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Journal of Forensic Sciences - October 1967.
Vol. 12, #4

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TECHNICAL SECTION

Firing Distance Determination by Neutron Activation Analysis*

S. S. *Krishnan, Ph.D.***

The need for a technique of accurately determining firing distances in criminal cases involving firearms, especially in the range where powder residues are not easily detectable by conventional techniques, has been recognized for a long time in forensic science. A new recently reported successful method (1) for this purpose uses the neutron activation analysis (NAA) technique and represents the first attempt in decades to fulfill this need. By this method it was shown that the concentration patterns of the metallic residue deposited around bullet holes could be used to determine the muzzle-target distance. The bullets used were made of lead alloy containing antimony.

This paper reports further data on the concentration patterns of antimony (the constituent of the bullet which is most easily detected by NAA) deposited around bullet holes. A practical method of shooting determination is recommended, and results from simulated shooting cases are reported. The value of NAA in other forensic science applications is by now well recognized and reported elsewhere (2), (3), (4), (5), (6).

Experimental Procedure

The experimental procedure is similar to the one reported in the previous paper (1) and involves the following steps:

1. Firing test shots on target material with the lead alloy bullets.

* Received for publication July 21, 1967. Accepted for publication August 25, 1967.

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2) Removal of sections of target material. For this purpose concentric circles, each 0.25 cm wide, are cut with the bullet hole as the center. Generally eight such sections are cut for each bullet hole.

3) Thermal neutron activation of these sections in a nuclear reactor at a neutron flux of approximately 10^{13} n/sec/cm^2 for 12 hours.

4) Allowing the radioactive samples to decay for four or five days and estimating the concentration of antimony by measuring the induced Sb^{122} activity. The cooling period is necessary to allow the interfering activities to decay leaving mainly the residual Sb^{122}.

This enables counting without any radiochemical separation procedures. In cases where the target has large amounts of interfering activities which are long-lived, radiochemical separation may be undertaken to separate the Sb^{122} activity by the procedure previously described (1). The counting is done by using a 3" x 3" sodium iodide crystal connected to a 400 channel pulse height analyzer. The concentrations of antimony in the samples are calculated by comparison with similarly treated weighed antimony standards.

Results

The test shots in this study were fired using mainly the Cooey .22 rifle (barrel length 22"), CIL ammunition and dry filter paper and cotton cloth targets. The weapon was chosen because of its popularity in this country and the target materials because of their good reproducibility (1). It was decided to study the effects of various parameters on the antimony concentration pattern using this weapon-ammunition-target combination. It is believed that other combinations would give similar results, thereby leading to conclusions similar to the ones derived from this study. It has already been shown that the NAA technique of determining firing distance is far more sensitive than the other existing methods (1). Therefore, no attempt was made in this study to determine the sensitivity of the method. The maximum firing distance studied was 3 feet because this is the maximum arm-length usually encountered. If the shot is fired from a distance of more than 3 feet, then the possibility of the often-claimed simple suicide or struggle during shooting can be eliminated. This was one of the principal objectives of this study, initially.

Variation of Antimony Concentration with Firing Distance

The variation of antimony with firing distance using filter paper and cloth targets is shown in Fig. 1. The samples in this study are referred to by their outer distances from the center of the bullet hole. In most instances, each point on these graphs represents an average of three readings. The antimony concentrations are given in units of 10^{-9} grams per square cm area of the target material. In order to obtain the correct area of the samples used, the samples are weighed after each counting and the area calculated from the previously measured value of the weight of target material per unit area.

In determining the firing distance by this method, the antimony concentrations in the samples taken from around the bullet hole in question are

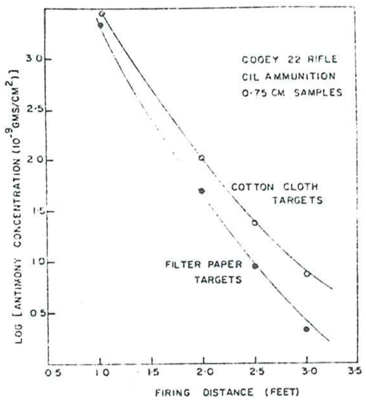

Fig. 1—Variation of antimony concentration with firing distance.

compared with graphs similar to the ones shown in Fig. 1. The error in the estimate of the shooting distance depends upon the accuracy with which the antimony concentrations are reproduced and also the extent by which the antimony concentration drops as the firing distance is increased. It was found that, in most cases, for a given distance, the average deviation for the antimony concentrations was less than 25%. Using the range of antimony concentrations obtained for each firing distance, and referring to the corresponding distance estimates obtained from Fig. 1, the possible error in the estimates of the distances by NAA was calculated. The results are given in Table 1.

Table 1

Estimates of Error in the Firing Distance Determination

(Cooey .22 rifle: CIL Ammunition: Dry Filter Paper Targets: 0.25 cm samples)

Firing Distance (Feet)	Deviation (Inches)	Percent Deviation
1	±1.2	10
2	±1.2	5
2.5	±3.0	10
3.0	±6.0	17

Effect of Different Target Materials

A series of test shots were fired using plain cotton, printed cotton, and filter paper as target materials. This was done to determine the variation of the concentration patterns of antimony around the bullet hole when different target materials are used. Typical results are shown in Fig. 2. It was found that for a given firing distance, the antimony concentration patterns on different target material are, with some exceptions, generally similar.

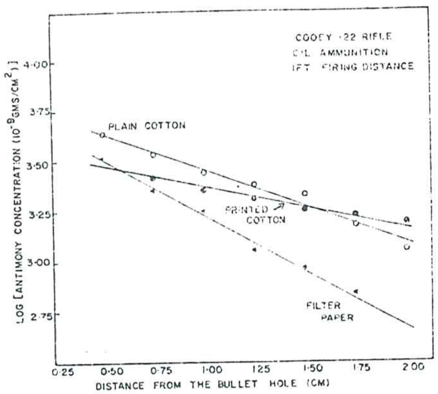

Fig. 2—Variation of antimony concentration with different target materials.

Effect of Different Ammunition

In cases where the bullet is lost or damaged beyond identification, it would become necessary to use any suitable ammunition for the test firings. Because of such cases, it is of importance to study the variation of concentration patterns of antimony when different kinds of ammunition are used. The results of such a study are shown in Fig. 3. It was found that different kinds of ammunition deposit somewhat different concentrations of antimony, although the orders of magnitude of the concentrations are in the same range. Such a result is logical because the source of the antimony, for the most part, with perhaps a smaller contribution from the gunpowder-primer mixture, is believed to be the bullet (1). Therefore, the amount of antimony deposited may vary depending on the alloy of lead used by the manufacturer of the ammunition.

Effect of Different Weapons

In criminal cases involving shooting where the weapon used cannot be located, it becomes necessary to use any other suitable available weapon

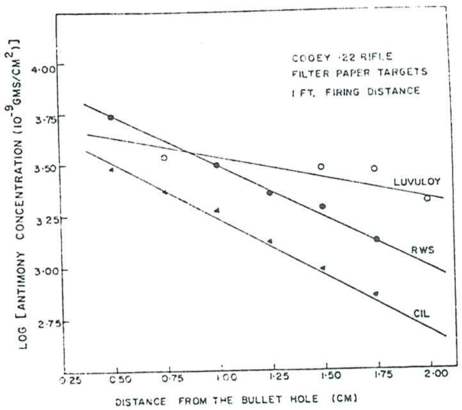

Fig. 3—Variation of antimony concentration with different ammunition.

for test firings. In these instances the knowledge of the variation in the concentration patterns of antimony when different weapons are used is of importance. The results of a series of test shots fired using different firearms under otherwise similar conditions are shown in Fig. 4. The data demonstrate that the antimony concentrations obtained from different weapons are somewhat different, although the orders of magnitude are similar.

Effect of the Angle of Shooting

All of the test shots fired in this study were controlled so that the line of the trajectory was perpendicular to the target. While this condition is convenient for comparison of different test firings, it is not often encountered in actual criminal cases. Therefore, it is important to study the effect of different shooting angles on the deposition of antimony around bullet holes. For this purpose, two shots were fired from the left and right side of the target at 45° angles to the vertical. The results are shown in Fig. 5. Here again it is noted that the orders of magnitude of the antimony concentrations obtained are similar.

Empirical Equation

An attempt was made to fit the antimony concentration data to an empirical equation. For this purpose the IBM 7094 computer at the University of Toronto was used, and various equations were fitted to the data

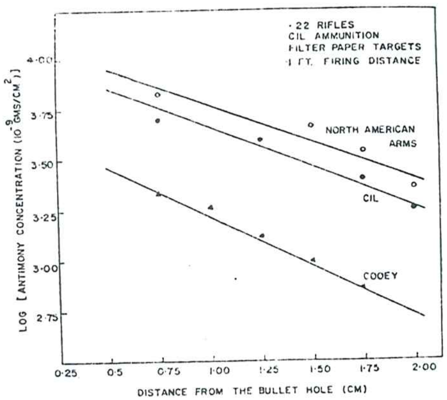

Fig. 4—Variation of antimony concentration with different weapons.

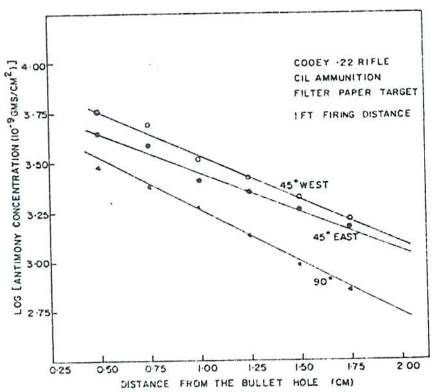

Fig. 5—Variation of antimony concentration with firing angle.

using the least square method. The best fit was obtained with the equation of the type

$$\text{Log (FD)} = A - m \text{ Log (Sb)}$$

where (FD) is the firing distance in feet, (Sb) is the concentration of antimony in grams per sq cm and A and m are numerical constants. These equations could also be expressed as

$$\text{(Sb)} = A \text{ (FD)}^{m}.$$

The set of equations obtained, along with the deviation between the experimental antimony concentrations and the values calculated using the equations, are given in Table 2. Typical graphs of Log (FD) vs. Log (Sb) obtained by experiments and calculations using these equations are given in Fig. 6. Similar results and similar sets of equations were also obtained for other targets, and also when antimony concentrations for a given bullet hole at a fixed firing distance are fitted with the sample distance from the bullet hole.

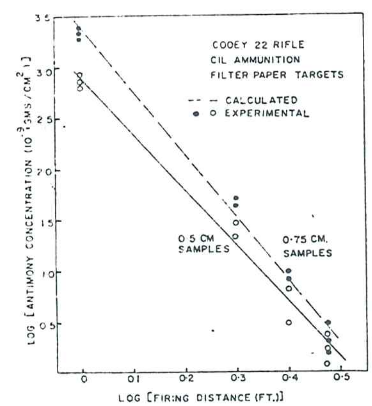

Fig. 6—Variation of antimony concentration with firing distance (comparison of experimental and calculated data).

Firing Distance Determination in Simulated Cases

In order to test whether the NAA method could effectively be used in actual cases, eight test shots were fired by a member of our firearms section and the firing distances were undisclosed. These shots were then

Table 2

Least Square Fit Equations

Log Firing Distance vs. Log Antimony Concentration

Cooey .22 rifle
CIL ammunition
Filter paper target
(FD) = Firing Distance in feet
(Sb) = Antimony concentration in 10^{-5} gms/cm²

Sample (outer distance in cm)	Equation	Maximum Deviation	Average Deviation
0.50	Log (FD) = 0.6206 — 0.178 Log (Sb)	18.0%	6.5%
0.75	Log (FD) = 0.5433 — 0.159 Log (Sb)	10.3%	4.1%
1.00	Log (FD) = 0.5608 — 0.1701 Log (Sb)	8.7%	4.4%
1.25	Log (FD) = 0.5696 — 0.1811 Log (Sb)	9.2%	3.7%
1.50	Log (FD) = 0.5283 — 0.1659 Log (Sb)	13.2%	8.4%
1.75	Log (FD) = 0.5271 — 0.1815 Log (Sb)	17.2%	6.1%
2.00	Log (FD) = 0.5073 — 0.1933 Log (Sb)	13.6%	5.3%

Average Equation:

$$\text{Log (FD)} = 0.5510 - 0.1756 \text{ Log (Sb)}$$

or

$$\text{(Sb)} = 1371 \text{ (FD)}^{-5.695}$$

turned over to the NAA group for distance determinations. The shooting distances were determined and a report was turned in as is done in regular cases. The results of this study are shown in Table 3. The correct shooting distances which were revealed after the reports were turned in are also tabulated for comparison. The excellent agreement between the reported and correct values shows the accuracy of the NAA technique in shooting distance estimations.

Long Distance Shots

It should be noted that the samples containing the bullet hole itself are not used in the distance determination. This is because of the fact that the antimony concentration in this sample is not reproducible because of the wiping action of the bullet. This produces the black ring, and the antimony concentration at this ring is not significantly different for different shooting distances—especially after a shooting distance of approximately 5 feet—nor is it as well reproducible as in the surrounding samples. However, the antimony in this ring is detectable at great firing distances (while no antimony is detected in areas immediately surrounding the ring) as shown in Table 4. Thus the detection of antimony, where lead bullets have been used, is of assistance in locating and identifying bullet holes when powder residues are not present.

Discussion

When a firearm is discharged, a number of metallic elements are deposited around the bullet hole along with the powder residues. Because the metallic deposits are in very small concentrations, little effort has so far been made in utilizing these patterns for a useful purpose. NAA is an extremely sensitive method of detecting traces of certain metallic elements, in amounts as small as 10^{-12} grams and therefore, is of use in determining firing distance. Antimony is used as a hardener in bullets, and it is by far the most easily detected metal in firearm discharge residues. This is despite the fact that more of the lead is deposited. Although this paper deals principally with the concentration patterns of antimony, other metals present in bullets, either as additives or impurities, could also be used for the same purpose. This would be particularly useful when the natural background antimony concentration in the target material is significantly high.

It is recommended that for test firings, insofar as is possible, the same target-ammunition-weapon combination as found in the case, be used.

Table 3

Determination of Firing Distances in Simulated Cases

(Cooey .22 rifle and CIL ammunition)

Case No.	Target	Firing Distance Estimates: Using the Empirical Equation (inches)	Using Graph of (Sb) vs. (FD) (inches)	Value Reported (inches)	Correct Value as Found Later (inches)	Deviations: Inches	%
1	Filter paper	11.3	8.2	10	13.5	3.5	26
2	Filter paper	18.1	20.25	19.2	18.5	0.7	4
3	Filter paper	30	30.6	30.3	27.5	2.8	10
4	Filter paper	36	34.5	35	33	2	6
5	Cotton cloth	15	19.4	17	17.25	0.25	1.4
6	Cotton cloth	29	29.7	29.4	30	0.6	2
7	Cotton cloth	>36	>38	>37	57	—	—
8	Cotton cloth	31.7	31.9	31.8	30	1.8	6

Table 4

Concentration of Antimony at the Bullet Hole in Long Distance Shots

Firing Distance (feet)	Antimony Concentration (10^{-9} gms/cm²): Filter paper targets	Cotton cloth targets
1	8347	16600
2	537	4285
2.5	924	3220
3.0	494	2364
5	119	316
10	128	229
15	73	239
20	84	177
30	91	241
50	98	199
70	86	210

Having perfected the method for one metal, antimony, and for CIL ammunition and Cooey .22 rifle, it is hoped to continue this project with other weapons such as revolvers and with other ammunition.

Preliminary experiments have indicated that copper-jacketed bullets deposit copper on the target in just the same manner as antimony is deposited from lead bullets. This would suggest that in cases when copper-jacketed bullets are used, a similar method involving copper patterns may be used for shooting distance determinations.

A procedure is recommended below for routine use of NAA for firing distance determination.

Recommended Routine Procedure for Firing Distance Determination by NAA

1) Fire duplicate test shots from suitable firing distances using the weapon, ammunition, and target used in the case.

2) Cut out eight concentric circles each 0.25 cm in width with the bullet holes as the center from the case shot and test shot targets.

3) Irradiate all the samples in a nuclear reactor with a thermal neutron flux (approximately 10^{13} n/sec cm²). Such

reactors are available in a considerable number of centers in various parts of North America and elsewhere.

4) Let the samples decay for a few days to allow all other major radioactivities except that due to antimony to decay.

5) Count the samples by any suitable counting equipment available for the 0.56 mev gamma rays from Sb^{122}.

6) Construct the antimony concentration vs. firing distance graph using the data from test shots.

7) Estimate the firing distance by comparison of the corresponding samples from case shots with those in the test shots.

8) Get an average firing distance value and estimate the error from the values obtained from the different samples and also the duplicate test shots.

Summary

The method of determination of firing distances using neutron activation analysis has now been developed for routine use. The method consists of 1) firing test shots using the same target, ammunition and weapon, as far as possible, as in the case; 2) removal of concentric circular sections of target material at various distances from around the bullet hole; 3) activation of these sections in a nuclear reactor; 4) waiting for a few days so that the radioactivities interfering with the antimony activity measurement have decayed; 5) the quantitative estimation of antimony by gamma ray scintillation spectrometry; and 6) estimation of firing distances by comparison with test shots.

The method is shown to give shooting distances with a deviation of ± 2 inches in many cases.

An empirical relationship between the antimony concentration around the bullet hole and the shooting distance has been derived.

In criminal cases where an accurate firing distance estimate is needed, the NAA method can be usefully applied.

Acknowledgments: The author would like to acknowledge with grateful appreciation the excellent cooperation received at the Centre of Forensic Sciences from the Director, the late Dr. H. Ward Smith; Mr. H. J. Funk; Mr. E. G. Clair; members of the ballistics section and the NAA group.

REFERENCES

1. Krishnan, S. S. Determination of Gunshot Firing Distances and Identification of Bullet Holes by Neutron Activation Analysis. J. Forensic Sci. 12, 112-122 (1967).
2. Erickson, N. E., Krishnan, S. S and A. K. Perkons. Neutron Activation in Forensic Investigations. Symposium on Trace Characteristics, Chemical and Physical, National Bureau of Standards, Gaithersburg, Maryland, October (1966).
3. Jervis, R. E. Recent Advances in Forensic Activation Analysis. Proceedings of Canadian Society of Forensic Science, 4, 95 (1964).
4. Guinn, V. P. Non-Biological Applications of Neutron Activation Analysis in Forensic Studies. Methods of Forensic Science, Vol. III, Edited by A. S. Curry. Interscience Publishers (London), pp 47–68 (1964).
5. Pro, M. J., Schlesinger, H. L. and C. M. Hoffman. Forensic Applications of Neutron Activation Analysis. Presented at the First International Conference of Forensic Activation Analysis, Sept. 19–21, 1966, San Diego, California.
6. Coleman, R. F., Cripps, F. H., Stinson, A. and H. D. Scott. The Trace Element Content of Human Head Hair in England and Wales and the Application to Forensic Science. Conference Abstracts, First International Conference on Forensic Activation Analysis, Sept. 19–21, 1966, San Diego, California.

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