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Morgan A. Turano

University of Rhode Island, morganturano@hotmail.com

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TRANSFER OF RESIDUES IN FINGERPRINTS

BY

MORGAN A. TURANO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

CHEMISTRY

UNIVERSITY OF RHODE ISLAND

2013

MASTER OF SCIENCE THESIS

OF

MORGAN A. TURANO

APPROVED:

Thesis Committee:

Major Professor James L. Smith

Jimmie C. Oxley

Sze C. Yang

Jan A. Northby

Nasser H. Zawia

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

2013

ABSTRACT

In today's society, it has become necessary to not only identify a terrorist participating in an attack, but determine what explosive was used and what the locations of the terrorist were prior to the attack. Such knowledge helps law officials determine if there are other credible threats, and link terrorists to each other and thereby identify potential terrorist cells.

Much of forensic science depends on Locard's Exchange Principle, which states that when two objects contact each other there is a transfer of material between them. It is therefore expected that when terrorists handle explosives, explosive materials will be transferred first to their hands, and then to other surfaces their hands touch. If the amount of explosive in these prints can be quantified, it may be possible to determine where a terrorist has been, and the order of events leading up to an attack.

This study therefore aimed to quantify the amount of energetic salt residue found in consecutive prints of ammonium nitrate and potassium chlorate on three different surfaces (filter paper, polypropylene, and polyurethane). By collecting and extracting consecutive prints from surfaces, it was possible to quantify the amount of trace explosive material in each print using ion chromatography (IC). The trends in material deposited in consecutive prints were then compared to each other to determine the reproducibility of prints between people and on different surfaces.

Results indicate both materials typically leave first prints in the amount of several hundred micrograms. Further, while most trials produced decreasing curves, occasional higher amounts were found in later prints. This indicates that occasionally aggregates of particles form and are deposited during printing.

While reproducibility indicates that the roughness of the surface did not significantly affect the rate at which material was deposited, the sorption properties of the energetic salts and the surfaces may play a role in the amount of material deposited. This was determined because the highest amounts of the hygroscopic ammonium nitrate were found on the liquid absorbent filter paper surfaces, while the highest amounts of the ionic powder potassium chlorate were found on the electrostatically chargeable polypropylene surfaces.

ACKNOWLEDGEMENTS

The author would like to acknowledge the people without whom this work would not be possible: major professors Drs Smith and Oxley; Ryan Rettinger for assistance using Sage; Sravanthi Vadlamannati for training on the IC; and Maria Donnelly for assistance in sample preparation. I would also like to thank committee members Dr Sze Yang and Dr Jan Northby, and committee chair Dr Surendra Malik for their time in reviewing this thesis.

Special thanks to my parents, and very special thanks to Jeff and Margot for their support.

DEDICATION

For Jeff

Sonnet – To Science

Science! true daughter of Old Time thou art!

Who alterest all things with thy peering eyes.

Why preyest thou thus upon the poet's heart,

Vulture, whose wings are dull realities?

How should he love thee? or how deem thee wise,

Who wouldst not leave him in his wandering

To seek for treasure in the jeweled skies,

Albeit he soared with undaunted wing?

Hast thou not dragged Diana from her car,

And driven the Hamadryad from the wood

To seek a shelter in some happier star?

Hast thou not torn the Naiad from her flood,

The Elfin from the green grass, and from me

The summer dream beneath the tamarind tree?

Edgar Allan Poe, 1829

PREFACE

This thesis was prepared in manuscript format and consists of one manuscript and six appendices. The manuscript was prepared for submission to the *Journal of Forensic Sciences*, a publication of the American Association of Forensic Scientists, of which I am a member.

The aim of the research in the manuscript “Transfer of Residues in Fingerprints” was to quantify the amount of residue in successive fingerprints after touching an energetic salt.

The appendices provide representative standard curves, chromatographs, and images, as well as tabulated data and analytical method details.

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Transfer of Residues in Fingerprints

Prepared for Publication in the Journal of Forensic Sciences

Morgan Turano, Jimmie Oxley

Chemistry Department, University of Rhode Island, Kingston, R.I., U.S.A.

Corresponding Author: Morgan Turano
Chemistry Department
University of Rhode Island
51 Lower College Road
Kingston, R.I., 02881, U.S.A.
Phone: 401-874-2318
Email address: mturano@chm.uri.edu

Abstract

The purpose of this study was to observe, quantify, and compare the amount of explosive precursors ammonium nitrate (AN) and potassium chlorate (KClO_3) in consecutive fingerprints on three surfaces: filter paper, polypropylene, and polyurethane. For the safety of the participants, only the explosive precursors ammonium nitrate (AN) and potassium chlorate (KClO_3) were used to contaminate fingers. Results indicate that while the amount of residue deposited with successive fingerprints tended to show a decrease, there was significant variability among trials. Some trials suggest that particles may occasionally be deposited in aggregates resulting in some amounts well above the expected trend. Typically, the initial print contained several hundred micrograms of AN or chlorate. The tenth print was significantly reduced but still contained tens to hundreds of nanograms. Of the three surfaces on which prints were made, the highest amounts of AN were recovered from filter paper, while higher amounts of KClO_3 were recovered from polypropylene.

Introduction

An important postulate of forensic science is Locard's Exchange Principle, which states when two objects come into contact there is transfer of material between them. Based on this postulate, individuals who handle explosives are expected to transfer some of the explosives to their hands during the process. Transfer of trace levels of the residue from their hands to handled objects is likely due to natural oils on the hands and the adhesive properties of the explosive particulates. Therefore, trace residue of explosives may be found on common items touched by contaminated hands, such as clothing, lap top computers, and luggage.¹⁻⁴ The amount of residue deposited in successive fingerprints is expected to decrease. However, several studies have shown a great amount of variability from one C4 fingerprint to the next.²⁻⁴ The amount of residue will depend on the amount initially present on the finger, the number and type of prior finger contacts,⁴ and the force applied by the contaminated finger.² The purpose of this study was to quantify the amount of energetic residue deposited by successive fingerprints on three different surfaces. To ensure the safety of all participants, only the energetic salts ammonium nitrate (AN) and potassium chlorate (KClO₃) were used.

Materials and Methods

Ammonium nitrate was ground in a coffee grinder resulting in particle sizes ranging from 125µm to 1845µm with an average particle size of 577µm. Unground potassium chlorate (Fisher) particles ranged in size from 82µm to 2382µm with an average of 1359µm. Particle size was measured using a Nikon Eclipse E400 Pol

microscope with Mettler Toledo FP90 central processor. Images of particles are in Appendix A.

To observe the affect that different surfaces have on residue transfer, three surfaces were used: filter paper (fp), polypropylene (pp), and fake vinyl polyurethane (pu). A photograph of these surfaces can be found in Appendix A. The filter papers (Whatman qualitative circles, 100mm) were cut in quarters, cleaned via acetone Soxhlet extraction for 24 hours, and oven dried flat at 90°C for 24 hours. The polyurethane (100% polyurethane on 50/50 polyester/cotton backing, 1.3mm thick) and polypropylene (0.2mm thick) were cut into 2 by 2 centimeter squares, washed with distilled water, and air dried.

Participants were categorized by the amount of information and experience they had prior to participating in the fingerprint trials. Participants 1 through 10 received verbal instructions only, while participants 11 through 20 received verbal and written instructions (shown in Appendix B). For trials 21 through 28 two laboratory researchers who were intimately knowledgeable of the testing protocols and goals created prints on one surface, filter paper. Odd number participants or trials used AN; even numbered trials used KClO_3 . Each participant created consecutive fingerprints on each surface; the surfaces were collected and extracted; extracts were analyzed by ion chromatography.

Oils on the fingertips, amounts of initial contamination, pressure applied by the fingertips, and numbers of prior prints affect the amount of trace residue transferred to surfaces; the instructions given attempted to limit these variables. Fingers were cleaned with soap and water and thoroughly dried with paper towels before each trial. False positives caused by hand oils, creams, or soaps were accounted for by having every

participant create a blank pre-exposure to the energetic salt. After creation of a blank, the finger was exposed to an energetic salt and printed on ten consecutive pieces of one type of surface. This procedure was repeated for each type of surface.

Energetic salts available to participants were provided as a “reservoir” of approximately 8 mg per trial; the salt was re-weighed after printing to estimate how much adhered to the finger by subtracting the two values. All prints were created by placing the same finger on a surface and placing a 200g steel cylinder on the back of the finger to create a consistent pressure during initial exposure and printing. Initial studies using different explosive powders, indicate that after the tenth fingerprint the prints no longer contained sufficient residue to be distinguished from blanks; therefore, only ten prints (and one blank) were collected per trial.

Each surface was extracted with 10 mL of Millipore water (18.2M Ω /cm), shaken for one hour at 240 rpm, and syringe filtered (5mL Luer-Lok tipped syringe with Millipore Millex – FG phobic PTFE 0.20 μ m) into individually labeled 0.5mL Dionex PolyVial IC vials. Samples determined to be too highly concentrated to be calibrated against the standard curve were diluted 1:25 in water.

All samples (25 μ L) were run on a Dionex ICS-2100 RFIC with an IonPac AS19 column. The eluent, potassium hydroxide (20mM), was run at a flow rate of 1mL/min; detection was performed with conductivity suppression (ASRS 300-4mm). Samples were run along with standards (ranging from 50ng/mL to 10000ng/mL) and periodically with Millipore water blanks and 500ng/mL standards.

Results

Results for AN trials are shown in Table 1 and for KClO_3 are shown in Table 2. Initial amounts of AN and KClO_3 adhering to the participants' fingers are based on the amount of salt missing from the residue reservoir. Generally, participants' fingertips picked up 2 to 3 mg of the energetic salt regardless of the salt used. Participants 1 through 20 made prints on three surfaces, while the two laboratory researchers (trials 21 to 28) printed only on filter paper. Tables 1 and 2 present all data in terms of nanograms of salt deposited per fingerprint. These values have been averaged by print number, but in all cases the standard deviation was of the same magnitude as the average itself. Tables 3 and 4 express the amount of residue as percent residue relative to the first print. In general, the amount of residue in the prints decreased with print number. However, there were several instances where later prints showed high amounts of salt suggesting particulate aggregates were occasionally deposited.

Table 1. Ammonium Nitrate in Nanograms Deposited on Various Surfaces

Subj.	mg initial	Ammonium Nitrate nanograms on Filter Paper (ng)											A
		1	2	3	4	5	6	7	8	9	10	15	
1	3.1	1.72E+05	1.26E+05	1.29E+05	7.11E+04	7.95E+04	7.79E+04	9.00E+04	8.17E+04	8.49E+04	2.83E+04	7.64E+03	+
3	1.4	7.20E+05	2.76E+05	1.87E+05	2.69E+05	1.39E+05	1.71E+05	1.93E+05	4.78E+05	1.58E+05	2.46E+05	8.68E+03	+
5	3.4	1.46E+05	2.85E+05	5.57E+05	2.54E+05	8.00E+04	6.56E+04	5.69E+04	1.85E+04	2.21E+04	2.05E+04	3.78E+03	+
7	2.9	9.13E+04	3.85E+05	1.13E+05	1.24E+05	7.50E+04	5.49E+04	5.48E+04	5.13E+04	3.38E+04	6.15E+04	2.67E+03	+
9	6.3	1.30E+05	2.97E+04	4.33E+04	9.33E+03	1.92E+04	1.63E+04	4.58E+03	1.34E+04	7.98E+03	1.12E+04	5.89E+03	+
11	3.3	7.01E+04	4.40E+04	3.23E+04	1.46E+05	2.25E+04	3.01E+04	1.75E+04	3.17E+04	1.67E+04	1.06E+05	5.46E+03	+
13	1.2	2.00E+06	9.80E+04	3.28E+05	6.01E+04	9.93E+04	4.41E+04	4.02E+05	2.79E+05	3.12E+05	4.55E+05	7.81E+03	+
15	1.3	4.97E+05	2.88E+05	3.65E+05	8.95E+04	1.01E+05	1.34E+05	1.17E+05	1.57E+05	1.06E+05	1.48E+05	3.79E+03	+
17	3.8	2.70E+05	2.61E+05	1.59E+05	1.86E+05	4.15E+04	1.24E+05	1.51E+05	1.11E+05	1.28E+05	1.55E+05	5.75E+03	+
19	6.6	1.70E+05	1.55E+05	1.27E+05	6.64E+04	7.82E+04	9.46E+04	1.73E+05	4.60E+04	6.18E+04	6.43E+04	3.95E+03	+
21	1.5	1.51E+06	1.19E+05	4.51E+04	1.00E+05	6.80E+04	2.87E+04	3.15E+04	5.39E+04	2.04E+04	2.60E+04	1.17E+04	+
23	3.3	1.86E+05	6.96E+04	1.04E+05	2.63E+05	2.34E+05	1.07E+05	3.87E+04	5.92E+04	7.70E+04	1.01E+05	2.66E+03	+
25	3.5	1.23E+05	6.51E+04	5.00E+04	8.38E+04	5.86E+04	5.54E+04	6.69E+04	3.03E+04	6.10E+04	3.29E+04	8.20E+03	+
27	4	1.54E+06	4.98E+05	2.56E+05	2.87E+05	9.93E+04	3.83E+04	4.17E+04	1.29E+06	1.38E+05	5.36E+04	4.06E+03	+
ave	3.3	5.45E+05	1.93E+05	1.78E+05	1.43E+05	8.53E+04	7.43E+04	1.03E+05	1.93E+05	8.77E+04	1.08E+05	5.86E+03	
std	1.7	6.51E+05	1.41E+05	1.51E+05	9.17E+04	5.34E+04	4.57E+04	1.04E+05	3.41E+05	8.05E+04	1.20E+05	2.65E+03	
%		100	35	33	26	16	14	19	35	16	20	1	
Subj.	mg initial	Ammonium Nitrate nanograms on Polypropylene (ng)											A
		1	2	3	4	5	6	7	8	9	10	Blank	
1	2.1	6.07E+05	3.31E+04	2.00E+04	2.48E+04	6.97E+03	9.67E+03	8.95E+03	8.51E+03	3.56E+04	7.16E+03	3.59E+03	+
3	2.8	4.52E+04	2.29E+05	1.29E+05	2.21E+04	1.61E+04	8.62E+05	1.21E+04	4.32E+04	2.28E+04	2.11E+04	4.26E+03	-
5	2.5	4.98E+04	2.35E+04	1.91E+04	1.33E+04	2.98E+04	2.97E+04	2.84E+04	3.86E+04	4.92E+03	5.35E+04	4.63E+03	+
7	2.7	1.81E+05	4.19E+04	6.69E+04	1.75E+04	7.99E+04	1.97E+04	2.38E+04	3.19E+04	2.60E+04	9.01E+04	2.68E+03	+
9	4.9	7.19E+04	5.42E+04	2.26E+04	1.57E+04	1.20E+04	1.18E+04	3.22E+04	9.86E+03	7.16E+03	9.27E+03	2.08E+03	+
11	3	1.03E+05	2.35E+04	2.70E+04	2.23E+04	3.33E+04	2.01E+04	3.03E+04	2.57E+04	2.74E+04	1.91E+04	3.05E+03	+
13	4.1	1.35E+05	1.14E+05	2.73E+05	5.42E+04	2.09E+04	3.83E+04		2.29E+04	2.03E+04	4.02E+04	3.10E+03	+
15	2	8.88E+04	1.88E+05	9.74E+04	2.56E+05	1.47E+05	1.80E+05	1.64E+05	3.54E+05	2.03E+05		3.05E+03	-
17	4.3	8.69E+04	8.44E+04	3.69E+04	4.07E+04	1.70E+05	6.98E+04	1.48E+05	9.55E+04	7.41E+04	8.03E+04	3.30E+03	+
19	5.1	2.58E+04	5.07E+04	8.76E+04	4.12E+04	3.55E+04	6.09E+04	3.54E+04	5.04E+04	3.35E+04	2.99E+04	3.17E+03	-
ave	3.4	1.39E+05	8.42E+04	7.79E+04	5.08E+04	5.50E+04	1.30E+05	5.36E+04	6.81E+04	4.55E+04	3.90E+04	3.29E+03	
std	1.1	1.70E+05	7.18E+04	7.84E+04	7.33E+04	5.81E+04	2.62E+05	5.87E+04	1.04E+05	5.85E+04	3.00E+04	7.34E+02	
%		100	60	56	36	39	93	38	49	33	28	2	
Subj.	mg initial	Ammonium Nitrate nanograms on Polyurethane (ng)											A
		1	2	3	4	5	6	7	8	9	10	Blank	
1	3.8	7.65E+04	2.99E+04	6.52E+04	1.94E+04	1.13E+04	1.14E+04	1.15E+04	9.21E+03	1.25E+04	1.19E+04	3.07E+03	+
3	1.1	1.78E+05	1.70E+05	2.34E+05	1.58E+05	1.67E+05	1.91E+05	6.60E+04	9.64E+04	3.15E+04	8.66E+04	3.15E+03	+
5	3.2	8.57E+04	9.27E+04	1.37E+05	9.92E+04	1.01E+05	9.75E+04	1.49E+05	1.03E+05	1.03E+05	8.66E+04	4.48E+03	-
7	3.3	2.54E+05	1.15E+05	7.91E+04	3.71E+04	8.85E+04	1.81E+05	4.80E+04	8.47E+04	1.78E+05	5.06E+04	1.87E+03	+
9	3.9	4.99E+05	3.74E+05	2.75E+05	4.12E+04	2.85E+04	6.30E+05	2.69E+04	6.45E+04	3.50E+04	7.18E+04	2.56E+03	+
11	2	8.62E+04	7.87E+04	6.57E+04	6.25E+04	6.59E+04	1.35E+05	6.50E+04	6.51E+04	6.99E+04	2.17E+05	4.43E+03	-
13	1.4	2.04E+05	9.16E+04	4.45E+04	5.45E+04	3.44E+04	3.08E+04	7.03E+04	3.31E+04	3.08E+04	4.77E+04	5.78E+03	+
15	2	8.93E+04	3.20E+04	5.91E+04	4.42E+04	3.32E+04	5.90E+04	3.01E+04	5.18E+04	4.05E+04	4.39E+04	3.69E+03	+
17	1.8	1.22E+05	8.24E+04	7.94E+04	7.45E+04	1.05E+05	1.60E+05	5.57E+04	6.54E+04	6.82E+04	1.21E+05	4.58E+03	+
19	2.6	1.55E+05	1.63E+05	2.56E+05	1.16E+05	1.20E+05	1.63E+05	9.84E+04	2.21E+05	1.06E+05	4.60E+05	5.03E+03	-
ave	2.5	1.75E+05	1.23E+05	1.30E+05	7.06E+04	7.54E+04	1.66E+05	6.20E+04	7.94E+04	6.74E+04	1.20E+05	3.86E+03	
std	1.0	1.28E+05	9.98E+04	9.04E+04	4.24E+04	4.93E+04	1.75E+05	3.94E+04	5.71E+04	4.97E+04	1.32E+05	1.21E+03	
%		100	70	74	40	43	95	35	45	39	68	2.2	

Table 2. Potassium Chlorate in Nanograms Deposited on Various Surfaces

		mg	Potassium Chlorate nanograms on Filter Paper (ng)											
Subj.		initial	1	2	3	4	5	6	7	8	9	10	Blank	A
2	2.3		8.54E+04	8.30E+04	8.87E+04	3.15E+04	1.34E+04	3.80E+04	1.50E+04	2.71E+03	6.81E+04	2.12E+04	1.03E+03	+
4	4		3.27E+05			8.71E+04				4.35E+03	4.72E+03	6.02E+03	1.26E+03	+
6	3.2		8.10E+04	7.09E+04	3.47E+04	1.17E+04	1.23E+03	1.32E+04	5.00E+03	5.00E+03	3.07E+04	3.62E+03	1.25E+03	+
8	4.7		8.10E+02	4.99E+03	4.12E+03	2.60E+03	8.96E+03	2.68E+03	1.08E+03	1.05E+03	1.66E+03	7.42E+03	8.10E+02	-
10	2.5		1.30E+05	6.94E+04	1.06E+05	1.17E+05	1.80E+05	1.48E+05	1.09E+05	1.04E+05	8.62E+04	3.50E+05	1.65E+03	-
12	4		6.75E+05	5.93E+05	8.50E+04	1.01E+06	2.27E+05	5.12E+05	5.00E+04	2.69E+05	3.92E+05	8.05E+03	8.90E+02	+
14	0.5		1.88E+06	4.31E+05	2.23E+05	2.57E+05	6.95E+04	8.58E+04	2.48E+05	4.59E+04	2.37E+03	2.99E+04	5.72E+06	+
16	1.7		3.11E+03	1.88E+06	4.93E+06	5.90E+05	3.95E+05	2.63E+04	7.91E+03	4.49E+03	2.01E+04	1.85E+04	1.21E+03	+
18	1.6		1.34E+03	1.34E+03	1.34E+03	1.34E+03	1.35E+03	1.34E+03	1.36E+03	1.37E+03	1.35E+03	1.34E+03	1.35E+03	-
20	4.4		2.36E+05	5.61E+04	4.55E+04	5.10E+04	1.98E+05	3.45E+04	8.32E+04	3.98E+05	9.21E+04	2.09E+04	1.15E+03	+
22	2.4		1.08E+05	2.91E+05	7.69E+04	2.33E+04	1.42E+05	1.83E+04	7.73E+03	5.67E+03	4.27E+04	1.34E+03	0	+
24	3.3		3.29E+05	3.31E+05	1.32E+05	1.23E+05	1.04E+04	3.23E+04	3.36E+03	3.75E+03	1.36E+04	0	0.00E+00	+
26	4.1		1.63E+06	9.95E+04	3.11E+04	2.95E+04	1.72E+04	7.78E+03	1.90E+04	3.41E+03	9.50E+03	8.13E+03	1.65E+03	+
28	2.6		3.18E+05	1.35E+03	4.27E+04	4.67E+03	5.50E+03	1.25E+03	8.17E+03	2.02E+03	2.00E+02	0	0	+
ave	3.0		3.27E+05	3.16E+05	5.07E+05	1.74E+05	1.09E+05	7.59E+04	2.81E+04	6.70E+04	6.34E+04	3.71E+04	9.08E+02	
std	1.2		4.73E+05	5.48E+05	1.47E+06	3.09E+05	1.30E+05	1.50E+05	3.65E+04	1.31E+05	1.08E+05	9.88E+04	6.02E+02	
%			100	97	155	53	33	23	9	21	19	11	0	

		mg	Potassium Chlorate nanograms on Polypropylene (ng)											
Subj.		initial	1	2	3	4	5	6	7	8	9	10	Blank	A
2	2.1		2.34E+04	4.79E+03	3.64E+03	4.12E+03	1.92E+03	4.10E+04	3.63E+04	2.03E+03	2.58E+04	1.34E+03	1.09E+03	+
4	1.8		1.37E+05	1.88E+04	8.39E+04	2.55E+03	1.26E+04	2.35E+04	2.08E+03	1.53E+03	4.92E+04	1.70E+03	1.24E+03	+
6	1.4		1.78E+05		4.55E+03	1.24E+03	2.98E+04		7.91E+03	2.19E+03	2.31E+03	1.05E+04	1.24E+03	+
8	2.1		6.78E+02	3.77E+03	4.66E+03	2.41E+03	3.17E+04	2.60E+03	9.33E+04	5.90E+02	8.38E+02	1.08E+03	5.88E+02	-
10	1.2		9.69E+04	6.49E+04	4.39E+04	3.04E+03	2.61E+03	2.65E+03	3.53E+04	6.18E+03	2.63E+04	6.20E+02	5.88E+02	+
12	2.2		2.50E+06	3.74E+05	3.85E+04	6.66E+04	2.88E+05	3.70E+04	3.70E+04	3.41E+04	1.72E+04	2.88E+05	8.90E+02	+
14	2.3		1.40E+06	4.35E+05	2.42E+05	1.50E+03	1.92E+04	3.82E+04	1.34E+03	5.93E+03	1.39E+06	1.27E+03	7.03E+04	+
16	1.4		3.09E+06	4.06E+04	5.83E+05	3.30E+03	3.52E+05	4.48E+03	1.71E+04	3.34E+04	2.60E+05	1.55E+03	1.24E+03	+
18	3.6		4.72E+06		1.59E+03	2.69E+05	1.56E+03	3.21E+04	2.54E+05	1.98E+03	1.77E+04	9.05E+04	4.63E+03	+
20	6.9		1.23E+04	1.85E+04	8.31E+04	7.94E+03	6.32E+03	1.03E+04	1.12E+04	5.23E+04	7.90E+04	2.56E+04	1.16E+03	-
ave	2.5		1.22E+06	1.20E+05	1.09E+05	3.61E+04	7.45E+04	2.13E+04	4.95E+04	1.40E+04	1.87E+05	4.22E+04	8.29E+03	
std	1.7		1.68E+06	1.77E+05	1.82E+05	8.41E+04	1.31E+05	1.64E+04	7.67E+04	1.87E+04	4.30E+05	9.07E+04	2.18E+04	
%			100	10	9	3	6	2	4	1	15	3	1	

		mg	Potassium Chlorate nanograms on Polyurethane (ng)											
Subj.		initial	1	2	3	4	5	6	7	8	9	10	Blank	A
2	2.8		1.62E+05	1.02E+05	2.10E+04	3.80E+04	1.58E+04	5.91E+04	1.10E+05	9.71E+03	7.34E+04		4.25E+03	+
4	5.9		1.62E+05	6.93E+04	5.19E+03	6.59E+03	9.11E+03	4.79E+03	5.12E+04	6.21E+03	5.05E+03	7.05E+03	1.24E+03	+
6	3		4.93E+04		5.03E+03	1.41E+03	1.53E+03	4.77E+03		2.88E+03	1.82E+03	4.13E+03	1.24E+03	+
8	2.5		8.55E+03	7.38E+04	4.26E+04	3.80E+03	5.34E+03	6.90E+02	1.28E+03	2.87E+03	7.77E+03	1.99E+04	5.85E+02	+
10	7.3		6.09E+04	4.24E+04	2.55E+04	1.29E+03		2.61E+04	3.74E+04	3.15E+03	9.44E+02	9.42E+02	3.58E+03	+
12	3.9		5.05E+04	4.94E+03	9.41E+05	3.37E+03	5.43E+05	1.77E+05	9.26E+05	4.83E+04	8.11E+04	1.01E+04	8.70E+02	-
14	2.7		3.35E+04	1.59E+03	3.79E+03	2.27E+03	1.01E+04	2.41E+03	3.29E+03	7.03E+05	2.39E+04	2.59E+03	1.41E+04	+
16	2.5		1.01E+06	1.98E+05	2.31E+03	3.32E+04	5.65E+04	1.56E+04	2.09E+05	3.62E+04	2.01E+04	2.12E+03	1.48E+03	+
18	2.1		2.36E+03	2.18E+03	2.21E+03	1.75E+03	1.60E+03	1.21E+06	8.00E+03	2.51E+04	7.20E+04	6.27E+03	1.46E+03	-
20	0.4		8.90E+04	6.97E+04	3.04E+05	2.30E+04	2.71E+04	2.55E+04	6.82E+05	2.59E+05	2.32E+04	1.88E+03	1.14E+03	-
ave	3.31		1.62E+05	6.26E+04	1.35E+05	1.15E+04	7.44E+04	1.53E+05	2.25E+05	1.10E+05	3.09E+04	6.11E+03	2.99E+03	
std	1.97059		3.42E+05	6.24E+04	2.98E+05	1.43E+04	1.76E+05	3.76E+05	3.40E+05	2.23E+05	3.20E+04	5.97E+03	4.07E+03	
%			100	39	83	7	46	94	139	68	19	4	2	

Discussion

All sets of prints generally decreased in a manner which could be fitted to a power law although there were occasional high amounts in later prints. There was a good deal of individual variability. Figure 1 shows exemplary data sets from 14 participants printing on filter paper. Results of each participants' ten-print, 3-surface trial can be found in Appendix C. To observe a general trend of residue deposit regardless of the type of residue or surface, data was normalized by relative percent; the first print in a trial was set to 100%, and all other prints in that trial were a percentage thereof (Tables 3 and 4). There were several difficulties with that approach. 1) In a few trials the first chlorate prints were lost. 2) In one case the blank contained more chlorate than any of the prints (6 mg), clearly an error. 3) In another case (18), all prints and the blank showed the same amount of chlorate (1.3 μg). 4) In many trials three of the ten fingerprints contained more residue than the initial one (Tables 3, 4). 5) There were many instances where one or two of the subsequent prints showed a sharp increase in the amount of residue, suggesting a chunk of residue was deposited. It is difficult to track the source of these errors. The participant may not have contaminated his hand or contaminated it before performing the "blank." Hand washing may have been skipped between data sets or excess pressure applied during printing. It was thought that humidity had an impact on the amount of residue transferred, particularly in the case of AN, which is highly hygroscopicity and deliquescent (62% RHD).⁵⁻¹⁰ In fact, AN tends to visibly aggregate and liquefy on hands.

Fig. 1. Plots of all AN prints on Filter Paper (left) and all KClO₃ on Filter Paper (right)

The data was handled as follows. 1) For the few trials (4-fp, 2-pu, 4-pu) in which the first print showed no chlorate, the first print average was inserted (in red) to permit processing of the rest of the data. 2) The fact that the blank showed more chlorate than any prints in trial 14-fp suggests participant error; thus, the entire data set was deleted. 3) In the case of 18-fp where all prints and the blank showed 1.3 μg of chlorate, the entire data set was dropped. Dealing with intermittent increases in energetic salt in late fingerprints was a more difficult problem. Several of approaches to analyzing the data in a legitimate, unbiased manner were employed. First, a mathematical program, Sage,¹¹ was used to test the goodness of each data set. The program fitted the data to the formula

$$y=A*e^{-x}+B,$$

where B is the intercept the percentage of residue as print number approaches infinity, while A tracks percentage of residue relative to the maximum amount. (The program can be found in Appendix D; the output table in Appendix E, and the plots in nanograms in Appendix F.) Since A governs the amount for each point, the curve direction is dictated by A, a positive A indicated an exponential decrease, while a negative A indicated an asymptotic curve increase. When a data set was identified as having a negative A, the entire data set was dropped. Exemplary Sage plots showing curves with both positive and

negative A values are shown in Figure 2. Using the “Sage A” discriminator, six AN data sets (3-pp, 15-pp, 19-pp, 5-up, 11-up, 19-up) and nine chlorate data sets (8-fp, 10-fp, 18-fp, 8-pp, 20-pp, 12-up, 14-up, 18-up, 20-up) were dropped.

Fig. 2. Exemplary Plots from Sage¹¹ showing a positive A (left) and negative A (right)

Tables 3 and 4 express the quantity of salt, AN and chlorate, respectively, found in each print as a percentage of that in the first print. When the percentage was greater than 110%, that datum was dropped. In Tables 3 and 4 data deleted due to the “Sage A” criterion are struck through, and those deleted due to the values exceeding 110% of the first print are marked in highlight. The total number of data ignored to obtain the average percentage of salt in each print is indicated on each Table. It is troublesome that in many cases 40% to 60% of the data were discarded. The final averages from all four Tables is shown and plotted in Figures 3 and 4. Figure 3 was constructed from the full data sets, with no data ignored. Figure 4, where residue is expressed as the percentage of the first

print, necessarily dropped outlining points. There are significant differences between the averages derived directly from the full data sets (Table 1 and Table 2) and those derived from the culled data.

Table 3. AN Residue in Prints Expressed as Relative Percentage of First Print

Ammonium Nitrate Relative % on Filter Paper (10 pts not in average)												
Subj.	1	2	3	4	5	6	7	8	9	10	Blank	
Filter Paper	1	100	73	75	41	46	45	52	48	49	16	4
	3	100	38	26	37	19	24	27	66	22	34	1
	5	100	195	381	173	55	45	39	13	15	14	3
	7	100	422	124	135	82	60	60	56	37	67	3
	9	100	23	33	7	15	13	4	10	6	9	5
	11	100	63	46	208	32	43	25	45	24	152	8
	13	100	5	16	3	5	2	20	14	16	23	0
	15	100	58	73	18	20	27	24	32	21	30	1
	17	100	97	59	69	15	46	56	41	48	57	2
	19	100	91	75	39	46	56	102	27	36	38	2
	21	100	8	3	7	5	2	2	4	1	2	1
	23	100	37	56	141	126	57	21	32	41	54	1
	25	100	53	41	68	48	45	54	25	50	27	7
	27	100	32	17	19	6	2	3	84	9	3	0
	ave	100	48	43	31	30	33	35	35	27	29	3
	std	0	30	25	24	24	21	28	23	17	21	2
Ammonium Nitrate Relative % on Polypropylene (38 pts not in average)												
Subj.	1	2	3	4	5	6	7	8	9	10	Blank	
Polypropylene	1	100	5	3	4	1	2	1	1	6	1	1
	3	100	507	285	49	36	1909	27	96	51	47	9
	5	100	47	38	27	60	60	57	78	10	108	9
	7	100	23	37	10	44	11	13	18	14	50	1
	9	100	75	31	22	17	16	45	14	10	13	3
	11	100	23	26	22	32	19	29	25	27	19	3
	13	100	84	202	40	15	28	0	17	15	30	2
	15	100	212	110	288	165	203	185	399	228	0	3
	17	100	97	42	47	195	80	170	110	85	92	4
	19	100	196	339	159	137	236	137	195	130	116	12
	ave	100	51	30	24	28	31	24	25	24	34	3
	std	0	35	14	15	21	29	23	27	28	33	3
Ammonium Nitrate Relative % on Polyurethane (37 pts not in average)												
Subj.	1	2	3	4	5	6	7	8	9	10	Blank	
Polyurethane	1	100	39	85	25	15	15	15	12	16	16	4
	3	100	96	132	89	94	107	37	54	18	49	2
	5	100	108	160	116	118	114	173	120	120	101	5
	7	100	45	31	15	35	71	19	33	70	20	1
	9	100	75	55	8	6	126	5	13	7	14	1
	11	100	91	76	73	76	156	75	76	81	252	5
	13	100	45	22	27	17	15	34	16	15	23	3
	15	100	36	66	49	37	66	34	58	45	49	4
	17	100	67	65	61	86	130	46	53	56	99	4
	19	100	105	165	75	77	105	63	143	68	297	3
	ave	100	58	54	39	41	42	27	34	32	39	3
	std	0	22	24	29	35	31	14	21	24	30	2

Highlighted or crossed out values indicate the point was dropped from the average and standard deviation due to values greater than 110% or a negative A value, respectively.

Table 4. KClO₃ Residue in Prints Expressed as Relative Percentage of First Print

Potassium Chlorate Relative % on Filter Paper (51 pts not in average)												
Subj.	1	2	3	4	5	6	7	8	9	10	Blank	
Filter Paper	2	100	97	104	37	16	45	18	3	80	25	1
	4	100			27				1	1	2	0
	6	100	88	43	14	2	16	6	6	38	4	2
	8	100	616	508	321	1107	331	133	130	205	916	100
	10	100	53	81	90	138	114	84	80	66	269	1
	12	100	88	13	150	34	76	7	40	58	1	0
	14	100	23	12	14	4	5	13	2	0	2	305
	16	100	60420	158631	18961	12711	846	254	144	645	595	39
	18	100	100	100	100	101	100	101	102	101	100	101
	20	100	24	19	22	84	15	35	169	39	9	0
	22	100	270	71	22	132	17	7	5	40	1	0
	24	100	101	40	38	3	10	1	1	4	0	0
	26	100	6	2	2	1	0	1	0	1	1	0
	28	100	0	13	1	2	0	3	1	0	0	0
ave	100	57	43	28	20	22	18	15	33	5	1	
std	0	42	35	27	31	26	27	27	30	8	1	
Potassium Chlorate Relative % on Polypropylene (25 pts not in average)												
Subj.	1	2	3	4	5	6	7	8	9	10	Blank	
Polypropylene	2	100	20	16	18	8	175	155	9	110	6	5
	4	100	14	61	2	9	17	2	1	36	1	1
	6	100		3	1	17		4	1	1	6	1
	8	100	557	687	356	4680	384		87	124	159	87
	10	100	67	45	3	3	3	36	6	27	1	1
	12	100	15	2	3	12	1	1	1	1	12	0
	14	100	31	17	0	1	3	0	0	100	0	5
	16	100	1	19	0	11	0	1	1	8	0	0
	18	100		0	6	0	1	5	0	0	2	0
	20	100	151	676	65	51	84	91	426	643	209	9
ave	100	25	20	4	8	4	7	3	25	3	2	
std	0	23	22	6	6	6	13	3	36	4	2	
Potassium Chlorate Relative % on Polyurethane (47 pts not in average)												
Subj.	1	2	3	4	5	6	7	8	9	10	Blank	
Polyurethane	2	100	63	13	23	10	36	68	6	45		3
	4	100	43	3	4	6	3	32	4	3	4	1
	6	100		10	3	3	10		6	4	8	3
	8	100	863	499	44	62	8	15	34	91	233	7
	10	100	70	42	2		43	62	5	2	2	6
	12	100	10	1862	7	1074	350	1834	96	161	20	2
	14	100	5	11	7	30	7	10	2097	71	8	42
	16	100	20	0	3	6	2	21	4	2	0	0
	18	100	92	94	74	68	51425	339	1062	3052	266	62
	20	100	78	341	26	30	29	766	291	26	2	1
ave	100	49	14	13	17	17	39	10	24	4	3	
std	0	365	199	17	25	18	24	12	37	4	3	

Highlighted or crossed out values indicate the point was dropped from the average and standard deviation due to values greater than 110% or a negative A value, respectively.

Fig. 3. Average Nanograms of Residue found on 3 Surfaces AN (left), KClO₃ (right)

Fig. 4. Residue as Percent of 1st Print found on 3 Surfaces AN (left), KClO₃ (right)

Table 5 summarizes the average amount of AN or chlorate found in print one and in print ten. The difference in the amount of AN versus chlorate found in the prints was not significant on polyurethane. However, AN appeared to have adhered to the filter paper slightly better than did chlorate. This may be due to the highly hygroscopic nature of AN. The high values of chlorate on polypropylene are more difficult to explain. Polypropylene is at the negative end of the triboelectric series, increasing its ability to become electrostatically charged, while paper and polyurethane are more neutral.¹² This may explain the increased transference of the ionic powder KClO₃ to polypropylene.

Nevertheless, data suggests that with either AN or chlorate in the first ten prints several tens of micrograms may be found.

Table 5. Nanograms Residue in the Print

surface/print #	AN		KClO ₃	
	1	10	1	10
Filter Paper	5.5E+05	1.1E+05	3.3E+05	3.7E+04
Polypropylene	1.4E+05	3.9E+04	1.2E+06	4.2E+04
Polyurethane	1.7E+05	1.2E+05	1.6E+05	6.1E+03

Conclusion

While most sets of prints showed a decrease in the amount of residue transferred over successive prints, this decrease was rarely smooth. Although the data could be plotted as a power law or exponential decrease, there were intermittent increases in the amount of energetic salt deposited. These are believed to be due to particulate aggregates which periodically dropped from the finger during printing. The variability of the data was the same regardless of the experience or knowledge of the participants – only instructed verbally (1 to 10), instructed in writing and verbally (11 to 20), or intimately familiar with the experiment (21 to 28). This suggests that variations in the data were not simply a matter of participant error, but rather likely due to the salt aggregates which at times were deposited on the surfaces.

The variability in results make it impossible to detect a difference in transfer between the AN and chlorate. Nevertheless, it is noticeable that more anomalous data was found in the chlorate sets than in the AN sets even though the amounts of residue found in each study were similar. Differences among the three surfaces were noted. The

hygroscopic nature of AN was thought to promote its adherence to filter paper, while chlorate was more attracted to polypropylene.

While it is not possible to determine from the amount of residue in a print the order in which the print was deposited, it is possible to detect whether an object was touched by someone who recently handled ammonium nitrate or potassium chlorate. Hundreds of micrograms could be expected to be in the first few prints.

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Additional Information and Reprint Requests:

URI Chemistry Department, 51 Lower College Rd., Kingston, R.I., 02881

APPENDIX A: IMAGES

Image 1: KClO_3 particle (magnified) measurements.

Image 2: AN particle (magnified) measurements.

Image 3: Surfaces used in trials – filter paper, polypropylene, and polyurethane (left to right).

Image 4: Representative ion chromatograph.

APPENDIX B: WRITTEN INSTRUCTIONS PROVIDED

TO PARTICIPANTS 11 THROUGH 20

Each time your finger touches a substrate or A.N. the weight **must** be added.

1. Place weight on finger between tip and first joint.
2. Release so that pressure is on finger but weight does not roll off of finger. Do not push.

To Make Fingerprints:

- I. Wash your hands with soap and water. Dry.
- II. Place clean, dry right index finger on first piece of paper substrate (Blank 1).
- III. Place same finger on second piece of paper substrate (Blank 2).
- IV. Place same finger on AN tray provided. Remember to add the weight.
- V. Place same finger on next piece of paper substrate.
- VI. Continue placing the finger on the pieces of paper until there are no paper substrates left.
- VII. Repeat steps 1 through 6 with the new tray of AN and plastic substrate.
- VIII. Repeat steps 1 through 6 with the new tray of AN and vinyl substrate.
- IX. Please wash your hands before leaving the lab.

APPENDIX C: FIGURES

Figure 1: Participant 1 – AN on all three surfaces.

Figure 2: Participant 2 – KClO₃ on all three surfaces.

Figure 3: Participant 3 – AN on all three surfaces.

Figure 4: Participant 4 – KClO₃ on all three surfaces.

Figure 5: Participant 5 – AN on all three surfaces.

Figure 6: Participant 6 – KClO₃ on all three surfaces.

Figure 7: Participant 7 – AN on all three surfaces.

Figure 8: Participant 8 – KClO₃ on all three surfaces.

Figure 9: Participant 9 – AN on all three surfaces.

Figure 10: Participant 10 – KClO₃ on all three surfaces.

Figure 11: Participant 11 – AN on all three surfaces.

Figure 12: Participant 12 – KClO₃ on all three surfaces.

Figure 13: Participant 13 – AN on all three surfaces.

Figure 14: Participant 14 – KClO₃ on all three surfaces.

Figure 15: Participant 15 – AN on all three surfaces.

Figure 16: Participant 16 – KClO₃ on all three surfaces.

Figure 17: Participant 17 – AN on all three surfaces.

Figure 18: Participant 18 – KClO₃ on all three surfaces.

Figure 19: Participant 19 – AN on all three surfaces.

Figure 20: Participant 20 – KClO₃ on all three surfaces.

Figure 21: AN on filter paper, all “verbal-only” instruction participants.

Figure 22: KClO₃ on filter paper, all “verbal-only” instruction participants.

Figure 23: AN on polypropylene, all “verbal-only” instruction participants.

Figure 24: KClO₃ on polypropylene, all “verbal-only” instruction participants.

Figure 25: AN on polyurethane, all “verbal-only” instruction participants.

Figure 26: KClO₃ on polyurethane, all “verbal-only” instruction participants.

Figure 27: AN on filter paper, all “verbal & written” instruction participants.

Figure 28: KClO₃ on filter paper, all “verbal & written” instruction participants.

Figure 29: AN on polypropylene, all “verbal & written” instruction participants.

Figure 30: KClO₃ on polypropylene, all “verbal & written” instruction participants.

Figure 31: AN on polyurethane, all “verbal & written” instruction participants.

Figure 32: KClO₃ on polyurethane, all “verbal & written” instruction participants.

Figure 33: AN on filter paper, all “laboratory researcher” participants.

Figure 34: KClO₃ on filter paper, all “laboratory researcher” participants.

Figure 35: Representative standard curve.

APPENDIX D: SAGE PROGRAM

```
def Process(fname):

    a=open(fname)

    c=0

    for x in a:

        c=c+1

    print c,' Rows in File'

    print

    a.close()

    import numpy as n

    #g,m,s,pn,ng,

    d=n.genfromtxt('/media/sf_SageFiles/TSA Bare.csv',

skip_header=1,dtype=None, delimiter=',', unpack=True)

    rows= range(len(d))

    Gmax= max([d[x][0] for x in rows])

    Mats= []

    Surfs=[]

    for x in rows:

        if d[x][1] in Mats:

            pass

        else:

            Mats.append(d[x][1])
```

```

    if d[x][2] in Surfs:

        pass

    else:

        Surfs.append(d[x][2])

D={}

for G in range(1,Gmax+1):

    for M in Mats:

        for S in Surfs:

            if S == 'P': S='PP'

            if S == 'V': S='PU'

            label = str(G)+'-'+str(M)+'-'+str(S)

            D[label]={ 'ng':[], 'rel-1': [], 'rel-mx': [], 'Print#':[],

'Group':G, 'Mat': M, 'Surf': S}

            count=0

        for x in rows:

            for G in range(1,Gmax+1):

                for M in Mats:

                    for S in sorted(Surfs):

                        if d[x][0] == G and d[x][1] == M and d[x][2] == S:

                            if S == 'P': S='PP'

                            if S == 'V': S='PU'

                            label = str(G)+'-'+str(M)+'-'+str(S)

                            D[label]['ng'].append(d[x][4])

```

```

        if d[x][3]== 'B':

            D[label]['Print#'].append(100.)

        else:

            D[label]['Print#'].append(float(d[x][3]))

for x in D:

    if D[x]['ng'] <> []:

        first=None

        for p in range(len(D[x]['Print#'])):

            if D[x]['Print#'][p] == 1:

                #they were strings; I told you!

                first=p

            if first <> None:

                D[x]['rel-1']= [float(n)/D[x]['ng'][first]*100 for n in
D[x]['ng']]

                for n in D[x]['ng']:

                    D[x]['rel-mx']= [float(n)/max(D[x]['ng'])*100 for n in
D[x]['ng']]

        return D

D=Process('/media/sf_SageFiles/TSA Bare.csv')

print D.keys()

def Plot(D,path):

    ss=open(path+'/Curve-fits.csv', 'w')

    ss.truncate(0)

```

```

ss.write('Group,Material,Surface,abs-FitA,abs-FitB,rel-1-FitA,rel-1-FitB,rel-mx-FitA,rel-
mxFitB\r\n')

import os

if os.path.exists(path+'/Plots/') == False: os.mkdir(path+'/Plots/')

if os.path.exists(path+'/Plots/Abs') == False:
os.mkdir(path+'/Plots/Abs')

if os.path.exists(path+'/Plots/Rel-1') == False:
os.mkdir(path+'/Plots/Rel-1')

if os.path.exists(path+'/Plots/Rel-mx') == False:
os.mkdir(path+'/Plots/Rel-mx')

for label in sorted(D.keys()):

    if D[label]['ng'] <> []:

        var('x,A,B,t,s')

        model(x)= A*exp(-x)+B

        F=find_fit(zip(D[label]['Print#'], D[label]['ng']),
model,variables=[x], parameters=[A,B], solution_dict=True)

        D[label]['fitA']=F[A]

        D[label]['fitB']=F[B]

        fa='N/A'

        fb='N/A'

        if 1 in D[label]['Print#']:

            fa=

D[label]['fitA']/D[label]['ng'][D[label]['Print#'].index(1)]

```

```

fb=
D[label]['fitB']/D[label]['ng'][D[label]['Print#'].index(1)]

print label, ',', D[label]['fitA']

ss.write(str(D[label]['Group'])+', '+str(D[label]['Mat'])+', '+str(D[label]['Surf'])+', '+str(F[A]
)+', '+str(F[B])+', '+str(fa)+', '+str(fb)+', '+str(D[label]['fitA']/max(D[label]['ng']))+
', ' + str(D[label]['fitB']/max(D[label]['ng'])))+'\r\n')

import matplotlib.pyplot as abs

abs.clf()

abs.plot(D[label]['Print#'],D[label]['ng'],'b.')

abs.ylabel('Extracted Residue (ng)')

abs.xlabel('Print #')

abs.xlim(0,13); abs.ylim(min(D[label]['ng'])*.8,
max(D[label]['ng'])*1.1)

star=max(D[label]['ng'])

abs.title('Group-%s; Mat-%s; Surf-%s
'%(D[label]['Group'],D[label]['Mat'],D[label]['Surf']))

abs.annotate('Y=%.2e*exp(-x)+ %.2e'%(F[A],F[B]), (3.5,star))

prez=srange(1,10,.25)

bi=D[label]['Print#'].index(100)

bv=D[label]['ng'][bi]

abs.plot([1,11],[bv,bv],'r--')

abs.annotate('Blank Value', (10.1, bv*1.1))

abs.plot(prez,[F[A]*exp(-t)+F[B] for t in prez], 'black')

```



```

abs.ticklabel_format(style='sci', scilimits=(0,0), axis='y')

abs.savefig(path+'Plots/Abs/%s.png'%label)

if 1 in D[label]['Print#']:

    import matplotlib.pyplot as r1

    r1.clf()

    fi=D[label]['Print#'].index(1)

    r1.plot(D[label]['Print#'], D[label]['rel-1'],'b.')

    r1.plot(prez,[(F[A]*exp(-t)+F[B])/D[label]['ng'][fi]*100

for t in prez], 'black')

    r1.xlim(0,14); r1.ylim(0,120)

    r1.title('Group-%s; Mat-%s; Surf-%s

'%(D[label]['Group'],D[label]['Mat'],D[label]['Surf']))

    r1.xlabel('Print #')

    r1.ylabel('Extracted Residue Rel to Print #1 (%)')

    for pt in range(len(D[label]['ng'])):

        xcord=D[label]['Print#'][pt]+.1

        ycord=D[label]['rel-1'][pt]-3.5

        r1.annotate('% .1e'%D[label]['ng'][pt],(xcord,ycord),

fontsize=7)

        bvr1=D[label]['rel-1'][bi]

        r1.annotate('Blank Value', (11.1,bvr1*.9))

        r1.plot([1,11],[bvr1,bvr1],r--)

    r1.savefig('%sPlots/Rel-1/%s-Rel-1.png'%(path,label))

```

```

import matplotlib.pyplot as rm

rm.clf()

rm.plot(D[label]['Print#'], D[label]['rel-mx'],'b.')

rm.plot(prez,[(F[A]*exp(-t)+F[B])/max(D[label]['ng'])*100 for t
in prez], 'black')

rm.xlim(0,14)

rm.ylim(0,105)

for pt in range(len(D[label]['ng'])):

    xcord=D[label]['Print#'][pt]+.1

    ycord=D[label]['rel-mx'][pt]-3.5

    rm.annotate('% .1e%D[label]['ng'][pt],
(xcord,ycord),fontsize=7)

rm.plot([0,11],[D[label]['rel-mx'][bi],D[label]['rel-mx'][bi]],'r--')

    rm.annotate('Blank Value', (11.1,D[label]['rel-mx'][bi]-1))

rm.title('Group-%s; Mat-%s; Surf-%s
'%(D[label]['Group'],D[label]['Mat'],D[label]['Surf']))

rm.xlabel('Print #')

rm.ylabel('Extracted Residue Rel to Group Max (%)')

rm.savefig('%sPlots/Rel-mx/%s-Rel-mx.png'%(path,label))

"""

if D[label]['ng'] <> []:

    import matplotlib.pyplot as mp

    mp.clf()

```

```
"""
```

```
ss.close()
```

```
Plot(D, '/media/sf_SageFiles/')
```

APPENDIX E: SAGE PROGRAM DATA TABLES

			Sage Plot Fit Values					
Trial			nanograms		1st Print = 100%		Max Print = 100%	
Subj.	Material	Surface	A (ng)	B (ng)	A (%)	B (%)	A (%)	B (%)
1	AN	FP	3.07E+05	6.98E+04	1.79	0.41	1.79	0.41
1	AN	PP	1.50E+06	-9.86E+03	2.47	-0.02	2.47	-0.02
1	AN	PU	1.76E+05	1.45E+04	2.29	0.19	2.29	0.19
3	AN	FP	1.33E+06	1.88E+05	1.85	0.26	1.85	0.26
3	AN	PP	-1.41E+05	1.35E+05	-3.12	3.00	-0.16	0.16
3	AN	PU	2.51E+05	1.12E+05	1.41	0.63	1.07	0.48
5	AN	FP	3.63E+05	1.18E+05	2.48	0.81	0.65	0.21
5	AN	PP	5.87E+04	2.37E+04	1.18	0.48	1.10	0.44
5	AN	PU	-1.72E+04	9.71E+04	-0.20	1.13	-0.12	0.65
7	AN	FP	3.09E+05	7.88E+04	3.39	0.86	0.80	0.20
7	AN	PP	3.64E+05	3.36E+04	2.01	0.19	2.01	0.19
7	AN	PU	4.42E+05	7.82E+04	1.74	0.31	1.74	0.31
9	AN	FP	3.11E+05	1.00E+04	2.38	0.08	2.38	0.08
9	AN	PP	1.76E+05	1.33E+04	2.45	0.18	2.45	0.18
9	AN	PU	1.13E+06	1.26E+05	2.27	0.25	1.79	0.20
11	AN	FP	6.86E+04	4.39E+04	0.98	0.63	0.47	0.30
11	AN	PP	2.03E+05	1.97E+04	1.97	0.19	1.97	0.19
11	AN	PU	-6.18E+03	8.35E+04	-0.07	0.97	-0.03	0.38
13	AN	FP	4.40E+06	1.39E+05	2.19	0.07	2.19	0.07
13	AN	PP	3.09E+05	5.42E+04	2.29	0.40	1.13	0.20
13	AN	PU	4.52E+05	3.49E+04	2.21	0.17	2.21	0.17
15	AN	FP	1.09E+06	1.25E+05	2.19	0.25	2.19	0.25
15	AN	PP	-2.32E+05	1.82E+05	-2.61	2.05	-0.65	0.51
15	AN	PU	1.24E+05	3.77E+04	1.39	0.42	1.39	0.42
17	AN	FP	4.97E+05	1.18E+05	1.84	0.44	1.84	0.44
17	AN	PP	3.42E+03	8.06E+04	0.04	0.93	0.02	0.48
17	AN	PU	1.04E+05	7.97E+04	0.85	0.65	0.65	0.50
19	AN	FP	2.94E+05	7.90E+04	1.73	0.46	1.70	0.46
19	AN	PP	-1.67E+04	4.22E+04	-0.64	1.63	-0.19	0.48
19	AN	PU	-2.56E+04	1.71E+05	-0.17	1.10	-0.06	0.37
21	AN	FP	3.74E+06	-1.45E+04	2.47	-0.01	2.47	-0.01
22	AN	FP	1.92E+05	1.03E+05	1.03	0.55	0.73	0.39
23	AN	FP	2.00E+05	4.72E+04	1.62	0.38	1.62	0.38
24	AN	FP	3.41E+06	2.06E+05	2.21	0.13	2.21	0.13

			Sage Plot Fit Values					
Trial			nanograms		1st Print = 100%		Max Print = 100%	
Subj.	Material	Surface	A (ng)	B (ng)	A (%)	B (%)	A (%)	B (%)
2	KClO3	FP	1.92E+05	3.06E+04	2.25	0.36	2.16	0.34
2	KClO3	PP	1.58E+04	1.24E+04	0.67	0.53	0.38	0.30
2	KClO3	PU	3.49E+05	3.98E+04	N/A	N/A	3.18	0.36
4	KClO3	FP	4.56E+06	3.51E+03	N/A	N/A	52.39	0.04
4	KClO3	PP	3.14E+05	1.37E+04	2.30	0.10	2.30	0.10
4	KClO3	PU	3.82E+05	8.40E+03	N/A	N/A	5.51	0.12
6	KClO3	FP	2.20E+05	1.18E+04	2.72	0.15	2.72	0.15
6	KClO3	PP	4.67E+05	3.40E+03	2.62	0.02	2.62	0.02
6	KClO3	PU	1.28E+05	1.67E+03	2.60	0.03	2.60	0.03
8	KClO3	FP	-4.93E+03	3.55E+03	-6.09	4.38	-0.55	0.40
8	KClO3	PP	-4.92E+04	1.55E+04	-72.50	22.90	-0.53	0.17
8	KClO3	PU	5.18E+04	1.25E+04	6.06	1.46	0.70	0.17
10	KClO3	FP	-6.17E+04	1.31E+05	-0.47	1.00	-0.18	0.37
10	KClO3	PP	2.53E+05	1.23E+04	2.61	0.13	2.61	0.13
10	KClO3	PU	1.45E+05	1.19E+04	2.38	0.20	2.38	0.20
12	KClO3	FP	1.21E+06	2.84E+05	1.79	0.42	1.20	0.28
12	KClO3	PP	6.20E+06	6.23E+03	2.48	0.00	2.48	0.00
12	KClO3	PU	-6.07E+05	2.85E+05	-12.01	5.65	-0.64	0.30
14	KClO3	FP	2.30E+06	6.95E+05	1.23	0.37	0.40	0.12
14	KClO3	PP	3.14E+06	1.61E+05	2.25	0.12	2.25	0.12
14	KClO3	PU	-2.33E+05	8.51E+04	-6.94	2.54	-0.33	0.12
16	KClO3	FP	7.78E+05	6.75E+05	250.04	217.09	0.16	0.14
16	KClO3	PP	7.50E+06	2.47E+03	2.42	0.00	2.42	0.00
16	KClO3	PU	2.50E+06	1.13E+04	2.49	0.01	2.49	0.01
18	KClO3	FP	-3.29E+01	1.35E+03	-0.02	1.01	-0.02	0.98
18	KClO3	PP	1.27E+07	-2.76E+04	2.69	-0.01	2.69	-0.01
18	KClO3	PU	-5.28E+05	1.49E+05	-223.64	63.32	-0.43	0.12
20	KClO3	FP	2.78E+05	9.59E+04	1.18	0.41	0.70	0.24
20	KClO3	PP	-3.87E+04	3.00E+04	-3.15	2.44	-0.47	0.36
20	KClO3	PU	-1.67E+05	1.46E+05	-1.87	1.64	-0.24	0.21
25	KClO3	FP	3.69E+05	4.56E+04	3.43	0.42	1.27	0.16
26	KClO3	FP	9.78E+05	3.72E+04	2.97	0.11	2.96	0.11
27	KClO3	FP	5.14E+06	-4.27E+04	2.47	-0.02	2.47	-0.02
28	KClO3	FP	7.88E+05	-6.80E+03	2.48	-0.02	2.48	-0.02

APPENDIX F: SAGE PLOTS IN NANOGRAMS

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