Hair as Forensic Evidence of Explosive Handling

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Abstract:

Hair has the ability to assimilate a variety of chemical compounds. The analysis of hair for determining first-hand exposure to illegal drugs is a popular forensic technique.[1-6] Molecules such as explosives can also become trapped in hair due to external exposure and detected at trace levels.[7-12] Hair analysis could prove a powerful, non-invasive method for the detection of individual exposure to illicit explosives. Previous studies showed that in a sealed vessel with adequate headspace, military explosives such as PETN, TNT, and RDX were sorbed to human hair. These organic explosives persisted on hair even after the hair was washed with detergents or solvent.[7,8] Such sorption was influenced by hair color, and levels of contamination were on the order of micrograms per gram hair after thousands of hours exposure. It was assumed that in the "real-world" explosives would sorb to hair through the condensation of vapors or by the deposition of solid particulates. This study involved the sampling of hair from students and instructors attending field classes for explosives handling at Fort A.P. Hill, Fredericksburg, VA and Redstone Arsenal, AL. Hair was sampled using combs fitted with cheesecloth, and the cheesecloth was extracted and analyzed by GC-ECD for PETN, TNT, and RDX. On average 80% of the participants were contaminated with PETN, found in detonating cord, after daily field exercises. Average participant contamination with TNT and RDX in hair ranged from 30% to 50%.

Introduction:

Hair mirrors its chemical environment. From the early 20th century researchers have tried to quantify chemical exposure in laboratory animals and humans through the analysis of their hair. Research has shown drugs, metals, and other chemicals can accumulate on hair by both internal and external modes. Sampling hair for the detection of drugs is a relatively non-invasive method.[1-6] The Society for Forensic Toxicology (SOFT) has accepted drug analysis of hair as a confirmatory technique, and the Substance Abuse and Mental Health Administration (SAMHA) has reviewed various factors pertinent to use of this technique as legal evidence.[12,13] Researchers at the Royal Armament Research and Development Establishment (RARDE) are credited as the first to suggest hair could be used as evidence of exposure to explosives.[11] They documented the sorption of explosives on cut human hair that had been exposed to EGDN (ethylene glycol dinitrate) and nitrobenzene. Our research group extended their study to include sorption by cut hair of 2,4,6-trinitrotoluene (TNT); hexahydro-1,3,5-trinitro-s-triazine (RDX, the active ingredient in C4); pentaerythritol tetranitrate (PETN, the explosive found in detonating cord and sheet explosives); EGDN; triacetone triperoxide (TATP), diacetone diperoxide (DADP), nitroglycerin (NG), and 2,4-dinitrotoluene (DNT). In addition to demonstrating differences in the extent of sorption over time, our studies have shown hair color affected the extent of explosive sorption. As expected, water solubility affected the persistence of explosives upon washing.[7-10]

The purpose of the present study was to determine how laboratory experiments with hair translate into the field by pre- and post-blast hair sampling of individuals involved in explosive disposal. Participants consisted primarily of bomb technicians attending refresher training offered by the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) at Fort A.P. Hill in

Fredericksburg, VA (2003) and a group of Army Corp Engineers investigating the efficiency of blow-in-place protocols at Redstone Arsenal in Alabama (2005).[14] Although non-military explosives (fireworks and ammonium nitrate formulations) were also used at Fort A.P. Hill, our analyses screened for only the military high explosives; PETN, TNT, and RDX. Three mechanisms of explosives contamination were postulated: (1) condensation of explosive vapor; (2) deposition of airborne explosive particulates; and (3) cross-contamination involving the transport of explosive particulates to hair via hands or clothing (i.e. gloves, hats etc.). Participants in these studies combed their hair using a comb fitted with cheesecloth wet with methanol. The used gauze/comb assembly was wrapped with aluminum foil, placed inside of a plastic bag and returned to the University of Rhode Island (URI) laboratory for subsequent solvent extraction and explosives analysis by GC-ECD. Herein is reported the recovery of PETN, TNT, and RDX from the hair of individuals participating in these tests.

Materials and Methods

Reagents

Ultra-pure (2-mMho) water was prepared by passing distilled water through a series of mixed bed and activated carbon filtration cartridges (Barnstead International - Dubuque, Iowa). "Water" referred to herein implies the use of this ultra-pure water. Organic solvents used were HPLC grade acetonitrile (Fisher Scientific, UV-cutoff 190nm), HPLC grade methanol (Fisher Scientific, UV-cutoff 205nm), and acetone. Ultra high purity (UHP 99.999%) helium, nitrogen, and hydrogen were used as carrier/makeup gases for gas chromatography and pre-purified nitrogen (99.9%) was used for solvent evaporation.

Combs for Sampling

Black "unbreakable" plastic combs were purchased in bulk and cleaned of residual contaminants by two 15 minute washes in a 1:1 acetone/water bath. Reagent grade cheesecloth

[Fisher Scientific cheesecloth wipes (cat.# 06-665-29) 46cm X 92cm – 100% pure reagent cotton] was cut into 13cm x 9cm bilayer pieces and cleaned of impurities by Soxhlet extraction in acetonitrile for a minimum of five full rinses. After drying on aluminum foil, each cheesecloth piece was folded twice widthwise and fed onto the teeth of a clean comb as seen in Figure 1. The combs were then wrapped in aluminum foil in sets of ten, and sealed in Ziploc® bags for transportation to the testing sites.

Sampling Protocol

Fort A.P. Hill, Fredericksburg,VA: Sampling was conducted during two separate ATF explosives training classes which included October 27-30, 2003 (Week 1) and November 3-6, 2003 (Week 2). Explosives used during both instructor demonstrations and student exercises are listed in Table 1. At the beginning of each week participants were asked to complete a consent form with questions pertaining to their experience with explosives and personal physical characteristics. Hair combings were performed each day before field work commenced and immediately following each day's field work. Directly before sampling, participants rinsed their hands with tap-water and dried them thoroughly with a paper towel. The cheesecloth on each comb was moistened with 1 to 3mL of methanol from a polyethylene squeeze bottle. Each participant was asked to comb their hair at least 10 times on each side of a single comb taking care not to touch the cheesecloth directly with their hands. Used combs were individually wrapped in aluminum foil and stored in small Ziploc® bags. Printed labels were affixed to the bags onto which participants were asked to provide their unique assigned identification number, the time of sampling, and any information pertaining to hair treatment on that specific day. The sample bags were separated in batches according to sampling date and time and placed in gallon size Ziploc® bags for storage and transport. Within one week of collection sample bags were stored in a freezer (-24°C) to prevent possible long term degradation prior to analysis.

Redstone Arsenal, AL: Sampling was conducted during explosive exercises over the timeframe April 4-28, 2005. The purpose of the exercises was to determine how much explosive contamination would be found in the environment after the firing of certain explosives.[14] Unlike the AP Hill exercises, explosive handling was generally limited to Arsenal personnel, but most participants were involved in collecting debris after each firing. Explosives used during the Redstone exercises are listed in Table 2. The collection procedure was identical to that used at Fort A.P. Hill except water was used in place of methanol to moisten the cheesecloth fitted on the combs.

Sample Processing

Information written on the sample bag labels was recorded at the University of Rhode Island (URI) laboratory. Cheesecloth pieces were removed from the combs using clean stainless steel forceps. Each piece of cheesecloth was placed in a clear, labeled, screw-capped vial (85mm H x 23mm OD) and ~17mL of acetonitrile was added. Vials were shaken for one hour mechanically (150 linear oscillations/minute for A.P. Hill samples and 325 orbital oscillations/minute for Redstone samples), removed, shaken vigorously by hand for one minute, and placed back on the mechanical shaker for an additional hour. Extracts were decanted through a glass funnel into a clean, clear screw-capped vial (85mm H x 23mm OD). The cheesecloth was transferred from the vial to the funnel, and residual solvent was pressed out of the cheesecloth using a spatula. The cheesecloth was placed back into the original vial and washed with an additional 7mL of acetonitrile by one minute of vigorous hand shaking. The second extract was decanted, pressed from the cheesecloth, and combined with the appropriate primary extract. Vials of filtered extract were capped and stored at -24°C until they could be concentrated using a nitrogen stream.

AP Hill sample extracts were concentrated to dryness with nitrogen via a custom designed manifold system (~1400mL/min per vial) which held up to 22 vials. An additional 1.00mL of water was added to Redstone samples prior to nitrogen concentration in order to prevent trace volatilization of TNT. At dryness, 2.00mL of acetonitrile was added to each vial, and the vials were resealed and gently agitated (~60 oscillations/minute) on an orbital shaker (Clay Adams – Nutator) for 30 minutes. The final extract was transferred to a labeled 2mL amber GC vial (Agilent Technologies) and stored at -24°C until GC-ECD analysis.

Quantitative Analysis

Fort A.P. Hill Samples: A Gas Chromatograph with a micro Electron Capture Detector (Agilent 6890N GC-μECD) was used to detect and quantify PETN, TNT, and RDX in the comb/ cheesecloth extracts. The column was a fused silica DB5-MS (J&W Scientific - 30m X 0.25mm ID X 0.25μm d_f). The injection port temperature was set at 175°C (5:1 split) with an injection volume of 1μL. The carrier gas was helium (8.0 mL/min., constant flow) and the makeup gas was nitrogen (40.0 mL/min.). The oven temperature program was as follows: 50°C for 1 min., 20°C/min. to 170°C with 1 min. hold, 5°C/min. to 185°C, 25°C/min. to 280°C with 5 minute final hold. The detector temperature was 300°C.

Redstone Samples: A GC-ECD (Hewlett Packard 5890 Series II) was used to quantify the PETN, TNT, and RDX. The column was a fused silica DB1 (J&W Scientific - 6m X 0.53mm ID X 1.5μm d_f). The injection port temperature was set at 175°C (splitless) with an injection volume of 1μL. The carrier gas was hydrogen (41.5 mL/min. measured at 27°C) and the makeup gas was nitrogen (63 mL/min.). The oven temperature program was as follows: 100°C for 2 minutes, 10°C/min. to 200°C, 20°C/min. to 250°C w/ 5 min. final hold. The detector temperature was 300°C.

At GC injector temperatures of 200 to 250°C the signal response for RDX and TNT was elevated; while that of PETN was much lower due to degradation in the injector. At lower injector temperatures (165°C) the instrument response for RDX decreased significantly; therefore, the optimized injector temperature was chosen to be 175°C. RDX and TNT peak tailing was reduced by keeping the detector temperature at 300°C and using a ramp rate of 5 or 10°C/min as TNT and RDX eluted.

To conserve sample extract, 250µL flat bottom glass vial inserts (Agilent Technologies) were utilized during GC analysis. A low temperature re-circulating water bath (Endocal - Neslab Instrument Inc., Newington, NH) was used to keep GC vials stored in the auto-sampler trays of both chromatographs at a constant temperature (5-10°C) during long runs.

Calibration Standards

Analytical stock solutions of 1000 ppm were individually prepared from PETN, TNT and RDX reference materials dissolved in acetonitrile. Calibration standards containing all three high explosive analytes were prepared from the stock solutions with concentrations ranging from 10 to 0.01 ppm in acetonitrile.

Quality Assurance

Unused combs returned from the sampling sites were extracted and processed as control samples using the identical extraction procedure as was used on samples. Detection limit studies were accomplished with these control samples. Cleaned cheesecloth was used for performing laboratory spike recovery studies and as preparation blanks included with each sample set. Spiked samples were prepared by adding 0.50 mL of the 1 ppm PETN/TNT/RDX calibration solution via volumetric pipette onto a piece of folded cheesecloth prior to extraction, yielding a concentration of 250 ppb of each explosive in the final sample extract to be analyzed. For every ten extracted samples analyzed, one spiked sample, one preparation blank, and one control

sample were generated. Accuracy of calibration standards was verified using a certified EPA explosives standard mix (Cerilliant EPA 8330 - cat. # ERE-021 containing 200µg/mL of the following components: 4-amino-2-6-dinitrotoluene, 1,3-dinitrobenzene, 2,6-dinitrotoluene, nitrobenzene, 3-nitrotoluene, 1,3,5-trinitrobenzene, 2-amino-4,6-dinitrotoluene, 2-nitrotoluene, 4-nitrotoluene, 2,4-dinitrotoluene, tetryl, TNT, RDX, and HMX). The concentrated mix was diluted to prepare a 200 ppb laboratory control standard that was analyzed once with every set of samples from Fort A.P. Hill. Redstone sample extracts were analyzed with individually prepared, 1 ppm laboratory control standards for PETN (Cerilliant cat.# P-037 – 1000ug/mL), TNT (Cerilliant cat.# ERT-0225 – 1000ug/mL) and RDX (Cerilliant cat.# ERR-0015 – 1000ug/mL).

In a small percentage (~5%) of the acetonitrile extracts, matrix interferences, probably caused by hair care products and natural oils, were observed as white suspended solids in the concentrated samples. Such interferences contributed to high baseline noise and made it necessary to evaluate the significance of the data.[15] Limits of quantification (LOQ) and limits of detection (LOD) were established for PETN, TNT and RDX for each sample set. The LOD for any analytical procedure is the point at which detection is feasible. LOD values (S*m*) were calculated based on the analysis of 20 control samples, using *eq. 1* where $\mathbf{S}m$ = *LOD,* $\mathbf{s_{bl}}$ = avg. analyte signal, k = *3,* $\mathbf{s_{bl}}$ = std. dev. signal.

$$Sm = S_{bl} + k s_{bl} \qquad (eq.1)$$

The LOQ is the concentration at which quantitative results can be reported with a high degree of confidence. LOQ values were calculated based on the same 20 control samples as the product of 10 and $\mathbf{s_{bl}}$. Peak values below the LOD were considered non-detectable (ND), while peak values between the LOD and LOQ were considered non-calculable (NC). Due to instability in the ECD

response, dynamic LOD and LOQ values, recalculated daily for each sample set, were found using *eq.2* and *eq.3:*

$$LOD = [1/8(a1_n/a1_i + \ldots + a8_n/a8_i)]\,[LOD_i] \qquad \textit{(eq. 2)}$$

$$LOQ = [1/8(a1_n/a1_i + \ldots + a8_n/a8_i)]\,[LOQ_i] \qquad \textit{(eq. 3)}$$

where

$a(1\text{-}8)_n$ = peak area of new calibration standard (8 standards total)

$a(1\text{-}8)_i$ = peak area of original calibration standard (8 standards total)

LOD_i = initial LOD (ppm) LOQ_i = initial LOQ (ppm).

Average LOD values for samples containing TNT, PETN, and RDX were usually near 6, 40, and 30 ppb, respectively, and average LOQ values were usually about 10, 100, and 70 ppb, respectively.

Chromatographic conditions for analysis of the Fort A.P. Hill samples on the 6890 GC-μECD fully resolved TNT, PETN, and RDX. Figure 2 is a chromatogram of a 5 ppm mixed calibration standard of TNT (8.3min.), PETN (8.9min.), and RDX (10.1min.). The peak for PETN was poorly shaped due to degradation in the 30 meter DB5-MS column. It was necessary to perform quantification using one of degradation products of PETN, seen in Figure 2 as peaks at 4.3, 5.3, 6.2, and 7.4 minutes. Peak ratios of the degradation products were unchanged in samples and standards stored for 3 months at -24°C. The peak at 5.3 minutes was chosen for quantification of PETN as it gave a very linear response to changes in PETN concentration and was conveniently positioned away from the majority of baseline sample interference observed in the comb extracts. A shorter (6 meter) megabore (0.53 mm I.D.) column was used for analyses of the Redstone samples on the 5890-ECD. These column dimensions have has been shown to reduce degradation of PETN and other explosives. Figure 3 is a chromatogram of a 0.5 ppm

mixed calibration standard of TNT (6.4min.), PETN (7.2min.), and RDX (8.1min.) analyzed on the 5890-ECD.

Figure 4 shows the chromatogram of actual extracted sample (9414-1030A, A.P. Hill) containing TNT, PETN, and RDX. Identification of these explosives was contingent on their retention time relative to the retention time of the calibration standards. A sample peak which eluted within ±0.005 minutes (±0.3 seconds) of a calibration standard peak was considered a positive identification. Quantification was accomplished by comparison of peak areas with calibration curves of standards (peak areas versus concentration). Calibration curves were linear ($R^2 \geq 0.99$) with a linear dynamic range of 0.05-30 ppm and an average relative standard deviation (avg. RSD) of 5.0% for PETN; 0.01-1 ppm with avg. RSD of 1.6% for TNT; and 0.01-2 ppm with avg. RSD of 3.5% for RDX. Worksheets were established containing raw and processed chromatographic data for each sample set which included: peak retention time, peak area, peak height, recalculated LOD/LOQ values, concentration based on standard calibration curves, explosive mass (ng) recovered, and standard percent recovery for PETN, TNT and RDX. Information from individual comb bag labels and personal consent forms along with masses of any of the explosive analytes were compiled for all samples in a master spreadsheet.

Results and Discussion

Tables 3 and 4 summarize the data for Week 1 and 2 at Fort A.P. Hill and Table 5 includes the average data from the Redstone Arsenal shots. Average results are reported for the date and time [morning (Mor.) before working with explosives versus afternoon (Aft.) after working with explosives]. Each column is headed by the total number of participants sampled at that time, and results below list the number of participants found containing each of the three explosives and the average amount of each explosive (ng) recovered from the contaminated

participants. Standard deviations are similar and, in some cases, even greater than the average amounts of explosives found on individual's hair. Thus, although average amounts of explosive contamination are reported in order to give a rough approximation of the amounts of explosive available for detection, the more significant number is the percent of participants who were contaminated.

At A.P.Hill (Week 1 and Week 2), more participants became contaminated with PETN and at greater quantities, than with TNT or RDX. Detonating cord (det cord) was used for most shots and is a ready source of contamination because it is packed with powdered PETN.[16] Det cord was also used at Redstone Arsenal, although most participants in the hair study were involved in debris collection and not direct setup of the explosive shots. Therefore, explosive contamination at Redstone was not as widespread in terms of participant percentages and the quantity of explosives recovered. For example, on average greater than 80% of participants at A.P. Hill were contaminated with PETN at over 3000ng while only 24% of Redstone participants were on average contaminated with 170ng PETN.

Surprisingly, at all three test series, several individuals showed detectable levels of RDX and PETN (A.P. Hill) on Monday morning before any explosives handling commenced. A similar observation was made at DSTL for people involved in handling explosives in the preparation of canine training aids.[7,10] For the A.P. Hill tests, where the hair of participants was tested every morning, it is easily seen that the number of participants contaminated at the start of the day, before handling explosives, steadily increased during the week. Morning sampling showed overnight persistence of PETN, TNT, and RDX, but the explosives which were present in higher amounts the previous afternoon were more likely to remain overnight. For example, PETN contamination in the hair of all the A.P. Hill participants (mean = 7068 ng) on the

afternoon of 11/05 led to the carry-over of PETN contamination for over 60% of those sampled the next morning. TNT recovered from the same participants on the afternoon of 11/05 was at an average of only 64 ng and was detected on only 4% of these participants on the following morning (Tables 3 and 4). Other factors which would affect persistence are the solubility of the explosive and its mode of binding to hair. At 20ºC, both TNT and RDX have low solubility in 100 g water (0.012 and 0.005 g respectively) while PETN is considered insoluble. In 100 g water at 100ºC, TNT and RDX have slightly increased solubility (0.147 and 0.28 g respectively) while PETN is unpublished.[17,18] By the final afternoon sampling during Week 2 at A.P. Hill every participant was contaminated with PETN and greater than 50% showed traces of RDX and TNT.

Correlations between the quantity of PETN, TNT, and RDX recovered from individuals' hair and individual physical characteristics were limited by the diversity of the sample pool. Participant hair length was mostly short or missing (bald), and greater than 90% of the participants were Caucasian males. A comparison of participants' hair color to explosive contamination was examined for the Week 1 and 2 Fort A.P. Hill samples combined. Table 6 shows hair color versus average explosives recovered (ng) and the percent of participants contaminated with PETN, TNT, and RDX. The relative percentages of explosive contamination (~90% PETN, ~50% RDX, and ~30% TNT) seem to hold across all hair colors within a deviation near 10%. There was a slight bias towards greater contamination on black hair, but this could be associated with experimental error.

Conclusions

Trace organic explosives can be successfully recovered from and detected on the hair of exposed individuals. Results from morning samplings, before any explosives were handled, indicate that explosive contamination can persist overnight, especially when the previous afternoon exposure was high. Over 60% of participants on the last morning of the A.P. Hill

testing had detectable amounts of PETN in their hair. Additionally, the average amount of PETN recovered in the afternoon (after explosive handling) increased over the course of each week at A.P. Hill. There appeared to be no correlation between the presence of hair treatment products and the degree or likelihood of explosive contamination, but these products did lead to increased matrix interferences in the chromatographic analyses. The limited participant pool, mostly Caucasian males with short hair, did not allow correlation of contamination with other physical characteristics, such as hair color or length.

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List of Tables

Table 1: Explosives Used at Fort A.P. Hill (2003)

	27-Oct	28-Oct	29-Oct	30-Oct
PETN containing	det cord	det cord, pentolite booster, detonator	det cord, pentolite booster	det cord, pentolite booster
RDX containing		oil well perforators		
TNT containing		pentolite booster	pentolite booster	pentolite booster
NG containing	smokeless powder	dynamite, smokeless powder	dynamite	dynamite
AN or other	fireworks		shock tube	fireworks, AN emulsion
	3-Nov	4-Nov	5-Nov	6-Nov
PETN containing	det cord, pentolite booster	det cord, pentolite booster	det cord	det cord, pentolite booster
RDX containing		oil well perforators		oil well perforators
TNT containing	pentolite booster	pentolite booster		pentolite booster, soil contaminated w/ TNT & DNT
NG containing			dynamite	
AN or other	fireworks, AN emulsion			ANFO, AN emulsion

Table 2: Explosives Used at Redstone Arsenal (2005)

	5-Apr	8-Apr	18-Apr	19-Apr	20-Apr	25-Apr	27-Apr	28-Apr
PETN containing	det cord	det cord	det cord	det cord	det cord	det cord	det cord	det cord
RDX containing	Haliburton shaped charge, 105mm projectile	Haliburton shaped charge, comp. B, 105mm projectile	105mm projectile	105mm projectile	Haliburton shaped charge, 105mm projectile	C4, 155mm projectile	Haliburton shaped charge, 155mm projectile	105mm projectile
TNT containing	105mm projectile	comp. B, 105mm projectile	comp. B, 105mm projectile	TNT, 105mm projectile	TNT, comp. B, 105mm projectile	comp. B, 155mm projectile	155mm projectile	TNT, 105mm projectile
AN or other	HMX (105mm projectile)	HMX (105mm projectile)	Kinepak (AN/NM), HMX (105mm projectile)	Kinepak (AN/NM), HMX (105mm projectile)	HMX (105mm projectile)	HMX (155mm projectile)	HMX (155mm projectile)	Kinepak (AN/NM), HMX (105mm projectile)

Table 3: Hair Contamination at Fort A.P. Hill, Week 1 (2003)

	27-Oct		28-Oct		29-Oct		30-Oct		Overall Average	
	Mor.	Aft.	Mor.	Aft.	Mor.	Aft.	Mor.	Aft.	Morning	Afternoon
# Participants	29	24	23	20	18	20	20	13	23	19
Part. w/ **PETN**	1	16	6	15	0	18	12	13	5	16
% contaminated	**3%**	**67%**	**26%**	**75%**	**0%**	**90%**	**60%**	**100%**	**21%**	**81%**
Avg. **PETN (ng)**	341	520	686	1529	0	4567	844	5913	468	3132
StdDev. (ng)	n/a	±336	±945	±1628	n/a	±4064	±354	±5420	±650	±2862
Part. w/ **TNT**	0	6	2	10	0	4	0	3	1	6
% contaminated	**0%**	**25%**	**9%**	**50%**	**0%**	**20%**	**0%**	**23%**	**2%**	**30%**
Avg. **TNT (ng)**	0	40	99	97	0	84	0	658	25	220
StdDev. (ng)	n/a	±15	±80	±140	n/a	±33	n/a	±649	±80	±209
Part. w/ **RDX**	1	4	1	8	1	4	0	7	1	6
% contaminated	**3%**	**17%**	**4%**	**40%**	**6%**	**20%**	**0%**	**54%**	**3%**	**30%**
Avg. **RDX (ng)**	96	206	1283	545	169	361	0	1065	387	544
StdDev. (ng)	n/a	±86	n/a	±653	n/a	±107	n/a	±1171	n/a	±504

Table 4: Hair Contamination at Fort A.P. Hill, Week 2 (2003)

	3-Nov		4-Nov		5-Nov		6-Nov		Overall Average	
	Mor.	Aft.	Mor.	Aft.	Mor.	Aft.	Mor.	Aft.	Morning	Afternoon
# Participants	25	28	29	30	29	27	27	28	28	28
Part. w/ **PETN**	4	17	3	27	8	26	18	28	8	25
% contaminated	**16%**	**61%**	**10%**	**90%**	**28%**	**96%**	**67%**	**100%**	**30%**	**87%**
Avg. **PETN (ng)**	493	2007	283	7032	387	7068	730	7741	473	5962
StdDev. (ng)	±187	±4722	±125	±13530	±137	±6125	±438	±26980	±222	±12840
Part. w/ **TNT**	0	2	0	7	1	6	1	19	1	9
% contaminated	**0%**	**7%**	**0%**	**23%**	**3%**	**22%**	**4%**	**68%**	**2%**	**30%**
Avg. **TNT (ng)**	0	88	0	81	21	64	29	145	13	95
StdDev. (ng)	n/a	n/a	n/a	±68	n/a	±46	n/a	±192	n/a	±102
Part. w/ **RDX**	2	6	0	23	2	15	2	15	2	15
% contaminated	**8%**	**21%**	**0%**	**77%**	**7%**	**56%**	**7%**	**54%**	**5%**	**52%**
Avg. **RDX (ng)**	263	391	0	3075	533	334	418	439	304	1060
StdDev. (ng)	±26	±263	n/a	±7052	±541	±228	±262	±368	±276	±1980

Table 5: Hair Contamination at Redstone Arsenal (2005)

	4-Apr	5-Apr	6-Apr	8-Apr	18-Apr		19-Apr	20-Apr	25-Apr		27-Apr	28-Apr	Overall Average	
	Mor.	Aft.	Aft.	Aft.	Mor.	Aft.	Aft.	Aft.	Mor.	Aft.	Aft.	Aft.	Morning	Afternoon
# Participants	10	10	10	10	7	7	8	8	6	7	7	5	8	8
Part. w/ **PETN**	0	2	1	4	0	1	2	4	0	1	1	1	0	2
% contaminated	**0%**	**20%**	**10%**	**40%**	**0%**	**14%**	**25%**	**50%**	**0%**	**14%**	**14%**	**20%**	**0%**	**24%**
Avg. **PETN (ng)**	0	91	518	224	0	187	151	148	0	216	17	3	0	173
StdDev. (ng)	n/a	±68	n/a	±355	n/a	n/a	±63	±107	n/a	n/a	n/a	n/a		
Part. w/ **TNT**	0	0	0	0	0	6	7	0	0	0	0	0	0	1
% contaminated	**0%**	**0%**	**0%**	**0%**	**0%**	**86%**	**88%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**18%**
Avg. **TNT (ng)**	0	0	0	0	0	331	248	0	0	0	0	0	0	64
StdDev. (ng)	n/a	n/a	n/a	n/a	n/a	±341	±326	n/a	n/a	n/a	n/a	n/a		
Part. w/ **RDX**	2	3	4	5	3	6	8	8	4	5	1	1	3	5
% contaminated	**20%**	**30%**	**40%**	**50%**	**43%**	**86%**	**100%**	**100%**	**67%**	**71%**	**14%**	**20%**	**39%**	**57%**
Avg. **RDX (ng)**	643	94	100	150	36	727	1201	151	30	78	40	32	236	286
StdDev. (ng)	±509	±64	±137	±105	±44	±622	±1193	±138	±21	±128	n/a	n/a		

Table 6: Hair Color vs. Explosive Contamination at Fort A.P. Hill (2003)

Mean daily participants (total = 50)		Overall Mean					
		PETN		TNT		RDX	
		Mor.	Aft.	Mor.	Aft.	Mor.	Aft.
Brown (27)	Part. w/ explosives	7	22	1	8	2	11
	% contaminated	25%	81%	2%	32%	5%	42%
	Mean mass (ng)	511	4293	22	139	299	743
Black (6)	Part. w/ explosives	1	6	0	3	1	3
	% contaminated	14%	95%	0%	45%	11%	54%
	Mean mass (ng)	168	4426	0	170	56	982
Blonde (4)	Part. w/ explosives	1	3	0	0	0	2
	% contaminated	19%	81%	0%	13%	6%	50%
	Mean mass (ng)	512	2405	0	16	75	492
Gray (12)	Part. w/ explosives	4	8	1	3	0	4
	% contaminated	36%	88%	4%	24%	0%	43%
	Mean mass (ng)	420	5127	9	36	0	410
Red (1)	Part. w/ explosives	1	1	0	0	0	1
	% contaminated	50%	100%	0%	25%	0%	75%
	Mean mass (ng)	237	2427	0	4	0	620

List of Figures

Fig .1. *Comb fitted with cheesecloth for hair sampling*

Fig. 2. *Chromatogram of 5ppm calibration standard (PETN/TNT/RDX) from 6890 GC-μECD*

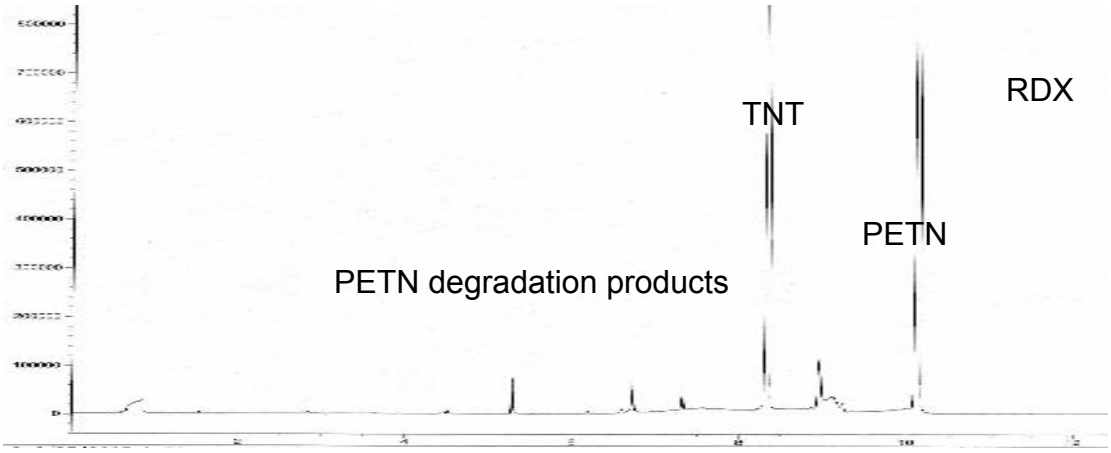

Fig. 3. *Chromatogram of 0.5ppm calibration standard (PETN/TNT/RDX) from 5890 GC-ECD*

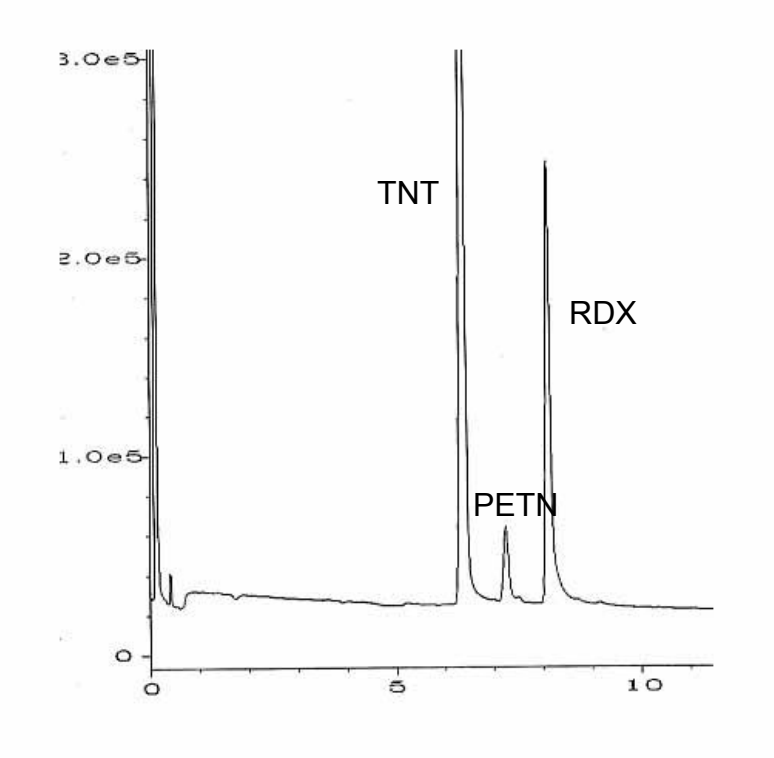

Fig. 4. *Chromatogram of sample 9414-1030A (Fort A.P. Hill) from 6890 GC-µECD*