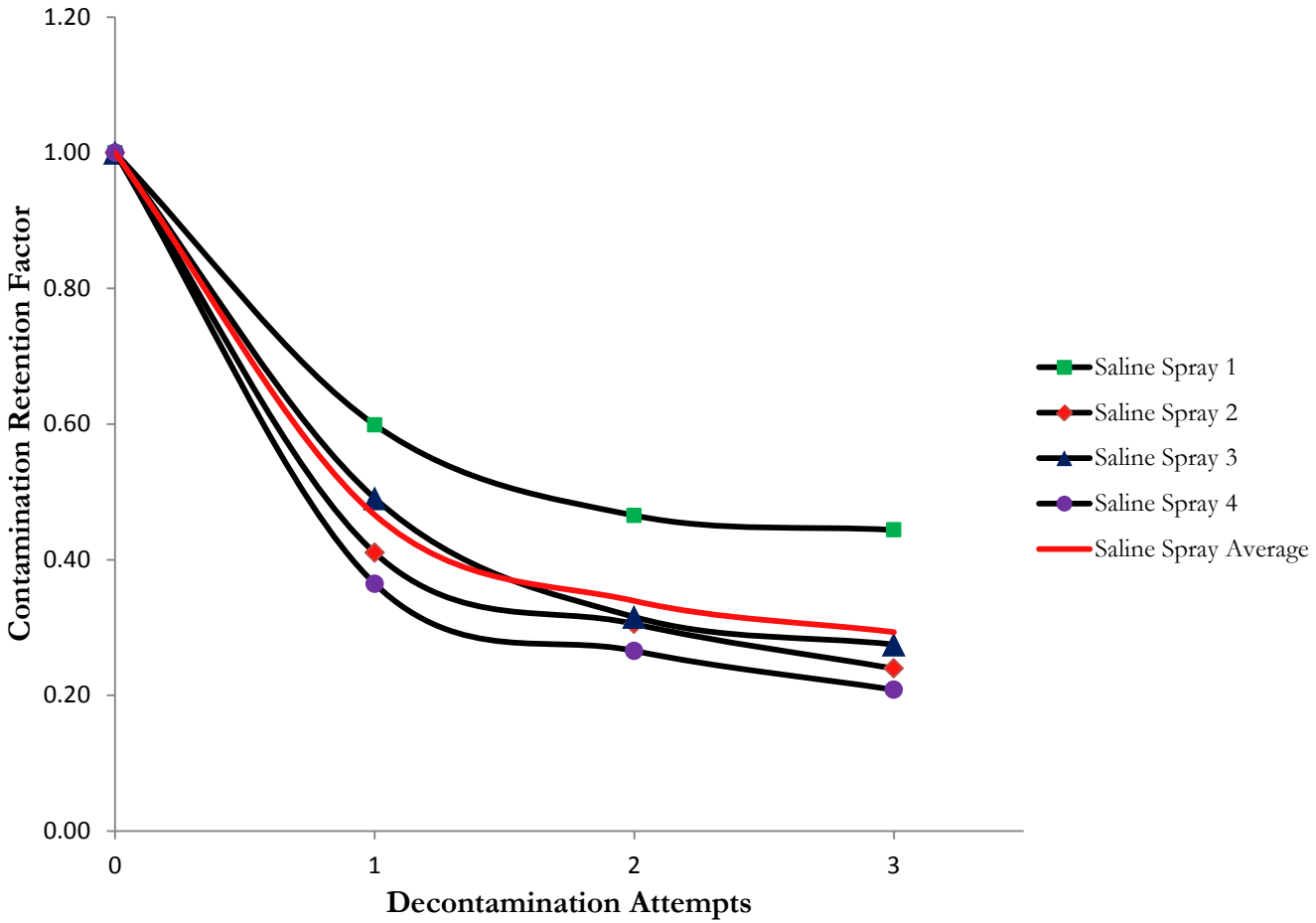

Figure A6: Blunt Force Trauma Wound Decontaminated With Saline Spray

Table A3: Saline Pour Decontamination Data

Saline Pour		Raw Data (CPM)				Corrected Count Rate (CPM)				Contamination Retention Factor			
Decontamination Attempt		0	1	2	3	0	1	2	3	0	1	2	3
Incision	1	990	600	580	580	940	550	530	530	1.00	0.59	0.56	0.56
	2	750	660	650	650	700	610	600	600	1.00	0.87	0.86	0.86
	3	880	600	600	600	830	550	550	550	1.00	0.66	0.66	0.66
	4	660	600	600	600	610	550	550	550	1.00	0.90	0.90	0.90
Jagged	5	1250	1010	1000	1000	1200	960	950	950	1.00	0.80	0.79	0.79
	6	1260	1000	880	880	1210	950	830	830	1.00	0.79	0.69	0.69
	7	1530	740	690	620	1480	690	640	570	1.00	0.47	0.43	0.39
	8	1780	1300	1280	1280	1730	1250	1230	1230	1.00	0.72	0.71	0.71
Blunt Force Trauma	9	1250	790	585	575	1200	740	535	525	1.00	0.62	0.45	0.44
	10	1800	1260	970	920	1750	1210	920	870	1.00	0.69	0.53	0.50
	11	1300	1250	1230	1230	1250	1200	1180	1180	1.00	0.96	0.94	0.94
	12	1223	892	824	812	1173	842	774	762	1.00	0.73	0.68	0.68
Average		364	269	251	254	364	269	251	254	0.00	0.14	0.17	0.18
Standard Deviation		990	600	580	580	940	550	530	530	1.00	0.59	0.56	0.56

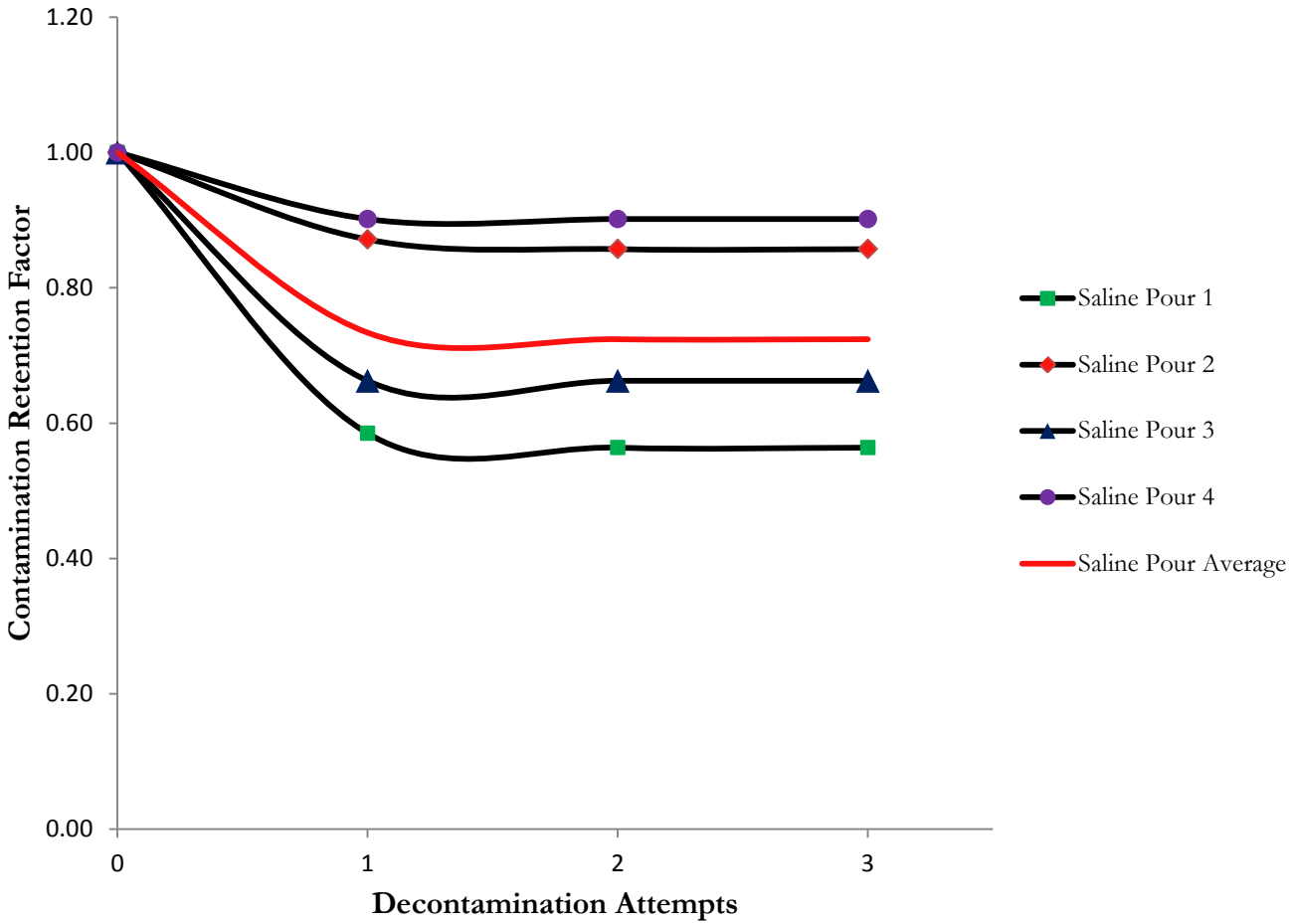

Figure A7: Incision Wound Decontaminated With Saline Pour

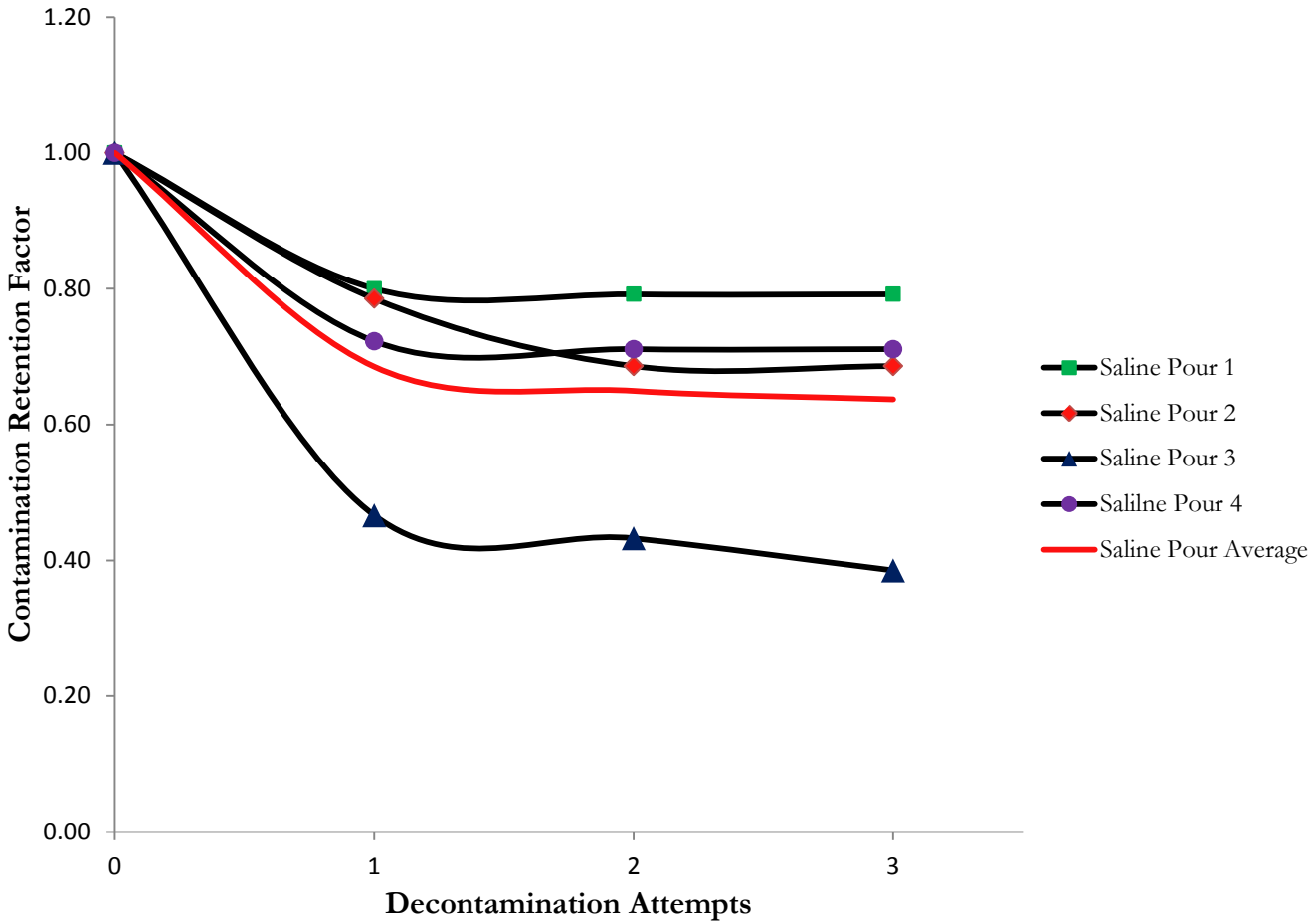

Figure A8: Jagged Wound Decontaminated With Saline Pour

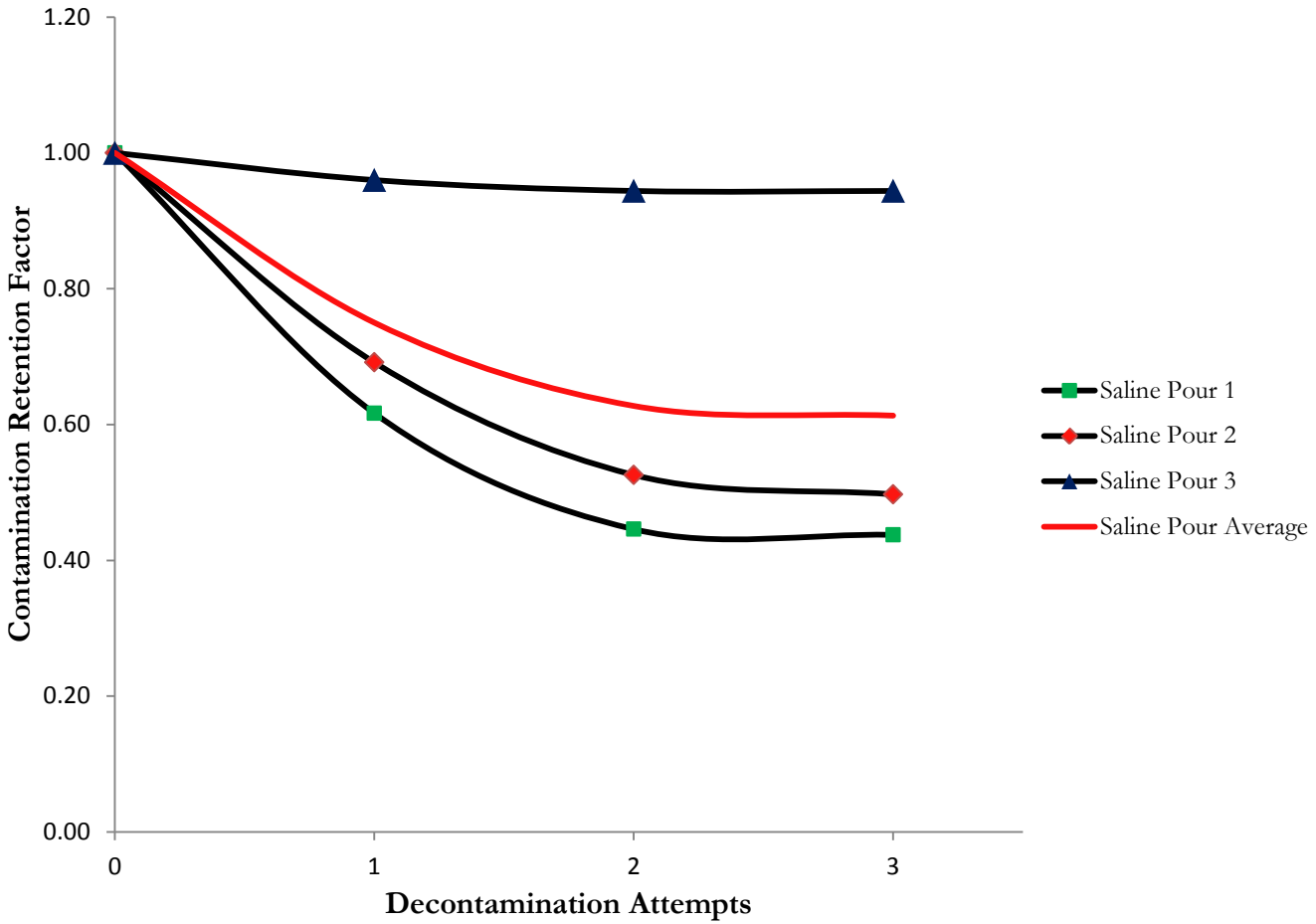

Figure A9: Blunt Force Trauma Wound Decontaminated With Saline Pour

APPENDIX B: EQUIPMENT

1. Glovebox

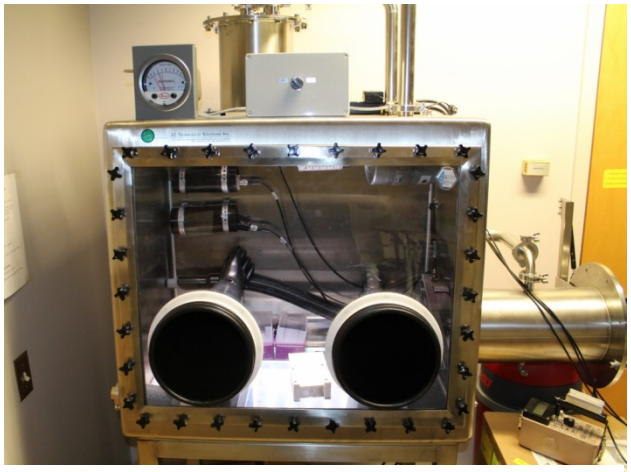

Figure B1: Glovebox

2. Scale

Fisher Scientific

Model: XL-400D

Capacity: 400/40 g

Resolution: 0.01/0.001 g

Calibration Date: 12/30/2011

Calibration Due Date: 12/2012

Serial Number: 3866

Calibrate by: Sercom Corp

Figure B2: Fisher Scientific Scale

3. RADIAC

Detector

LUDLUM Measurements, Inc

Geiger-Müeller Pancake Detector

Model: 44-9

Serial Number: PR309907

Figure B3: LUDLUM G-M Pancake Detector

Meter

LUDLUM Measurements, Inc

Survey Meter

Model: 2241-3

Serial Number: 287405

Calibration Date: 9/14/2012

Calibration Due Date: 3/14/2013

Figure B4: LUDLUM Survey Meter