Edgars Rudzitis,[1] *Ph.D.*

Analysis of the Results of Gunshot Residue Detection in Case Work

---

REFERENCE: Rudzitis, E., "**Analysis of the Results of Gunshot Residue Detection in Case Work,**" *Journal of Forensic Sciences,* Vol. 25, No. 4, Oct. 1980, pp. 839-846.

ABSTRACT: The results of gunshot residue tests in more than 800 criminal cases are described. A combination of neutron activation and atomic absorption analyses was found to be the most efficient method for the determination of trace amounts of antimony and barium on swabs. A statistical treatment was used as a basis for the evaluation of individual test results.

KEY WORDS: criminalistics, gunshot residues, chemical analysis, antimony, barium, neutron activation analysis, atomic absorption spectrometry

There are about two dozen publications on gunshot residue (GSR) detection by trace element analysis. The first and most extensive study was that of Schlesinger and co-workers [*1*] who, using neutron activation analysis (NAA), tried to quantify Harrison and Gilroy's [*2*] observation that upon discharge of a gun trace amounts of barium, antimony, and lead are deposited on hands. A recent extensive study of more than 1500 test firings extending over some eight years was published by Krishnan [*3*]. Other earlier publications (see the bibliography in Ref *3*) almost exclusively correlate variables encountered in test firings and sampling techniques. In contrast, this paper describes the results obtained from 827 actual criminal cases by analyzing the contents of 1250 GSR kits over a six-year period. In addition, a statistical treatment is presented that establishes a consistent method for the evaluation of an analysis of a particular GSR test kit in terms of an "inconclusive" or "GSR-consistent" opinion. Finally, some observations are made on the efficiency of NAA compared with that of analysis by atomic absorbtion spectrometry (AAS) in determining barium and antimony in GSR.

Developmental Stage of the Project

In 1970 the author was commissioned to establish NAA capability for the Bureau of Identification of the State of Illinois (now known as the Bureau of Scientific Services). This was prompted by the proximity of a high-flux nuclear reactor (CP-5) at Argonne National Laboratory (ANL). In anticipation of a heavy need for GSR work it was decided to plan for simplicity and directness of operation:

1. Analyze for barium and antimony only (lead is not specific).
2. Simplify and economize on test kits (incidentally, some 2700 kits were distributed over a six-year period).
3. Apply swab technique; use one swab per hand surface.

Received for publication 4 Feb. 1980; accepted for publication 28 April 1980.

[1] Forensic scientist, Lemont, Ill.

4. Eliminate postirradiation chemistry.
5. Establish a statistical basis for relating the barium and antimony content of a test swab to a logically defensible inconclusive or GSR-consistent opinion.

To eliminate postirradiation chemistry a comprehensive research project was carried out in cooperation with ANL [*4,5*]. The avoidance of postirradiation separations eliminated "hot" chemistry and associated contamination problems; also, the time constraints imposed by 83-min ^{139}Ba were substantially lessened. Thus, 130 samples from 24 kits including two sets of standards could be conveniently processed, irradiated, and analyzed in a batch operation.

Evaluation of the Results

Relating the barium and antimony content found on swabs to a scientifically defensible opinion as to the level of GSR-consistent results has long been a weak point in GSR detection. The frustrating fact is that often the emissions of barium and antimony from the same caliber weapon vary over several orders of magnitude. It appears that among other variables the quality (tightness) of the gun is an important factor. Guinn et al [*6*] devised a quite complicated log-bivariate normal analysis for interpretation of the results of analysis of swabs in terms of test firings. However, it was impractical for a lucid court presentation, and therefore laboratories engaged in GSR work established their own empirical GSR-consistent values. These varied from 0.3 μg barium and 0.2 μg antimony [*7*] to 1.0 μg barium and 0.1 μg antimony [*1*]. Considering the intrinsic shortcomings of these two approaches it was decided to use as a basis "handblank" values—the amounts of barium and antimony found on the hands of persons who have not recently handled a gun. At this point, it may be useful to digress shortly to the so-called occupational handblanks. It is well known that some occupations (for example, garage workers) encounter some substances that contain barium and antimony and, therefore, have higher handblanks than the average person. It can be argued, however, that shootings seldom occur at the place of work and, of course, any contact, especially with water after work, tends to diminish the differences between occupational and nonoccupational handblanks.

According to the central limit theorem (see the Appendix) it should be expected that in analogy with other physiobiological phenomena the trace amounts of barium and antimony in handblanks should follow a normal (Gaussian) distribution. If so, normal rules of statistics in terms of averages and standard deviations are applicable. The results of analyses of 32 sets of handblanks are presented in the Appendix. They show that the distribution of barium and antimony in a set of 128 samples is indeed normal. The averages $\bar{x}_{\text{Ba}}$ and $\bar{x}_{\text{Sb}}$ are 140 and 8 ng, respectively. The standard deviation for both are close to 100% (that is, $s_{\text{Ba}} = \pm 140$ ng and $s_{\text{Sb}} = \pm 8$ ng). In the light of previous results [*1*] and the AAS results for barium the final values were rounded off to $\bar{x}_{\text{Ba}} = 100$ ng and $\bar{x}_{\text{Sb}} = 10$ ng with $s = \pm 100\%$ for both. The next step was to compare the amounts of barium and antimony on swabs of a particular test kit with the established means of handblanks in terms of standard deviations and establish the probabilities of the test results belonging to a handblank population. No definite ratio between the amounts of barium and antimony was expeted [*1,3*]. The probability rules were applied arbitrarily but consistently, based on relative probabilities of encountering just one or two combined events (barium or antimony; barium and antimony):

1. Both elements present in excess of 5*s* from $\bar{x}_{\text{Ba}} \geq 0.5$ μg and $\bar{x}_{\text{Sb}} \geq 0.05$ μg is consistent with GSR. The combined probability for belonging to handblank population, according to multiplication rule, is approximately $10^{-4} \times 10^{-4} = 10^{-8}$.
2. If one element is below the 5*s* level or is not detected at all the other has to be in excess of 10*s* from $\bar{x}_{\text{Ba}} \geq 1.0$ μg and $\bar{x}_{\text{Sb}} \geq 0.1$ μg in order to qualify as being consistent with GSR.

In some 50 court presentations this concept has not been challenged.

Case Statistics

In keeping with the practical aspect of the GSR program Table 1 is presented. It shows the yearly case growth rate. It can be seen that the demand increased steadily. The dip in 1977 is related to the switch to the AAS technique. The initial investment, mostly by the Law Enforcement Assistance Administration, over approximately a two-year period was approximately $100 000 for the PDP-12 computer with a pulse height analyzer system and the AA spectrometer. The subsequent support, mostly for the use of the CP-5, some $3000 per year, was modest—roughly $20 per kit or $4 per sample. Some 150 law enforcement agencies, including local police departments, sheriff's police, and coroners, in that order of frequency, have used the GSR detection program.

Table 2 shows various offenses involved in the GSR case work. An earlier presentation of this nature [*8*] covering some 135 cases was less detailed but in general agreement with our work. Table 3 expands on Table 2 on a yearly basis. With two exceptions in 1974 the percentage of GSR-consistent findings is quite constant. This shows, as has been well demonstrated in the insurance industry, that statistics of uncontrollable events may be reliable, provided that a large enough sample is available.

During the six-year period three different techniques were used: from 1974 through 1976, exclusively NAA; in 1977, exclusively AAS; and in 1978 and 1979, AAS for barium and NAA for antimony. The large amount of data lends itself to other observations and correlations:

1. In 58% of the kits the presence of both barium and antimony in levels greater than 5*s* from the established averages determined the opinion of GSR-consistent. Antimony alone,

TABLE 1—*Number of cases on yearly basis.*

Year	Cases	% Gain
1974	84[a]	...
1975	141	68
1976	158	12
1977	118	−25
1978	207	75
1979	266[b]	29

[a] Includes seven 1973 cases.
[b] Linearly extrapolated values.

TABLE 2—*Total cases 5/31/73 to 6/30/79.*

Offense No.	Offense	*n*	% of Total	% of Positive Findings
1	death investigation (suicide)	366	44	62
2	homicide	207	25	51
3	attempted murder	76	9	41
4	aggravated assault	59	7	35
5	miscellaneous	57	7	26
6	unlawful use of weapon	30	4	43
7	armed robbery	17	2	64
8	manslaughter	6	2	0
9	battery	5		20
10	burglary	3		33
11	assault	1		100
Total	...	827	...	...

in levels more than 10s from $\bar{x}_{Sb}$, accounted for 27% of the determinations and barium alone for 15%. The greater number of determinations from antimony alone may be purely chemical—antimony is "stickier."

2. Krishnan [3] questions the advantages of swabs from the back of the hand and palm as compared to rinses of the total hand in a plastic bag. Examination of our GSR-consistent suicide cases showed that 70% had sufficient GSR on the back of the hand and only in 30% was the opinion based on residue on the palm only. These findings may be explained by the "tight" gun theory. In our experience about one third of the guns test fired were "tight," that is, a single firing did not leave enough residue on the back of the hand(s) for a GSR-consistent opinion. However, as a result of handling and loading, the combined amounts of GSR from previous firings may leave sufficient amount of residue on the palm(s) for a GSR-consistent opinion.

3. Cowan et al [8], analyzing their data, conclude that the incidence of finding GSR on the right hand exceeds that on the left. Our data show the following distributions: right back, 22%; right palm, 28%; left back, 19%; and left palm, 31%.

Another correlation that may be of some interest is the effect of caliber on GSR-consistent findings. After correction for incidence (176/139) (Table 4), .38-caliber weapons gave 61% and .22-calibers gave 39%, which is, of course, as expected. Table 4 also shows the distribution of caliber and type of 636 weapons involved in our GSR cases; the results are in

TABLE 3—*Offenses 1 to 4,[a] yearly cases.*

	Offense 1		Offense 2		Offense 3		Offense 4	
Year	Total	%(+)[b]	Total	%(+)	Total	%(+)	Total	%(+)
1974	18	72	18	44	11	63	5	67
1975	62	69	47	58	16	26	7	29
1976	70	67	42	48	12	25	10	20
1977	67	67	23	33	6	20	7	17
1978	92	10	50	38	20	31	14	29
1979	57	48	27	41	11	32	15	27

[a] See "Offense No." of Table 2.
[b] Percentage of total positive findings.

TABLE 4—*Weapon correlations.*

Weapon	n	%
.38	176	28
.22	139	22
Shotgun	94	15
.25	52	8
.357	51	8
.32	51	8
.45	23	3
Rifle	20	3
9 mm	18	3
Others	12	2
Total	636[a]	...

[a] The number of weapons does not match the number of cases (839) because in a number of cases the weapon was missing.

reasonably good agreement with the data of Table 3 of Ref *8*. It is not surprising that the incidence of rifles and shotguns used in crimes increases from cities to rural areas: Cowan et al [*8*] (Cleveland and vicinity), 11%; this work (Illinois), 15%; and Krishnan [*3*] (Ontario), close to 50%.

Effect of Time Delay in Swabbing

A time limit of 3 h was set for comparison. Data show that approximately two thirds of the suspects were sampled during that time period, the rest later. An apparent contradictory result emerges when the GSR-consistent opinions of each group are compared: 35% of the first and 43% of the second. The discrepancy can be explained by the common practice that in suicide cases, which produce most of the GSR-consistent findings, the swabbing is often delayed. This leads to the observation, which has also been emphasized by Krishnan [*3*], that time delay in actual cases is not as important a factor as in test firings.

Comparison of Techniques

Instrumentation advances in AAS have made the sensitivity of this technique comparable with that of NAA for many elements. The obvious advantages of AAS are that it does not require neutrons, is much faster, and is less expensive. There are also several subtle disadvantages [*3*]. On the basis of an article [*7*] expounding the virtues of AAS in GSR work, AAS was used exclusively for an eight-month period. Comparison of the results of AAS to those of NAA for Offenses 1 and 2 (suicides and homicides) revealed that the AAS technique had yielded 25 and 14% GSR-consistent findings as compared to 67 and 33%, respectively, by NAA for a similar sample size. It can be assumed that the other offenses display a similar pattern. Subsequent investigation of the cause for the low yield revealed that AAS is insensitive to antimony below 0.2 μg. When low temperature ashing is not used antimony does not desorb completely from the cotton, thus aggravating the situation. (In contrast, NAA can detect antimony on cotton in nanogram quantities.) On the other hand, the sensitivity and accuracy of our AA spectrometer (Perkin-Elmer 460 with HGA 2600) for barium was superior to those of NAA. In fact, a redetermination of handblank values of 56 samples yielded an average of 77 ng with a standard deviation of ± 8 ng, or 10%. The sensitivity was sufficient to determine the barium "background" of control swabs. Twenty-one samples yielded an average of 4 ± 4 ng.

In conclusion, it should be noted that this work establishes several salient points not previously presented: (1) a large number of cases analyzed in considerable detail, (2) elimination of postirradiation chemistry, (3) combination of NAA and AA techniques, and (4) a statistical treatment based on handblanks for a court-acceptable interpretation of GSR test results.

Acknowledgments

The author thanks Dr. J. Talboy and Messrs. J. J. Hartig and G. Schulke of ANL for providing accommodations for lab work and their assistance with CP-5 operations. The contribution of the Law Enforcement Assistance Administration towards the acquisition of the instruments is gratefully acknowledged, and so are comments and editing help by my colleagues Dr. Donald M. Plautz and Mr. Blair Schultz.

APPENDIX

With the availability of some 50 sets of handblanks (environmental natural levels of barium and antimony on hands), firing tests, and calibrations, we considered a different concept for the interpretation of the results. The evaluation consisted of two steps: (1) establishing that the values of barium and antimony in handblanks of the accumulated population sample followed a normal (Gaussian) distribution as statistically approximated by the t distribution, and (2) use of a relatively simple statistical formalism for the calculation of the probability that the amount of barium and antimony found on a given swab belongs to the established handblank population.

The normal distribution is represented by the well-known bell-shaped curve, where the maximum is represented by the mean $\bar{x}$ and the standard deviation s by the width at the inflection point. The basis of its application to many natural phenomena is the central limit theorem, which states that the sum of a large number of independent variables will be approximately normally distributed regardless of their individual distributions. The theory of the normal distribution was developed from a large number of samples, which, of course, cannot be strictly applicable in most practical cases. This was recognized early by Gosset [*9*], who formed the basis of the "small sample theory"—the t distribution and student's t test. The theory, in effect, states that the t distribution has the same shape as the normal distribution except that the curve is flatter and has a longer tail. The t test, which is an estimate of the probability by which a given sample falls into an established t distribution, is represented by the formula $t = (x_1 - x/s)n^{1/2}$, where x_1 is the value of a given sample and x, s, and n are the parameters of a previously established t distribution. The calculated t value is compared with tabulated theoretical values and the probability of fit is thus determined. The one-tail test, in which only one half of the curve is tested, is indicated when below-average values are not of interest or when the sensitivity is limited, as in very low level antimony or barium determinations.

Table 5 presents the mean values and standard deviations as percentages of the mean value of the four separate hand swabs, right back, right palm, left back, and left palm, collected from 32 persons. The hands of crime lab technicians and police officers were swabbed "as is" without any pretreatment. As can be seen from the table, the mean values of right back and palm, and left back and palm, did not differ significantly and it was convenient to lump them as the total hand averages of 8 and 140 ng for antimony and barium, respectively, with an approximate standard deviation of ±100%, that is, ±8 and ±140 ng, respectively.

There is no a-priori reason to doubt that the central limit theorem, and consequently the normal distribution concept, applies to trace element distribution, including antimony and barium on hands in a human population, because these concentrations are affected by such random variables as location, diet, and metabolism. However, since enough data were at hand (some 120 samples per element), it was of interest to test the normal distribution experimentally by examination of the t distribution. The probability density plots of 0.2- and 3-ng increments, for antimony and barium, respectively, had similar appearances. The actual distribution test was carried out only for antimony because of better data resulting from the more convenient half-life of ^{122}Sb. After normalization of the data by shifting x at maximum (origin) to zero, a one-tail t test was carried out. The theoretical and experimental values are compared in Table 6 as a function of weight increments of antimony. The agreement is as good as can be expected for an average of 13 samples per weight increment. The experimental values show the tail expected for a t distribution. Therefore, the application of t tests to determine the probability of a given amount of antimony on a hand swab being a natural background handblank amount is justified. By analogy, the same conclusion may be made for relating amounts of barium found on swabs to handblanks.

Thirteen known one-hand-one-shot firings of both automatics and revolvers of various calibers were selected. The means and ranges of values of antimony and barium for the firing hand are presented in Table 7. If the means are taken as a characteristic test firing, it is obvious from the range that standard deviations have little meaning for comparison with handblanks—one of the difficulties encountered in previous investigations when statistics were based on test firings. It may be coincidental that the firing hand back has roughly twice the

TABLE 5—*Handblank values.*

Sample	Mean, ng	Standard Deviation, %
Antimony		
Right back	8	81
Right palm	10	116
Left back	6	87
Left palm	8	110
Barium		
Right back	120	116
Right palm	160	87
Left back	100	128
Left palm	200	93

TABLE 6—*Theoretical versus experimental* t *distribution for antimony handblanks.*

Antimony, ng	Theoretical	Experimental
0.0	42	42
0.2	32	32
0.4	19	15
0.6	9	14
0.8	3	7
1.0	1	5
1.2	0	4
1.4	...	0
1.6	...	1

TABLE 7—*Firing test data.*

Sample	Mean, ng	Range, ng
Back of firing hand		
Antimony	100	25-270
Barium	1400	270-6600
Palm of firing hand		
Antimony	66	4-260
Barium	680	0-2230

amount of antimony and barium as the palm, which in turn shows about ten times the amounts of a typical handblank.

References

[1] Schlesinger, H. L., Lukens, H. R., Guinn, V. P., Hackelman, R. P., and Korts, R. F., "Special Report on Gunshot Residues Measured by Neutron Activation Analysis," Report GA-9829, Gulf General Atomic, Inc., San Diego, Calif., 10 Aug. 1970.

[2] Harrison, R. C. and Gilroy, J., *Journal of Forensic Sciences,* Vol. 4, No. 2, April 1959, pp. 19-36.

[3] Krishnan, S. S., *Journal of Forensic Sciences,* Vol. 22, No. 2, April 1977, pp. 304-324.

[4] Rudzitis, E., Kopina, M., and Wahlgren, M., *Journal of Forensic Sciences,* Vol. 18, No. 2, April 1973, pp. 93-100.

[5] Rudzitis, E. and Wahlgren, M., *Journal of Forensic Sciences,* Vol. 20, No. 1, Jan. 1975, pp. 119-124.

[6] Guinn, V. P., Hackelman, R. P., Lukens, H. R., and Schlesinger, H. L., "Applications of Neutron Activation Analysis in Scientific Crime Investigation," Report 9882, Gulf General Atomic, Inc., San Diego, Calif., Jan. 1970.

[7] Goleb, J. A. and Midkiff, R. C., Jr., *Journal of Applied Spectroscopy,* Vol. 29, No. 1, 1975, pp. 44-48.

[8] Cowan, M. E., Purdon, P. L., Hoffman, C. M., Brunelle, R., Gerber, S. R., et al, *Journal of Radioanalytical Chemistry,* Vol. 15, No. 1, 1973, pp. 203-218.

[9] "Student," *Biometrika,* Vol. 6, No. 1, 1908.

Address requests for reprints or additional information to
Edgars Rudzitis, Ph.D.
Bluff Rd., R.R.#2
Lemont, Ill. 60439