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SPECIAL REPORT ON GUNSHOT RESIDUES MEASURED BY NEUTRON ACTIVATION ANALYSIS

by

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ABSTRACT

The idea of determining whether a person has recently fired a handgun, via the neutron activation analysis determination of traces of barium and antimony (from the cartridge primer) in residue material removed from the back of the gunhand, was conceived at General Atomic in 1961. During the period from 1962 through 1969, the technique for accomplishing reliable Ba and Sb measurements was developed, along with the conduct of small-scale studies of the numerous variables (gun type, gun caliber, length of gun barrel, condition of gun, particular chamber fired, brand of ammunition, wind velocity and direction, etc.) that affect the amount of gunshot residue deposited on the back of the gunhand. Various methods of removing gunshot-residue material from the back of the hand (in the area determined experimentally to be the area of maximum deposit) were also investigated — resulting in the "paraffin-lift" technique being selected as the method of choice. The possibilities of tagging the gunpowder, or the primers, used in various commercial brands of ammunition, with small amounts of rare, high-sensitivity elements were also explored.

During the last two years of the investigation, large-scale statistical studies were conducted of gunshot residues from revolvers and automatic pistols of various common calibers, and of Ba and Sb present on the hands of persons, of various occupations, who had not recently fired a gun ("occupational handblanks"). These large-scale studies resulted in a large body of experimental data — presented in full in this report. Concurrently, a suitable statistical method for the interpretation of such Ba-Sb data was developed: the bivariate-normal (BVN) method — actually a bivariate log-normal treatment. The development of the BVN method, its application to

the accumulated Ba-Sb data, and its potential use in the interpretation of actual criminal-case results are also presented in this report. It is shown that, in most instances, Ba-Sb results — properly obtained and properly interpreted — can provide a fairly definitive distinction between a hand that has recently fired a handgun and one that has not (or one that has subsequently been washed clean before being sampled).

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

LIST OF TABLES

SUMMARY

The use of thermal neutron activation analysis (TNAA) to determine whether a person has fired a handgun has been extensively investigated. It has been unequivocally established that the elements, barium and antimony, are deposited on the gun hand of a person who fires a handgun, and that these deposited elements can be accurately determined by TNAA.

A number of methods of removing and determining gunshot residues were examined. It was ascertained that the preferred method is to apply melted paraffin to the hand (especially the trigger finger and thumb web). The paraffin is removed after it solidifies, the resulting handlift is activated (bombarded with thermal neutrons) in a nuclear reactor; the analytical indicator radioisotopes of Ba and Sb produced by activation are radiochemically separated from the sample; and the indicator radioisotopes are quantitatively measured by gamma-ray spectrometry.

The elements Ba and Sb are not largely distributed in the usual environment of contact of most persons. It was found that the levels of these elements on the hands of persons in most occupations were significantly less than those to be found after firing a gun in most cases, especially those cases in which a large caliber gun was fired. Nevertheless, the frequency of cases where the difference between handblank and post-firing levels were insignificant was sufficient to warrant a definition of relevant statistics. The largest effort in the program was devoted to defining the probabilities, given the Sb and Ba values from a handlift, that a gun had or had not been fired.

In this work 613 handlifts were analyzed, of which 260 were handblanks. The 353 handlifts taken after individuals fired a gun addressed a wide variety of weapons and cartridges. The weapon calibers investigated

were 0.22-caliber (108 firings), 0.25-caliber (18 firings), 0.38-caliber (74 firings), 0.44-caliber (5 firings), 0.45-caliber (83 firings), and 9 mm (83 firings).

Four occupational classifications were discerned among the handblanks. These included the following:

1. Class A, low Ba and low Sb (165 handlifts): Carpenters, accountants, TV technicians, secretaries, watch repairmen, gardeners, laboratory technicians, radioisotope technicians, theoretical chemists, photographers, electronics technicians, chauffeurs, electricians, computer operators, nurses, physicians, storekeepers.
2. Class B, high Ba and low Sb (38 handlifts): Plumbers, graphic artists, mechanics, draftsmen, heating and air-conditioning repairmen.
3. Class C, low Ba and high Sb (16 handlifts): Electronic assemblers.
4. Class D, high Ba and high Sb (41 handlifts): Auto mechanics, painters, machinists, maintenance men.

The samples were adequate, except for class C handblanks and 0.44-caliber firings, to define the desired probabilities. Given the occupational class and caliber of weapon involved, it is possible to evaluate the TNAA analysis of a handlift in terms of the probabilities that the Ba and Sb values represent a handblank, for example.

In view of the fact that there is a finite possibility of definitively detecting a firing in all classification combinations addressed (occupation and weapon caliber), and since the probability estimates derive from a large body of experimental data, this work has resulted in the best tool for the purpose available to the criminalist at this time.

The program involved the examination of related topics. The effect of wind velocity and direction was found to be noticable but not excessive. It was found that handling a fired and uncleaned weapon resulted in increased levels of Ba and Sb on the palms. In the absence of hand washing, gunshot residues were found to be detectable up to ~24 hours after firing a weapon; however, hand washing was found to remove most of the residues. Deposition of residues on hands and face was detected subsequent to rifle firing, but this subject was not extensively pursued. It was ascertained that most of the Ba and Sb residues derive from the presence of these elements in primers. It was shown that cartridges tagged with rare earth elements would provide improved probabilities of detecting gunshot residues.

These ancillary investigations were interesting and often suggestive of future improvements. However, with the successful establishment of TNAA as a useful tool to the criminalist for determining if a person fired a gun, the program's main goal was achieved.

1. INTRODUCTION

A recent federally sponsored report[17] reveals that over 9,000 suicides by firearms occur annually in this country. In general, no witnesses are available in such incidents and only physical evidence is available to the investigating officers.

The same report quotes a survey by the Chicago Police Department showing that in seventy-four percent of the homicides investigated in 1967, the victim was known to the attacker and the relationship between the individuals involved could be categorized under one of the following headings: "friends or acquaintances, spouse or lover, other family, neighbors, or business". In these cases, while both suspects and witnesses may be readily available to the investigating officers, verbal evidence may be lacking or equivocal. In both apparent suicides and homicides by acquaintances, an obvious need exists for a reliable method for determing whether or not an individual has recently fired a handgun. Mary Cowan[1] points out that one reason for the continuing use of the discredited diphenylamine test for residues in such cases is the need by investigating officers for the information supposedly provided by the method.

It is worthwhile to briefly examine the history of the diphenylamine test and one other proposed test intended to provide the same information. The purpose will be to gain an historical perspective of the problem.

The reaction of nitrates (both inorganic nitrates and as nitro groups in organic compounds) with solutions of sulfuric acid and diphenylamine to produce a blue color is well known. Its first use in the detection of powder residues is attributed by I. Castellanos[2] to his fellow worker, G. Iturrioz, in 1914. Since the acidic solution is quite strong, the reagent was actually applied to a paraffin cast which was then removed from the hand. The cast was formed by applying molten paraffin to the hand, then imbedding a piece of cloth in successive layers of paraffin until a self-supporting cast was formed which could be removed intact — (hence the name "paraffin test"). Both surfaces of the hand were sampled.

The procedure was first demonstrated in the United States in 1935 by T. Gonzalez (the name "Gonzalez Test" is found in some early references), a visiting Mexican criminalist.

In 1935, the Federal Bureau of Investigation[3] reported a list of eleven substances which gave positive results with the diphenylamine reagent. Inconclusive results from test firings were also reported. The occurrence of false positive and false negative results from the diphenylamine test have been reported after conscientous and well-controlled investigations.[1, 4, 5] In spite of this, the test is still performed in various crime laboratories in this country, although generally only for "investigative purposes".

Recognition of these shortcomings resulted in a new test developed by Harrison and Gilroy,[6] that depended on detection of metallic elements deposited on the hand by the discharge of a firearm. Antimony, barium, and lead were detected by spot tests with various chemical reagents. The three elements sought were chosen as being common constituents of primer material. In this test, residues were removed from the hand with a moist cloth and the reagents were then applied to the cloth.

While the published report indicates a high degree of success with test firings of revolvers, the test is rarely employed by criminalists. Private conversations with criminalists indicate that inconclusive results were obtained by some workers attempting to duplicate the published results. A source of inconsistency may be reflected in the fact that while Harrison and Gilroy report that residues are only infrequently deposited from discharge of automatic pistols, our results (reported below) show that

0.45-caliber automatics deposit as much or more residues than do 0.38-caliber revolvers. The authors do not state the calibers of the weapons employed in their work, nor do they include a table showing the results from all of the test firings done.

One explanation for the lack of success of this method is that it is qualitative in nature and depends on color tests for obtaining positive results. At the levels at which residues are deposited on the hand — about one microgram for barium and less for antimony — color tests are not, in general, reliable unless performed by relatively tedious techniques such as chemical microscopy.

It was due to the lack of a generally accepted method that Ruch, Guinn, and Pinker[7] developed the TNAA procedure described in Appendix 1. The applicability of this procedure has been the subject of further studies reported herein.

Much of the work on the present subject has been reported in detail during its progress,[11] and the first six years of effort has been summarized in detail.[12] Therefore, while this report treats all relevant aspects of the work, excessive repetition of details is avoided.

In all of the TNAA work, samples were activated in the TRIGA Mark I nuclear reactor, and the relevant radioisotopic analytical indicators formed during the activation were measured (usually after post-irradiation radiochemical separation) by multichannel gamma-ray spectrometry.

2. EXPERIMENTAL

2.1 REVIEW OF EARLIER WORK AND RESULTS

A number of criminalists, including R. H. Pinker (Chief Criminalist, Los Angeles Police Department, retired), indicated that a reliable gunshot residue test was highly necessary. The method of Harrison and Gilroy,[6] though sound in concept, proved disappointing in practice by virtue of limited analytical sensitivity. Inasmuch as TNAA has extremely great analytical sensitivity for at least two of the elements addressed in the Harrison and Gilroy method — namely, barium and antimony — there was ample reason to investigate this application of TNAA.

Early experiments confirmed the determination of gunshot residue elements in very dilute nitric acid washings of hands subsequent to 0.38-caliber revolver firings. In the first experiments, the hands were first washed and rinsed, and the hands were then rinsed with the dilute acid to provide the blank measurements. The acid contained 0.03 μg Sb, the pre-firing acid rinse contained 0.05 μg Sb, and the postfiring acid rinse contained 0.12 μg of Sb (the volume of acid being the same in all cases). Additional experiments showed that barium and copper could be detected, also; however, the latter element later proved to be of little use due to its large and widespread occurrence in handblanks.

The removal of gunshot residues from the hands was investigated. Reagents alternative to dilute nitric acid were tested as rinses, wipings with special papers (such as Whatman filter paper) and cotton swabs were were tried, and the more traditional paraffin handlift was tried. Of all methods, the last appeared to be the most satisfactory. Ordinary canning wax was found to have very little barium and antimony contamination, it stores well, and its application to the hand is simple and reproducible. It is easily removed from the hand and subsequently convenient to analyze.

Because of the sodium and chlorine content of perspiration, it is necessary to carry out postirradiation radiochemical separation procedures to prepare the analytical indicator radioisotopes of Ba and Sb for counting. The entire procedure finally devised, from the taking of handlifts through the analytical work, is described in the Appendix.

It was found that, in general, the Ba and Sb levels in most hand-blanks (handlifts from people who had not recently fired a gun) were $\sim$0.1 μg and $\sim$0.01 μg, respectively, and that the levels of these elements were about 10-fold higher in handlifts taken after firing a weapon. It was found that the gunshot residues were deposited mainly on the trigger finger and thumb web, with lesser amounts on the back of the hand and very little deposited on the palm. On the other hand, persons who did not fire, but handled, uncleaned weapons had increased levels of Ba and Sb on the palms of their hands — especially if they handled the barrel or chamber of the weapon. Considerably more residue was found on the barrel and chamber of fired weapons than on the handle. This may be due to the fact that the hand protects the handle from depositions during firing.

In addition to the foregoing, other parameters were also studied. Winds, at least of moderate velocity did not seem to drastically diminish the amounts of residue deposited. On the other hand, even casual washing of the hands after firings, decreased the levels of residue to levels found in handlifts from persons who had not recently fired a handgun.

An important finding was that successive firings of the same weapon did not lead to linearly increasing levels of residue. The only conclusion to be drawn from this fact is that successive firings tend to remove residue particles from the skin. In view of the results from firings in windy conditions, one must conclude that it is a shock effect of firing rather than the stream of residue laden gas that is the principal agent in removing previously deposited residue particles.

Another parameter studied was the time interval in which particles would reside on hands which were not washed. Studies showed residues persisting up to twenty-four hours, but at the end of that period, levels were quite near the levels usually associated with handblanks.

The last topic discussed in this section is the possibility of adding some unique component or mixture of components to handgun cartridges at the time of manufacture. The presence of the tagging components on the hands of a person would then be inexorably associated with the firing of a handgun.

In the Annual Reports for 1964 and 1965,[11] the feasibility of using rare earths, either singly or in combination, as tagging materials was discussed. Experiments were performed which convincingly demonstrated the soundness of the proposed technique. Recently, another group has verified the work,[18] and explored the economic considerations[19] associated with the implementation of the procedure.

At the present time there is no indication that tagging materials will be added to cartridges in the near future by any manufacturer. Even if a tagging program were instituted immediately by all U.S. manufacturers, untagged ammunition of prior production, and imported ammunition would remain in wide circulation.

2.2 LARGER STUDY OF HANDBLANKS AND FIRINGS

In all respects, results from the variety of earlier studies indicated the TNAA method for determining the presence of gunshot residue to be promising. It was decided that the actual utility of the method should be as rigorously defined as possible within the scope of a many-faceted program. As a preparation for the larger study, relevant questions were included in a questionnaire that was sent to each member of the California Association of Criminalists. The questions pertaining to firearms were as follows:

1. Of the analyses or examinations involving firearms residues or bullets, with which you have been involved, approximately what percentage were:

   a. automatic pistols ___
   b. revolvers ___
   c. rifles ___
   d. shotguns ___
   e. other ___

2. Of the revolver analyses or examinations, what was the approximate percentage of:

   a. 0.22 caliber ___
   b. 0.32 caliber ___
   c. 0.38 caliber ___
   d. 0.44 - 0.45 caliber ___
   e. other ___

3. Similarly, of the automatic pistol analyses or examinations, what was the approximate percentage of:

   a. 0.22 caliber ___
   b. 0.32 caliber ___
   c. 0.38 caliber ___
   d. other ___

The answers to the first question indicated revolvers to be most frequently involved (44%), followed by automatic pistols (33%), rifles (12%), shotguns (8%), and other (3%).

Obviously the most important categories are the handguns. Of these, 57% involve revolvers comprised of 0.22 caliber (21%), 0.32 caliber (4%), 0.38 caliber (19%), 0.44 - 0.45 caliber (6%), and other (7%). The 43% involvement of automatic pistols was comprised of 0.22 caliber (11%), 0.32 caliber (9%), 0.38 caliber (6%), 0.44 - 0.45 caliber (9%), and other (8%).

The category "other" included 9 mm and 0.25 calibers, and the 0.44 - 0.45 caliber category was dominated by the 0.45 caliber weapons. The ensuing work was planned to conform with these statistics on hand weapons. Other weapons were not to be studied in this larger work. Dr. C. R. Kingston, consultant to the Law Enforcement Assistance Administration, participated in the formulation of the plans.

In addition to the work of taking and analyzing handlifts from a large number of firings of various weapon-cartridge combinations, a large number of handblanks were to be analyzed. These were to be taken from persons in a wide variety of occupations so that a true representation of the Ba and Sb levels on the hands of persons who had not recently fired a weapon might be obtained. The subjects were not to wash their hands prior to application of the paraffin.

Another feature of the plan was that an appropriate method for the interpretation of the data should be developed. This would involve a consideration of the most appropriate statistical model, and the goal would be to allow a given handlift analysis to be interpreted as representing a firing or handblank with the greatest possible degree of confidence.

The plan was implemented, and the results are described in the following sections. The next section discusses the statistical considerations that initially evolved. Then the analytical results are presented, and the final few sections are devoted to the interpretation of the work.

As part of the study, some effort was directed toward the analysis of primers, which are the chief source of Ba and Sb in gunshot residues. This was done to elucidate any systematic effects of certain brands of ammunition on the amount of gunshot residues in handlifts.

3. THE BIVARIATE NORMAL STATISTICAL MODEL

Wide variations are found in the amounts of barium and antimony present in handlifts obtained from individuals who have not recently fired a handgun. Repetitive firings of the same combination of weapon and ammunition deposit amounts of these two elements on the firing hand which fluctuate over far greater ranges than can be ascribed to random errors of the analytical procedure. It was natural to use the well-developed methods of statistical analysis to help interpret the results obtained, and then to use probablistic methods to assess the success of the neutron activation analysis method in correctly identifying the sources of particular samples.

A relatively sophisticated approach to these problems was used which is new to the criminalistics literature. Consideration of some practical problems are included where they influence the statistical model.

Inspection of the results obtained from the analysis of many sets of results revealed an apparent log-normal distribution of the values. The log-normal distribution differs from the normal, or Gaussian, distribution in that the logarithms are used throughout this study, whereas natural (Naperian) logarithms are often used in other applications.

Log-normal distributions are common in nature. The essential features can be described in terms of one well-known example, the distribution of barnacles on a piling. There is some point P on a piling above which no barnacles can be found. Below this point the density of barnacles rises rapidly to a maximum. Further down the piling the density decreases, but some individuals can be found quite far below the point of maximum density. If the distribution is drawn, plotting the logarithm of the random variable (depth of the barnacles below P) as the abcissa, the resulting curve would have the familiar bell shape of the normal distribution.

Since both barium and antimony are intimately mixed in primer formulations, in proportions which are held within certain tolerances by the manufacturer, it would be expected that when large numbers of results from firings are inspected, high levels of one element would be associated with high levels of the other. On the other hand, when results from hand-blanks are inspected where no occupational exposure to both elements is present, there should be little relationship between the barium and antimony values. A scheme for interpreting the results should consider both the absolute levels of the two elements and their ratio.

The bivariate normal distribution is a well-known probabilistic model often used to analyze such data. A central feature of this model is the density function used to represent a given group of data. Suppose that perpendicular coordinate axes are drawn, and that the logarithm of the barium level in a handlift is measured along one axis, while the logarithm of the amount of antimony is measured along the other. The the analysis of each handlift can be associated with a certain point in the coordinate plane. The bivariate normal density function used to approximate the distribution of the data looks somewhat like a London policeman's hat resting on the plane. The values of the function (i.e., height of the hat) over a small region of the plane are approximately proportional to the probability that a data point from the group will occur in this region. Slices through the surface parallel to the plane are ellipses. All of the points on the plane below a given ellipse represent combinations of barium and antimony levels that occur with equal frequency in the group. Slices near the brim are large and enclose most of the data points; slices near the crown are small, but enclose the most frequently occurring combinations. The center of the crown is over the point defined by the average of the logarithms of barium and antimony values for the set of data being analyzed.

The location and shape of the density function are determined by five parameters. These are the average logarithms of the amounts of barium and antimony, the variances (a measure of spread, or dispersion, equal to the square of the standard deviation) of the logarithms, and the coefficient of correlation (a measure of the association) between the logarithms. Although these parameters can never be measured or calculated exactly, they can be estimated readily from the data.

A convenient way to represent these three-dimensional surfaces on a flat piece of paper is simply to draw the outlines of successive ellipses, labeling each with the percentage of observations estimated from the model to lie inside of the ellipse. Many such figures accompany this report, for example see Fig. 1.

After it is shown that the probabilistic model is an adequate representation of the analytical results the information provided by the model can be used to help determine the origin of a particular combination of barium and antimony values which may have originated from two alternative sources. For example, the known facts in a particular case may be that an apparent suicide was committed with a 0.45 caliber automatic and that the individual involved had an occupation that did not reveal high barium or antimony levels when surveyed.

The analytical results obtained from a handlift removed from the victim would then be compared with plots of the density function for the two appropriate sets of data. If the results fell in an area with a high frequency-of-occurrence for firings and a low frequency-of-occurrence for nonfirings it would indicate that the individual had indeed committed suicide.

A more quantitative method of interpreting the results can be used. It is derived from the field of statistics and falls in the category of "hypothesis testing". When it is employed, numerical values can be assigned to the probabilities that a given pair of barium and antimony values do or do not belong to (have a similar history as) two sets of analytical results.

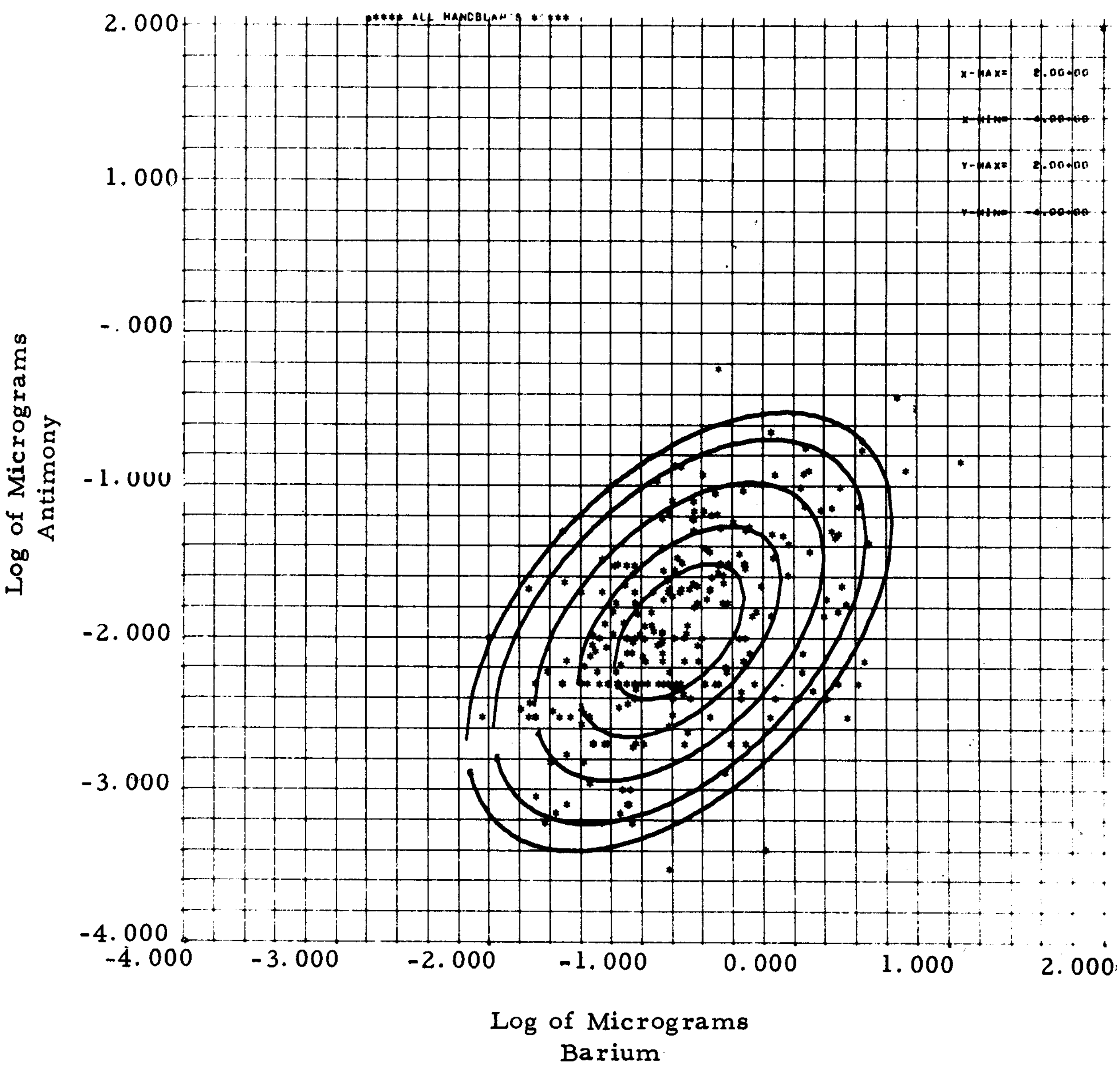


Fig. 1

Plot of Logarithms of Results Obtained from All Handblanks Analyzed, and Associated Solutions of the Bivariate Normal Density Function

It is assumed that the population of all measurements that might occur can be subdivided into several groups, and that, in turn, the variability within each group can be represented by means of a bivariate normal distribution for some particular choice of the five parameters described above. These subpopulations are chosen to represent test firings with various types of weapons and handblanks from individuals in various occupational-environmental categories.

In any actual case in which this procedure might be used as a guide, the type of weapon involved and the background of any suspect would, in general, be known. Thus, the problem is one of discriminating between two hypothesis: the null hypothesis (H_0) that the amount of Ba and Sb found on a suspects' hand(s) can be explained as a handblank from his environmental category, versus the alternative hypothesis (H_1) that the observation resulted from the suspect having recently fired a given type of weapon. Naturally, one seeks to control the probability of both types of error which could result from making a wrong decision.

Of the several approaches to controlling these error probabilities, one that seems reasonable is to fix an upper bound α (e.g., $\alpha = 0.01$) on the probability of obtaining a false positive (rejecting H_0 when it is true), and then minimize the probability of a false negative (accepting H_0 when it is false). It can be shown that this leads to the test (for the ideal case in which all parameters are known):

reject H_0 if and only if

$$f_0(X)/f_1(X) < k \quad ,$$

where X is the observed point, f_i is the bivariate normal density specified by H_i, and k is determined by α and the parameters of the two densities. The inequality divides the coordinate plane into two regions, so that the decision procedure could be automated by preparing a set of graphs, one for each possible pair of hypotheses. In an actual case, the appropriate graph could be selected and the value of the observation would then determine into which region (accept H_0 or reject H_0) it falls.

As one would expect, the sensitivity of the decision procedure decreases as the uncertainty in the subpopulation parameters increases. However, it is always possible, within the content of the assumed model, to quantitatively assess the probabilities of committing the two types of errors.

In regard to the estimation of probabilities for the barium and antimony data, it can be readily understood that the failure of the method to correctly identify the source of a particular sample may lead to drastic results. It may result in a guilty person escaping justice or an innocent one unjustly incarcerated. To prevent either eventuality the "odds" should be made as large as possible. That is, the arbitrarily chosen probability of making one of the assignments incorrectly should be small. The potential value of the procedure is indicated by the probability (denoted by α) that a handblank sample from a given category would be erroneously interpreted as a specified type of firing and also the probability (denoted by β) that the Ba and Sb levels in a sample from a hand which had recently fired a specified type of weapon would be incorrectly interpreted as a handblank from a given category. It should be mentioned that this procedure is optimal for deciding between the two hypotheses in question, i.e., no other procedure has both a smaller α and a smaller β.

As will be shown in the section, "Statistical Treatment of the Data", an alternative method of describing probabilities based on BVN statistics was suggested by the data.[21]

4. TABULATION OF THE DATA

Tables 1 - 5 inclusive contain the data used in the statistical evaluation of the method. Some results were omitted from these tables as not being of interest. These include blank determinations, at least one of which was included with every set of samples irradiated. Samples irradiated and analyzed in connection with actual crimes are also not included, except for a few instances where test firings were performed to assist in the interpertation of test results. A third class of samples, hand sampled after firing with the other hand, are not included. In many instances, these samples were taken as controls. As this report was being written it was discovered that one page of computer output had not been produced. These data are given in Table 5 Supplement. Thus altogether the tables list 260 handblanks and 353 firings.

The same format is used in each of these tables. The data is entered in roughly chronological order by sample number. In much of the early data parameters later found of interest, such as barrel lengths, were not recorded. This information is listed as "UNK". The tables were produced from computer output and some of the entries require explanation.

In the column headed Caliber, the entry 38INS means 0. 38 caliber; similarly 9MM means 9 millimeter.

The barrel lengths were measured to the nearest half-inch, from the tip of the muzzle to the rear of the barrel. This practice is inconsistent, in that cartridges are chambered in the barrels of automatic pistols and in the cylinders of revolvers. However, in practice the functioning of the two types of weapons is so different that results obtained from one should not be compared with that obtained from the other, regardless of barrel length.

Table 1

CLASS A HANDBLANKS

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
1	LAPD	R	UNK	0	0 INS	****	****	**********	.1400	-.0000	.0600	-.0000
2	LAPD	L	UNK	0	0 INS	****	****	**********	.2200	-.0000	.0600	-.0000
3	LAPD	R	UNK	0	0 INS	****	****	**********	.3200	-.0000	.0300	-.0000
4	LAPD	L	UNK	0	0 INS	****	****	**********	.1900	-.0000	.0100	-.0000
5	LAPD	R	UNK	0	0 INS	****	****	**********	.0300	-.0000	.0500	-.0000
6	LAPD	L	UNK	0	0 INS	****	****	**********	.0400	-.0000	.0050	-.0000
7	LAPD	R	UNK	0	0 INS	****	****	**********	.1600	-.0000	.0200	-.0000
8	LAPD	L	UNK	0	0 INS	****	****	**********	.1200	-.0000	.0200	-.0000
9	LAPD	R	UNK	0	0 INS	****	****	**********	.4800	-.0000	.0100	-.0000
10	LAPD	L	UNK	0	0 INS	****	****	**********	.4400	-.0000	.0100	-.0000
11	LAPD	R	UNK	0	0 INS	****	****	**********	.1800	-.0000	.0050	-.0000
12	LAPD	L	UNK	0	0 INS	****	****	**********	.3200	-.0000	.0050	-.0000
13	LAPD	R	UNK	0	0 INS	****	****	**********	.0700	-.0000	.0050	-.0000
14	LAPD	L	UNK	0	0 INS	****	****	**********	.0200	-.0000	.0050	-.0000
15	LAPD	R	UNK	0	0 INS	****	****	**********	.0300	-.0000	.0050	-.0000
16	LAPD	L	UNK	0	0 INS	****	****	**********	.0300	-.0000	.0050	-.0000
17	LAPD	R	UNK	0	0 INS	****	****	**********	.1700	-.0000	.0050	-.0000
18	LAPD	L	UNK	0	0 INS	****	****	**********	.0600	-.0000	.0050	-.0000
19	LAPD	R	UNK	0	0 INS	****	****	**********	.0900	-.0000	.0300	-.0000
20	LAPD	L	UNK	0	0 INS	****	****	**********	.0700	-.0000	.0050	-.0000
21	LAPD	R	UNK	0	0 INS	****	****	**********	.1500	-.0000	.0050	-.0000
22	LAPD	L	UNK	0	0 INS	****	****	**********	.0700	-.0000	.0050	-.0000
23	LAPD	R	UNK	0	0 INS	****	****	**********	.0400	-.0000	.0200	-.0000

Table 1 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
24	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0100	-.0000	.0100	-.0000
25	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.2200	-.0000	.0800	-.0000
26	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0600	-.0000	.0100	-.0000
27	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.0300	-.0000	.0050	-.0000
28	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0400	-.0000	.0050	-.0000
29	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.0900	-.0000	.0050	-.0000
30	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0800	-.0000	.0300	-.0000
31	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.2600	-.0000	.0050	-.0000
32	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0900	-.0000	.0200	-.0000
33	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.1100	-.0000	.0050	-.0000
34	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0600	-.0000	.0050	-.0000
35	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.1000	-.0000	.0050	-.0000
36	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0800	-.0000	.0050	-.0000
37	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.2600	-.0000	.0050	-.0000
38	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.1300	-.0000	.0050	-.0000
39	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.1500	-.0000	.0200	-.0000
40	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.2500	-.0000	.0100	-.0000
41	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.0900	-.0000	.0050	-.0000
42	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0900	-.0000	.0100	-.0000
43	LAPD	R	UNK	0	0 INS	••••	••••	••••••••••	.0700	-.0000	.0050	-.0000
44	LAPD	L	UNK	0	0 INS	••••	••••	••••••••••	.0200	-.0000	.0050	-.0000
121	CARPENTER	R	UNK	0	0 INS	••••	••••	••••••••••	.3100	-.0000	.0900	-.0000
122	CARPENTER	L	UNK	0	0 INS	••••	••••	••••••••••	.2900	-.0000	.0650	-.0000

Table 1 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
123	CARPENTER	R	UNK	0	0 INS	••••	••••	••••••••••	.4040	-.0000	.0580	-.0000
124	CARPENTER	L	UNK	0	0 INS	••••	••••	••••••••••	.2640	-.0000	.0390	-.0000
125	STOREKEEPER	R	UNK	0	0 INS	••••	••••	••••••••••	.1270	-.0000	.1100	-.0000
126	STOREKEEPER	L	UNK	0	0 INS	••••	••••	••••••••••	.1610	-.0000	.1350	-.0000
127	PUB. ACCT.	R	UNK	0	0 INS	••••	••••	••••••••••	.0910	-.0000	.0020	-.0000
128	PUB. ACCT.	L	UNK	0	0 INS	••••	••••	••••••••••	.1030	-.0000	.0020	-.0000
129	TV. TECH.	R	UNK	0	0 INS	••••	••••	••••••••••	.0470	-.0000	.0020	-.0000
130	TV. TECH.	L	UNK	0	0 INS	••••	••••	••••••••••	.0570	-.0000	.0020	-.0000
131	SECRETARY	R	UNK	0	0 INS	••••	••••	••••••••••	.1370	-.0000	.0110	-.0000
132	SECRETARY	L	UNK	0	0 INS	••••	••••	••••••••••	.0680	-.0000	.0060	-.0000
137	WATCH REP.	R	UNK	0	0 INS	••••	••••	••••••••••	.2190	-.0000	.0510	-.0000
138	WATCH REP.	L	UNK	0	0 INS	••••	••••	••••••••••	.2810	-.0000	.0030	-.0000
139	GARDENER	R	UNK	0	0 INS	••••	••••	••••••••••	.2190	-.0000	.0230	-.0000
140	GARDENER	L	UNK	0	0 INS	••••	••••	••••••••••	.2670	-.0000	.0180	-.0000
143	STU-LAB TECH	R	UNK	0	0 INS	••••	••••	••••••••••	.1160	-.0000	.0120	-.0000
144	STU-LAB TECH	L	UNK	0	0 INS	••••	••••	••••••••••	.0590	-.0000	.0020	-.0000
145	STU-LAB TECH	R	UNK	0	0 INS	••••	••••	••••••••••	2.6800	-.0000	.0740	-.0000
146	STU-LAB TECH	L	UNK	0	0 INS	••••	••••	••••••••••	.3460	-.0000	.0230	-.0000
147	PHOTOGRAPHER	R	UNK	0	0 INS	••••	••••	••••••••••	.2200	-.0000	.0690	-.0000
148	PHOTOGRAPHER	L	UNK	0	0 INS	••••	••••	••••••••••	.2570	-.0000	.0690	-.0000
149	RADISO. TECH	R	UNK	0	0 INS	••••	••••	••••••••••	.6120	-.0000	.0220	-.0000
150	RADISO. TECH	L	UNK	0	0 INS	••••	••••	••••••••••	.2000	-.0000	.0120	-.0000
151	RADISO. TECH	R	UNK	0	0 INS	••••	••••	••••••••••	.0680	-.0000	.0170	-.0000

Table 1 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
152	RADISO. TECH	L	UNK	0	0 INS	••••	••••	••••••••••	.0550	-.0000	.0200	-.0000
153	RADISO. TECH	R	UNK	0	0 INS	••••	••••	••••••••••	.0550	-.0000	.0330	-.0000
154	RADISO. TECH	L	UNK	0	0 INS	••••	••••	••••••••••	.0450	-.0000	.0030	-.0000
161	THEO. CHEM.	R	UNK	0	0 INS	••••	••••	••••••••••	.1190	.0090	.0110	.0010
162	THEO. CHEM.	L	UNK	0	0 INS	••••	••••	••••••••••	.0800	.0100	.0080	.0009
167	ELECTRON TEC	R	NO	0	0 INS	••••	••••	••••••••••	.1470	.0090	.0240	.0020
168	ELECTRON TEC	L	NO	0	0 INS	••••	••••	••••••••••	.0900	.0100	.0170	.0020
169	SECRETARY	R	UNK	0	0 INS	••••	••••	••••••••••	.2080	.0060	.0040	.0010
170	SECRETARY	L	UNK	0	0 INS	••••	••••	••••••••••	.1520	.0060	.0060	.0010
185	CARPENTER	R	NO	0	0 INS	••••	••••	••••••••••	.2140	.0060	.0620	.0060
186	CARPENTER	L	NO	0	0 INS	••••	••••	••••••••••	.1620	.0060	.0210	.0010
189	CARPENTER	R	UNK	0	0 INS	••••	••••	••••••••••	.3400	.0200	.0170	.0010
190	CARPENTER	L	UNK	0	0 INS	••••	••••	••••••••••	.2300	.0200	.0170	.0010
191	CARPENTER	R	NO	0	0 INS	••••	••••	••••••••••	.2900	.0060	.0250	.0010
192	CARPENTER	L	NO	0	0 INS	••••	••••	••••••••••	.3330	.0060	.0310	.0010
193	CARPENTER	R	NO	0	0 INS	••••	••••	••••••••••	.1580	.0040	.0190	.0010
194	CARPENTER	L	NO	0	0 INS	••••	••••	••••••••••	.1900	.0050	.0070	.0010
195	CHAUFFEUR	R	NO	0	0 INS	••••	••••	••••••••••	.0970	.0070	.0106	.0008
196	CHAUFFEUR	L	NO	0	0 INS	••••	••••	••••••••••	.0870	.0070	.0094	.0009
197	CARPENTER	R	UNK	0	0 INS	••••	••••	••••••••••	.1370	.0050	.0070	.0010
198	CARPENTER	L	UNK	0	0 INS	••••	••••	••••••••••	.1370	.0050	.0080	.0010
199	CHAUFFEUR	R	NO	0	0 INS	••••	••••	••••••••••	.1390	.0060	.0280	.0020
200	CHAUFFEUR	L	NO	0	0 INS	••••	••••	••••••••••	.1520	.0070	.0210	.0020

Table 1 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
203	ELECTRICIAN	R	UNK	0	0 INS	....	....	....	.5100	.0100	.0540	.0020
204	ELECTRICIAN	L	UNK	0	0 INS	....	....	....	.4700	.0100	.0940	.0020
245	COMPUT. OPER	R	UNK	0	0 INS	....	....	....	.1020	.0070	.0076	.0008
246	COMPUT. OPER	L	UNK	0	0 INS	....	....	....	.0410	.0050	.0015	.0009
247	COMPUT. OPER	R	NO	0	0 INS	....	....	....	.0400	.0030	.0027	.0008
248	COMPUT. OPER	L	NO	0	0 INS	....	....	....	.0710	.0040	.0035	.0008
249	COMPUT. OPER	R	NO	0	0 INS	....	....	....	.0320	.0060	.0017	.0008
250	COMPUT. OPER	L	NO	0	0 INS	....	....	....	.0250	.0050	.0015	.0007
251	COMPUT. OPER	R	NO	0	0 INS	....	....	....	.1920	.0060	.0020	.0020
252	COMPUT. OPER	L	NO	0	0 INS	....	....	....	.1680	.0060	.0049	.0008
253	COMPUT. OPER	R	UNK	0	0 INS	....	....	....	.0450	.0030	.0011	-.0000
254	COMPUT. OPER	L	UNK	0	0 INS	....	....	....	.0320	.0030	.0008	-.0000
255	COMPUT. OPER	R	UNK	0	0 INS	....	....	....	.0730	.0050	.0067	-.0000
256	COMPUT. OPER	L	UNK	0	0 INS	....	....	....	.0620	.0100	.0006	-.0000
257	NURSE	R	UNK	0	0 INS	....	....	....	.1050	.0030	.0120	.0010
258	NURSE	R	UNK	0	0 INS	....	....	....	.0320	.0030	.0070	.0010
259	NURSE	L	UNK	0	0 INS	....	....	....	.0480	.0020	.0020	.0006
260	NURSE	R	NO	0	0 INS	....	....	....	.0800	.0040	.0008	-.0000
261	NURSE	L	NO	0	0 INS	....	....	....	.0910	.0030	.0046	.0009
262	NURSE	R	UNK	0	0 INS	....	....	....	.0260	.0020	.0033	.0006
263	NURSE	L	UNK	0	0 INS	....	....	....	.0230	.0020	.0006	-.0000
264	NURSE	R	NO	0	0 INS	....	....	....	.0720	.0040	.0007	-.0000
265	NURSE	L	NO	0	0 INS	....	....	....	.0650	.0040	.0107	.0007

Table 1 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
266	NURSE	R	NO	0	0 INS	••••	••••	••••••••••	.0270	.0030	.0007	-.0000
267	NURSE	L	NO	0	0 INS	••••	••••	••••••••••	.0200	.0030	.0009	-.0000
268	PATHOLOGIST	R	NO	0	0 INS	••••	••••	••••••••••	.0860	.0030	.0006	-.0000
269	PATHOLOGIST	L	NO	0	0 INS	••••	••••	••••••••••	.1050	.0040	.0100	.0007
270	PATHOLOGIST	R	NO	0	0 INS	••••	••••	••••••••••	.0410	.0040	.0032	.0008
271	PATHOLOGIST	L	NO	0	0 INS	••••	••••	••••••••••	.0160	.0020	.0034	.0007
272	PATHOLOGIST	L	UNK	0	0 INS	••••	••••	••••••••••	.1590	.0030	.0048	.0007
273	RADIOLOGIST	R	NO	0	0 INS	••••	••••	••••••••••	.2000	.0040	.0024	.0006
274	RADIOLOGIST	L	NO	0	0 INS	••••	••••	••••••••••	.1870	.0050	.0043	.0007
275	SURGEON	R	NO	0	0 INS	••••	••••	••••••••••	.0310	.0030	.0235	.0009
276	SURGEON	L	NO	0	0 INS	••••	••••	••••••••••	.0480	.0030	.0104	.0009
277	LAB. TECH.	R	NO	0	0 INS	••••	••••	••••••••••	.0540	.0030	.0006	-.0000
360	POLICE DEPT.	R	UNK	0	0 INS	••••	••••	••••••••••	.0811	.0040	.0037	.0008
361	DEP DIST ATT	L	UNK	0	0 INS	••••	••••	••••••••••	.0879	.0047	.0019	.0009
362	CRIMINALIST	R	UNK	0	0 INS	••••	••••	••••••••••	.0418	.0039	.0065	.0009
363	POLICE DEPT.	L	UNK	0	0 INS	••••	••••	••••••••••	.0461	.0062	.0076	.0009
364	TREAS. DEPT.	R	UNK	0	0 INS	••••	••••	••••••••••	.4570	.0090	.0044	.0011
365	POLICE DEPT.	L	UNK	0	0 INS	••••	••••	••••••••••	.0588	.0060	.0087	.0010
366	PROFESSOR	R	UNK	0	0 INS	••••	••••	••••••••••	.0185	.0070	.0037	.0012
367	INVESTIGATOR	L	UNK	0	0 INS	••••	••••	••••••••••	.0576	.0141	.0125	.0014
607	HOUSEWIFE	L	NO	0	0 INS	••••	••••	••••••••••	.0240	.0020	.0060	-.0000
608	HOUSEWIFE	R	NO	0	0 INS	••••	••••	••••••••••	.0900	.0030	.0040	-.0000
609	HOUSEWIFE	L	NO	0	0 INS	••••	••••	••••••••••	.1390	.0030	.0050	-.0000

Table 1 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
610	HOUSEWIFE	R	YES	0	0 INS	....	....	....	.0800	.0030	.0100	.0020
611	HOUSEWIFE	L	YES	0	0 INS	....	....	....	.0510	.0030	.0060	-.0000
612	HOUSEWIFE	R	YES	0	0 INS	....	....	....	.0440	.0040	.0050	-.0000
613	HOUSEWIFE	L	YES	0	0 INS	....	....	....	.0340	.0020	.0030	-.0000
614	TEACHER	R	YES	0	0 INS	....	....	....	.0200	.0030	.0030	-.0000
615	TEACHER	L	YES	0	0 INS	....	....	....	.0290	.0030	.0030	-.0000
616	HOUSEWIFE	R	YES	0	0 INS	....	....	....	.0180	.0020	.0030	-.0000
617	HOUSEWIFE	L	YES	0	0 INS	....	....	....	.0200	.0030	.0030	-.0000
618	HOUSEWIFE	R	YES	0	0 INS	....	....	....	.0090	.0020	.0030	-.0000
619	HOUSEWIFE	L	YES	0	0 INS	....	....	....	.0450	.0030	.0030	-.0000
620	HOUSEWIFE	R	NO	0	0 INS	....	....	....	.0670	.0040	.0300	.0030
621	HOUSEWIFE	L	NO	0	0 INS	....	....	....	.0180	.0020	.0210	.0020
622	TYPIST	R	NO	0	0 INS	....	....	....	.6480	.0090	.0004	.0001
623	TYPIST	L	NO	0	0 INS	....	....	....	.7120	.0090	.2320	.0020
624	TYPIST	R	YES	0	0 INS	....	....	....	.1510	.0040	.0003	.0001
625	TYPIST	L	YES	0	0 INS	....	....	....	.1390	.0030	.0180	.0005
626	EDITOR	R	NO	0	0 INS	....	....	....	.0480	.0020	.0020	-.0000
627	EDITOR	L	NO	0	0 INS	....	....	....	.1060	.0020	.0070	-.0000
628	LIBRARIAN	R	NO	0	0 INS	....	....	....	.0740	.0030	.0010	-.0000
629	LIBRARIAN	L	NO	0	0 INS	....	....	....	.1170	.0050	.0150	.0010
630	TYPIST	R	NO	0	0 INS	....	....	....	.7030	.0070	.0030	-.0000
631	TYPIST	L	NO	0	0 INS	....	....	....	1.1600	.0100	.0080	.0010
632	TYPIST	R	YES	0	0 INS	....	....	....	2.2300	.0100	.0030	.0010

Table 1 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
633	TYPIST	L	YES	0	0 INS	....	....	....	2.8900	.0300	.0070	.0010
634	[illegible]	R	YES	0	0 INS	....	....	....	.1600	.0050	.0040	.0010
635	EDITOR	L	YES	0	0 INS	....	....	....	.0830	.0030	.0010	-.0000
636	LIBRARIAN	R	YES	0	0 INS	....	....	....	.0526	.0030	.0050	.0010

Table 2

CLASS B HANDBLANKS

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
141	HEAT.AIR REP	R	UNK	0	0 INS	....	....	....	1.2800	-.0000	.0370	-.0000
142	HEAT.AIR REP	L	UNK	0	0 INS	....	....	....	1.1600	-.0000	.0740	-.0000
157	PLUMBER	R	UNK	0	0 INS	....	....	....	.0497	.0039	.0082	.0008
160	GRAPHIC ART.	R	UNK	0	0 INS	....	....	....	.7310	.0160	.0339	.0012
163	PLUMBER	R	NO	0	0 INS	....	....	....	1.6500	.0200	.0180	.0010
164	PLUMBER	L	NO	0	0 INS	....	....	....	2.1900	.0300	.0168	.0009
165	PLUMBER	R	UNK	0	0 INS	....	....	....	.4800	.0200	.0520	.0020
166	PLUMBER	L	UNK	0	0 INS	....	....	....	.8600	.0500	.0470	.0020
171	GRAPHIC ART.	R	NO	0	0 INS	....	....	....	.3620	.0040	.0060	.0010
172	GRAPHIC ART.	L	NO	0	0 INS	....	....	....	.3530	.0050	.0013	-.0000
173	GRAPHIC ART.	R	YES	0	0 INS	....	....	....	1.1400	.0100	.0060	.0010
174	GRAPHIC ART.	L	YES	0	0 INS	....	....	....	2.6100	.0200	.0050	.0010
175	GRAPHIC ART.	R	UNK	0	0 INS	....	....	....	1.9500	.0200	.0050	.0009
176	GRAPHIC ART.	L	UNK	0	0 INS	....	....	....	1.5700	.0200	.0140	.0010
177	GRAPHIC ART.	R	NO	0	0 INS	....	....	....	.7520	.0070	.0040	.0010
178	GRAPHIC ART.	L	NO	0	0 INS	....	....	....	.3600	.0050	.0064	.0009
179	GRAPHIC ART.	R	NO	0	0 INS	....	....	....	.5500	.0100	.0050	.0010
180	GRAPHIC ART.	L	NO	0	0 INS	....	....	....	.5090	.0060	.0080	-.0000
181	GRAPHIC ART.	R	UNK	0	0 INS	....	....	....	.4830	.0060	.0020	.0010
182	GRAPHIC ART.	L	UNK	0	0 INS	....	....	....	1.3400	.0100	.0045	.0009
183	GRAPHIC ART.	R	YES	0	0 INS	....	....	....	.2310	.0040	.0090	.0010
184	GRAPHIC ART.	L	YES	0	0 INS	....	....	....	.2350	.0050	.0070	.0010
187	MECHANIC	R	NO	0	0 INS	....	....	....	1.9600	.0300	.0490	.0010

Table 2 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
[illegible]	MECHANIC	L	NO	0	0 INS	••••	••••	••••••••••	1.8500	.0200	.0460	.0010
213	DRAFTING	R	NO	0	0 INS	••••	••••	••••••••••	.7100	.0040	.0140	.0020
214	DRAFTING	L	NO	0	0 INS	••••	••••	••••••••••	.0860	.0040	.0080	.0010
215	DRAFTING	R	NO	0	0 INS	••••	••••	••••••••••	.1350	.0040	.0092	.0009
216	DRAFTING	L	NO	0	0 INS	••••	••••	••••••••••	.1270	.0050	.0090	.0010
217	DRAFTING	R	NO	0	0 INS	••••	••••	••••••••••	.5400	.0100	.0140	.0010
218	DRAFTING	L	NO	0	0 INS	••••	••••	••••••••••	.4700	.0080	.0070	.0010
219	DRAFTING	R	UNK	0	0 INS	••••	••••	••••••••••	.1710	.0040	.0340	.0020
220	DRAFTING	L	UNK	0	0 INS	••••	••••	••••••••••	.2200	.0060	.0160	.0010
221	DRAFTING	R	UNK	0	0 INS	••••	••••	••••••••••	1.6700	.0100	.0040	.0010
222	DRAFTING	L	UNK	0	0 INS	••••	••••	••••••••••	1.6400	.0100	.0040	.0010
223	DRAFTING	R	UNK	0	0 INS	••••	••••	••••••••••	.1590	.0050	.0810	.0020
224	DRAFTING	L	UNK	0	0 INS	••••	••••	••••••••••	.1670	.0050	.1360	.0030
225	DRAFTING	R	NO	0	0 INS	••••	••••	••••••••••	.1650	.0050	.0100	.0010
226	DRAFTING	L	NO	0	0 INS	••••	••••	••••••••••	.3730	.0060	.0310	.0020

Table 3

CLASS C HANDBLANKS

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
809	ELEC. ASMBLR	R	YES	0	0 INS	....	....	....	.0761	.0041	.0127	.0014
810	ELEC. ASMBLR	R	NO	0	0 INS	....	....	....	.1650	.0071	.0314	.0018
811	ELEC. ASMBLR	L	NO	0	0 INS	....	....	....	.3160	.0110	.0661	.0022
812	ELEC. ASMBLR	R	NO	0	0 INS	....	....	....	.0522	.0031	.0100	.0020
813	ELEC. ASMBLR	L	NO	0	0 INS	....	....	....	.0703	.0037	.0306	.0017
814	ELEC. FBRCTR	R	NO	0	0 INS	....	....	....	.9360	.0120	.0420	.0017
815	ELEC. FBRCTR	L	NO	0	0 INS	....	....	....	.3300	.0061	.0532	.0018
816	ELEC. FBRCTR	R	YES	0	0 INS	....	....	....	.0771	.0068	.0222	.0014
817	ELEC. FBRCTR	L	YES	0	0 INS	....	....	....	.0647	.0053	.0150	.0012
818	ELEC. FBRCTR	R	NO	0	0 INS	....	....	....	.1370	.0062	.0395	.0016
819	ELEC. FBRCTR	L	NO	0	0 INS	....	....	....	.1520	.0062	.0656	.0023
820	ELEC. ENGNR	R	YES	0	0 INS	....	....	....	.0940	.0075	.0144	.0009
821	ELEC. ENGNR	L	YES	0	0 INS	....	....	....	.0970	.0057	.0089	.0012
822	ELEC. TCHNCN	R	NO	0	0 INS	....	....	....	.3240	.0087	.0272	.0012
823	ELEC. TCHNCN	L	NO	0	0 INS	....	....	....	.1970	.0069	.0108	.0000
834	ELEC. ASMBLR	L	YES	0	0 INS	....	....	....	.0677	.0061	.0263	.0015

Table 4

CLASS D HANDBLANKS

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
116	PAINTER	R	UNK	0	0 INS	••••	••••	••••••••••	.4530	-.0000	.0040	-.0000
117	PAINTER	L	UNK	0	0 INS	••••	••••	••••••••••	.3650	-.0000	.0020	-.0000
118	PAINTER	R	UNK	0	0 INS	••••	••••	••••••••••	.4810	-.0000	.0310	-.0000
119	PAINTER	L	UNK	0	0 INS	••••	••••	••••••••••	.3030	-.0000	.0050	-.0000
120	PAINTER	L	UNK	0	0 INS	••••	••••	••••••••••	.4720	-.0000	.0310	-.0000
133	AUTO MECH.	R	UNK	0	0 INS	••••	••••	••••••••••	1.7800	-.0000	.0510	-.0000
237	MACHINIST	R	NO	0	0 INS	••••	••••	••••••••••	12.1000	.0800	.1450	.0020
238	MACHINIST	L	NO	0	0 INS	••••	••••	••••••••••	5.2800	.0500	.1280	.0020
239	MACHINIST	R	NO	0	0 INS	••••	••••	••••••••••	.2620	.0090	.0210	.0010
240	MACHINIST	L	NO	0	0 INS	••••	••••	••••••••••	.4400	.0100	.0360	.0010
241	MACHINIST	R	NO	0	0 INS	••••	••••	••••••••••	.3700	.0070	.0170	.0010
242	MACHINIST	L	NO	0	0 INS	••••	••••	••••••••••	.2040	.0070	.0210	.0010
243	MACHINIST	R	UNK	0	0 INS	••••	••••	••••••••••	.1600	.0200	.0031	.0008
244	MACHINIST	L	UNK	0	0 INS	••••	••••	••••••••••	.1500	.0100	.0026	.0008
134	AUTO MECH.	L	UNK	0	0 INS	••••	••••	••••••••••	2.7800	-.0000	.1740	-.0000
135	AUTO MECH.	R	UNK	0	0 INS	••••	••••	••••••••••	4.7000	-.0000	.3830	-.0000
136	AUTO MECH.	L	UNK	0	0 INS	••••	••••	••••••••••	2.8000	-.0000	.1980	-.0000
155	PAINTER	R	UNK	0	0 INS	••••	••••	••••••••••	.2810	.0310	.0208	.0012
156	PAINTER	R	UNK	0	0 INS	••••	••••	••••••••••	.1360	.0058	.0095	.0008
158	MACHINIST	R	UNK	0	0 INS	••••	••••	••••••••••	3.1000	.0320	.0427	.0012
159	MACHINIST	R	UNK	0	0 INS	••••	••••	••••••••••	.1350	.0053	.0108	.0012
201	PAINTER	R	UNK	0	0 INS	••••	••••	••••••••••	.4810	.0090	.0290	.0020
202	PAINTER	L	UNK	0	0 INS	••••	••••	••••••••••	.7200	.0100	.0490	.0020

Table 4 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
205	MAINTENANCE	R	NO	0	0 INS	....	....	....	.2300	.0100	.0220	.0020
206	MAINTENANCE	L	NO	0	0 INS	....	....	....	.2800	.0200	.0370	.0020
207	MAINTENANCE	R	UNK	0	0 INS	....	....	....	1.2100	.0100	.1800	.0030
208	MAINTENANCE	L	UNK	0	0 INS	....	....	....	.7600	.0100	.1190	.0020
209	PAINTER	R	YES	0	0 INS	....	....	....	1.1700	.0100	.1210	.0030
210	PAINTER	L	YES	0	0 INS	....	....	....	1.5100	.0200	.0700	.0020
211	PAINTER	R	NO	0	0 INS	....	....	....	.9200	.0100	.0260	.0020
212	PAINTER	L	NO	0	0 INS	....	....	....	.5670	.0080	.0150	.0020
227	MACHINIST	R	NO	0	0 INS	....	....	....	2.0600	.0200	.0220	.0030
228	MACHINIST	L	NO	0	0 INS	....	....	....	1.9400	.0200	.0150	.0010
229	MACHINIST	R	NO	0	0 INS	....	....	....	1.1200	.0200	.0990	.0020
230	MACHINIST	L	NO	0	0 INS	....	....	....	1.2600	.0200	.1270	.0020
231	MACHINIST	R	NO	0	0 INS	....	....	....	.1650	.0050	.0280	.0010
232	MACHINIST	L	NO	0	0 INS	....	....	....	.3450	.0090	.0260	.0010
233	MACHINIST	R	NO	0	0 INS	....	....	....	.2550	.0090	.1200	.0020
234	MACHINIST	L	NO	0	0 INS	....	....	....	.3200	.0100	.5980	.0060
235	MACHINIST	R	UNK	0	0 INS	....	....	....	1.7900	.0200	.0720	.0020
236	MACHINIST	L	UNK	0	0 INS	....	....	....	1.9900	.0200	.0980	.0020

Table 5

RESULTS FROM THE ANALYSIS OF HANDLIFTS REMOVED AFTER CONTROLLED FIRINGS

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
68	UNK	U	UNK	1	38 INS	UNK	REV	REM-PETERS	1.4400	-.0000	.6150	-.0000
69	UNK	U	UNK	1	38 INS	UNK	REV	REM-PETERS	.6400	-.0000	.3250	-.0000
90	UNK	U	UNK	1	38 INS	UNK	REV	REM-PETERS	.9600	-.0000	.2550	-.0000
91	UNK	U	UNK	1	38 INS	UNK	REV	REM-PETERS	.2500	-.0000	.0750	-.0000
92	UNK	U	UNK	1	38 INS	UNK	REV	REM-PETERS	.6500	-.0000	.2950	-.0000
93	UNK	U	UNK	3	36 INS	UNK	REV	REM-PETERS	2.4000	-.0000	.6250	-.0000
94	UNK	U	UNK	3	38 INS	UNK	REV	REM-PETERS	1.5400	-.0000	.5750	-.0000
95	UNK	U	UNK	3	38 INS	UNK	REV	REM-PETERS	3.2800	-.0000	.5550	-.0000
96	UNK	U	UNK	3	38 INS	UNK	REV	REM-PETERS	1.7300	-.0000	.2850	-.0000
97	UNK	U	UNK	3	38 INS	UNK	REV	REM-PETERS	.6900	-.0000	.3850	-.0000
278	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.4890	.0080	.1030	.0020
280	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.3300	.0100	.0810	.0020
282	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.4720	.0060	.1990	.0020
284	POLICEMAN	R	UNK	1	36 INS	UNK	REV	UNKNOWN	2.7500	.0200	.6780	.0010
286	POLICEMAN	R	UNK	1	36 INS	UNK	REV	UNKNOWN	.9900	.0100	.3600	.0090
288	POLICEMAN	R	UNK	1	36 INS	UNK	REV	UNKNOWN	.6700	.0100	.1630	.0020
290	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.7130	.0090	.2530	.0030
292	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.2520	.0070	.0670	.0010
294	POLICEMAN	R	UNK	2	38 INS	UNK	REV	UNKNOWN	.2500	.0100	.0880	.0020
296	POLICEMAN	R	UNK	2	38 INS	UNK	REV	UNKNOWN	.3030	.0060	.0960	.0020
298	POLICEMAN	R	UNK	4	38 INS	UNK	REV	UNKNOWN	1.4600	.0200	.3930	.0050
300	POLICEMAN	R	UNK	4	38 INS	UNK	REV	UNKNOWN	2.1100	.0200	.7910	.0070
302	POLICEMAN	R	UNK	1	44 INS	UNK	REV	UNKNOWN	1.4900	.0200	.2590	.0090

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
304	POLICEMAN	R	UNK	1	22 INS	UNK	AUTO	UNKNOWN	.5400	.0200	.1110	.0020
306	POLICEMAN	R	UNK	1	22 INS	UNK	AUTO	UNKNOWN	1.2500	.0200	.2420	.0030
308	POLICEMAN	R	UNK	1	22 INS	UNK	AUTO	UNKNOWN	.3200	.0100	.0560	.0020
310	POLICEMAN	R	UNK	1	25 INS	UNK	AUTO	UNKNOWN	7.2000	.0700	1.2600	.0100
312	POLICEMAN	R	UNK	1	25 INS	UNK	AUTO	UNKNOWN	2.2200	.0300	.4990	.0060
314	POLICEMAN	R	UNK	1	25 INS	UNK	AUTO	UNKNOWN	8.4600	.0800	.5610	.0060
316	POLICEMAN	R	UNK	1	25 INS	UNK	AUTO	UNKNOWN	.9600	.0200	.2080	.0030
318	POLICEMAN	R	UNK	1	22 INS	UNK	REV	UNKNOWN	.7100	.0100	.0720	.0020
320	POLICEMAN	R	UNK	1	22 INS	UNK	REV	UNKNOWN	.2130	.0040	.0390	.0010
322	POLICEMAN	R	UNK	1	44 INS	UNK	REV	UNKNOWN	4.5200	.0300	1.5200	.0200
324	POLICEMAN	R	UNK	1	44 INS	UNK	REV	UNKNOWN	.3770	.0060	.1660	.0020
326	POLICEMAN	R	UNK	1	9 MM	UNK	AUTO	UNKNOWN	15.4000	.1000	.0560	.0020
328	POLICEMAN	R	UNK	1	9 MM	UNK	AUTO	UNKNOWN	5.5900	.0700	.7530	.0090
330	POLICEMAN	R	UNK	1	9 MM	UNK	AUTO	UNKNOWN	11.3000	.0600	2.0500	.0200
332	POLICEMAN	R	UNK	1	9 MM	UNK	AUTO	UNKNOWN	3.6300	.0040	.6100	.0070
335	POLICEMAN	R	UNK	1	9 MM	UNK	AUTO	UNKNOWN	1.3700	.0200	.1900	.0030
336	POLICEMAN	R	UNK	1	44 INS	UNK	REV	UNKNOWN	.1680	.0080	.0550	.0020
338	POLICEMAN	R	UNK	1	44 INS	UNK	REV	UNKNOWN	.4050	.0060	.1130	.0030
340	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	1.0400	.0100	.3140	.0040
342	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	1.2100	.0200	.4050	.0060
344	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	1.1300	.0200	.3340	.0040
346	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	1.0900	.0200	.2050	.0030
348	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.7100	.0100	.1670	.0020

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
350	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.5560	.0090	.1480	.0020
352	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	1.1300	.0200	.4100	.0040
354	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.5740	.0070	.1350	.0020
356	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.7600	.0100	.2340	.0030
358	POLICEMAN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	4.8700	.0300	.9900	.0100
373	UNKNOWN	R	UNK	1	38 INS	UNK	REV	UNKNOWN	.1680	-.0000	.0930	-.0000
375	UNKNOWN	R	UNK	1	38 INS	UNK	UNK	UNKNOWN	.5140	-.0000	.3980	-.0000
377	UNKNOWN	R	UNK	1	38 INS	UNK	UNK	UNKNOWN	.7620	-.0000	.6660	-.0000
379	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1500	.0100	.0370	.0020
380	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.2800	.0100	.6730	.0080
381	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1650	.0050	.0840	.0020
382	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.5300	.0100	.1380	.0030
383	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1700	.0050	.0840	.0030
384	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.3700	.0100	.2870	.0050
385	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.2620	.0050	.1950	.0040
386	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1600	.0100	.1210	.0030
387	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.8300	.0100	.3830	.0060
388	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.7400	.0100	.4180	.0060
389	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.4300	.0100	.2110	.0040
390	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.7200	.0100	.1870	.0040
371	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.4500	.0200	.1460	.0040
392	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.0700	.0040	.0340	.0020
393	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.5270	.0070	.2630	.0040

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
394	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.2790	.0040	.1610	.0030
395	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.7300	.0200	.3140	.0040
396	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.2220	.0040	.0780	.0020
397	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.0600	.0020	.0300	.0010
398	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.0790	.0020	.0700	.0010
399	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.3200	.0100	.1930	.0030
400	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1230	.0020	.0410	.0010
401	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.0180	.0020	.0140	.0010
402	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1970	.0050	.1990	.0040
403	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1690	.0060	.0970	.0020
404	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.3400	.0100	.1660	.0030
405	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1290	.0040	.0920	.0020
406	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	2.7000	.0200	.4320	.0050
407	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.1210	.0050	.0750	.0020
408	WASHEDHANDS	R	YES	1	38 INS	UNK	REV	UNKNOWN	.2000	.0100	.1500	.0030
409	WASHED HANDS	R	NO	1	22 INS	6.0	REV	WINCHESTER	.5300	.0070	.1260	.0020
410	WASHED HANDS	R	NO	1	22 INS	6.0	REV	WINCHESTER	.1200	.0030	.0500	.0010
411	WASHED HANDS	R	NO	1	22 INS	6.5	AUTO	WINCHESTER	5.8900	.0400	.1440	.0030
412	WASHED HANDS	R	NO	1	22 INS	6.0	REV	WINCHESTER	.1550	.0040	.0400	.0010
413	WASHED HANDS	R	NO	1	22 INS	6.5	AUTO	WINCHESTER	4.5000	.0300	.3020	.0050
414	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.2810	.0030	.0700	.0020
415	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	1.6900	.0200	.1460	.0020
416	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.2530	.0040	.0700	.0020

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
417	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	1.1200	.0100	.2520	.0030
418	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.0820	.0020	.0370	.0010
419	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	1.2300	.0100	.1330	.0020
420	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1980	.0030	.0450	.0010
421	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.4000	.0200	.2880	.0030
422	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1930	.0040	.0360	.0020
423	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.7400	.0300	.0640	.0010
424	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1510	.0030	.0430	.0020
425	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	1.2900	.0100	.3120	.0040
426	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1440	.0030	.0400	.0020
427	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	6.1700	.0400	.0610	.0020
428	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1370	.0030	.0370	.0010
429	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.0990	.0030	.0250	.0010
430	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	5.2400	.0350	.1920	.0030
431	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.0400	.0200	.1300	.0030
432	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	4.9200	.0300	2.9100	.0200
433	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.8800	.0200	.0980	.0020
434	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.0670	.0020	.0150	.0010
435	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.4600	.0200	.1840	.0030
436	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.4870	.0050	.0580	.0010
437	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.6150	.0070	.1110	.0020
438	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1690	.0040	.0370	.0010
439	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	1.2700	.0120	.1270	.0020

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
440	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.2150	.0040	.0660	.0020
441	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.9800	.0100	.1210	.0020
442	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1590	.0030	.0470	.0020
443	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.6500	.0200	.5210	.0060
444	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.3510	.0040	.1010	.0020
445	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.1300	.0200	1.1200	.0200
446	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.0650	.0020	.0290	.0010
447	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.7300	.0200	.0760	.0030
448	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.0550	.0020	.0160	.0010
449	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.9600	.0100	.1140	.0030
450	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1490	.0030	.0400	.0020
451	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1600	.0100	.0410	.0020
452	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	1.6700	.0200	.0450	.0020
453	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.1720	.0040	.0320	.0020
454	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.5900	.0100	.1990	.0050
455	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.2210	.0050	.0430	.0020
456	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	.1750	.0040	.0470	.0030
457	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.2910	.0040	.0960	.0030
458	WASHED HANDS	R	NO	1	22 INS	6.0	REV	FEDERAL	3.0100	.0200	.0240	.0030
459	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	1.1200	.0100	.0750	.0030
460	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.8400	.0100	.0360	.0020
462	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	2.4000	.0200	.0640	.0030
463	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.3410	.0040	.1380	.0030

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
464	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1610	.0030	.0310	.0010
465	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.0920	.0020	.0220	.0010
466	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1400	.0100	.0170	.0020
467	WASHED HANDS	R	NO	1	22 INS	1.0	AUTO	WINCHESTER	.9700	.0100	.1410	.0030
468	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1330	.0050	.0270	.0020
469	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	1.5600	.0100	.0740	.0020
470	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1040	.0030	.0310	.0020
471	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.2900	.0100	.0570	.0020
472	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1630	.0040	.0470	.0030
473	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.3510	.0050	.0360	.0020
474	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1130	.0050	.0200	-.0000
475	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	1.1000	.0100	.1170	.0020
476	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1440	.0040	.0340	.0020
477	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1280	.0040	.0240	.0010
478	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.3580	.0060	.0730	.0020
479	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.0910	.0040	.0090	.0010
480	WASHED HANDS	R	NO	1	22 INS	UNK	AUTO	WINCHESTER	.1680	.0040	.0150	.0020
547	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	2.2700	.0200	.9300	.0100
548	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	3.2200	.0200	.5700	.0100
549	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	2.7700	.0200	.8400	.0100
550	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.6400	.0200	.2470	.0060
551	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.2700	.0100	.3800	.0100
552	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.1100	.0100	.3600	.0100

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
553	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.0200	.0100	.5800	.0100
554	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.6900	.0200	.4900	.0100
555	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.2200	.0200	.4600	.0100
556	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	4.8000	.0400	3.0500	.0200
557	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	2.1400	.0200	.7100	.0100
558	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	1.3600	.0200	.7000	.0100
559	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.8400	.0100	.1640	.0020
560	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	.7500	.0100	.2960	.0030
561	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.5600	.0100	.1240	.0020
562	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	1.6300	.0100	.4950	.0060
563	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	.4130	.0040	.1230	.0020
564	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.4190	.0050	.1420	.0020
565	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	1.2600	.0100	.2180	.0020
566	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.6400	.0100	.0820	.0010
567	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	1.3100	.0100	.7190	.0070
568	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.2470	.0040	.1920	.0030
569	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	.4340	.0040	.8200	.0100
570	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.2840	.0030	.2410	.0030
571	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	.4400	.0050	.1870	.0020
572	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.4640	.0040	.3380	.0030
573	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	2.9000	.0200	.6800	.0100
574	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.5280	.0050	.0860	.0020
575	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	6.6500	.0400	3.1800	.0300

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
576	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.5700	.0100	.1330	.0030
577	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	2.3400	.0200	.8600	.0100
578	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.6180	.0060	.1130	.0030
579	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	8.5900	.0500	3.2300	.0300
580	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.4830	.0050	.1490	.0030
581	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	5.3400	.0400	2.5700	.0200
582	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	2.3300	.0200	.2320	.0030
583	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	6.7400	.0400	3.1700	.0200
584	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	8.5600	.0600	1.2000	.0100
585	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	1.4400	.0100	.7700	.0100
586	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.5560	.0050	.1450	.0030
587	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	4.6600	.0400	.5200	.0100
588	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	.5100	.0100	.2270	.0040
589	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	2.4700	.0200	.3800	.0100
590	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	2.5200	.0200	1.5700	.0200
591	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.5600	.0200	.2150	.0050
592	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	9.2900	.0600	4.2000	.0400
593	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.0400	.0100	.1830	.0040
594	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	2.6600	.0200	1.1500	.0100
595	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	3.2400	.0300	.6300	.0100
596	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	1.9400	.0200	.9900	.0100
597	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	3.0900	.0200	1.5200	.0200
598	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	1.0000	.0100	.2660	.0050

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
599	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	1.1600	.0100	.1300	.0030
600	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	2.1900	.0300	1.2900	.0200
601	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	REM-PETERS	.4700	.0100	.1020	.0030
602	WASHED HANDS	R	NO	1	9 MM	UNK	AUTO	WINCHESTER	2.6700	.0200	.8400	.0100
603	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	WINCHESTER	2.6700	.0200	.3540	.0050
604	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	WINCHESTER	4.9200	.0400	2.3700	.0200
605	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	WINCHESTER	2.1200	.0200	1.0900	.0100
606	WASHED HANDS	R	NO	1	9 MM	4.0	AUTO	WINCHESTER	.7300	.0100	.1560	.0030
637	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	4.1000	.0300	.6040	.0050
639	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	2.4300	.0200	.2960	.0050
641	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	3.8100	.0300	.1480	.0020
643	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	3.4700	.0300	.3410	.0030
645	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	14.2000	.0900	1.6700	.0200
647	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	1.4400	.0200	.2660	.0050
650	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	2.9800	.0200	.6240	.0060
652	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	3.8400	.0300	.5790	.0060
654	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	1.0900	.0100	.1500	.0030
656	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	1.6100	.0200	.3070	.0040
658	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	2.2600	.0200	.4630	.0050
660	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	2.2200	.0200	.3590	.0050
662	WASHED HANDS	R	YES	1	25 INS	2.0	AUTO	UNKNOWN	2.1200	.0200	.4190	.0040
664	WASHED HANDS	R	YES	1	25 INS	4.5	AUTO	FEDERAL	1.0500	.0080	.2530	.0040
666	WASHED HANDS	R	NO	1	22 INS	UNK	REV	UNKNOWN	.0250	.0020	.0070	.0010

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
668	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.0500	.0030	.0270	.0020
670	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.0830	.0040	.0180	.0010
672	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.1700	.0040	.1840	.0030
674	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.0780	.0050	.0140	.0010
676	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.0400	.0040	.0110	.0010
678	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.0340	.0020	.0049	.0006
682	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.8540	.0070	.2360	.0030
684	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	1.1700	.0100	.2690	.0030
686	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.8500	.0100	.2150	.0030
688	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.3680	.0070	.1200	.0020
690	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.2790	.0050	.0940	.0020
692	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.2420	.0040	.0910	.0020
694	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.4100	.0100	.1600	.0020
696	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.2300	.0100	.1120	.0020
701	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	UNKNOWN	6.3700	.0400	1.8800	.0100
703	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	UNKNOWN	15.6000	.0800	4.3500	.0300
705	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	UNKNOWN	9.4000	.0600	3.3500	.0200

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
736	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	26.1000	.1400	3.2400	.0420
737	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	5.6800	.0360	1.7300	.0220
738	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	5.2400	.0260	1.4000	.0190
739	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	2.3500	.0170	.6420	.0097
740	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	19.9000	.1000	5.9800	.0610
741	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	3.7900	.0310	1.2900	.0170
742	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	5.5900	.0360	1.6300	.0180
743	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	4.0600	.0280	11.6000	.1400
744	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	2.0900	.0160	.5800	.0075
745	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	2.4400	.0170	.8890	.0100
746	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	2.8900	.0180	1.1100	.0130
747	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	2.9600	.0240	.9330	.0110
748	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	8.6800	.0560	3.0100	.0360
749	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	2.7700	.0250	1.5500	.0200
750	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	8.5500	.0460	2.1700	.0230
751	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	3.7500	.0260	1.3100	.0170
752	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	9.7200	.0520	2.5600	.0250
753	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	2.5600	.0190	.9970	.0160
754	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	7.2000	.0410	2.7400	.0270
755	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	WINCHESTER	.6660	.0064	.2660	.0072
756	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	4.8600	.0320	1.3100	.0260
757	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	FEDERAL	.5610	.0067	.2320	.0070

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
758	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	3.3600	.0260	1.6000	.0180
759	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	2.1700	.0220	.7540	.0120
760	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	3.1700	.0320	1.2700	.0190
761	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	6.4400	.0430	2.0300	.0240
762	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	7.9200	.0790	2.7000	.0260
763	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	1.9500	.0250	.8080	.0150
764	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	6.2800	.0470	1.7100	.0210
765	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	2.0700	.0180	.3430	.0036
766	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	11.0000	.0540	2.3200	.0150
767	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	5.3200	.0390	.8360	.0076
768	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	1.7500	.0190	.2080	.0020
769	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	13.7000	.0660	3.5000	.0210
770	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	2.7300	.0200	.3730	.0046
771	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	FEDERAL	5.8700	.0350	1.1700	.0094
772	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	4.6800	.0390	.9350	.0081
773	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	5.2600	.0360	1.4100	.0110
774	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	7.0000	.0530	1.0200	.0099
775	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	13.4000	.0660	2.1200	.0140
776	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	FEDERAL	7.6800	.0480	2.0900	.0130
777	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	1.8400	.0170	.3820	.0036
778	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	WINCHESTER	.8790	.0120	.1320	.0020
779	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	13.1000	.0760	4.2100	.0400
780	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	UNKNOWN	.7470	.0081	.1740	.0027

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
781	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	.8430	.0130	.2960	.0041
782	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	5.9300	.0490	.5520	.0067
783	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	1.3800	.0140	.2800	.0043
784	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	6.1200	.0380	1.2200	.0100
785	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	3.0000	.0260	1.1200	.0110
786	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	6.3400	.0670	2.5500	.0320
787	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	2.1400	.0180	1.4000	.0160
788	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	13.0000	.0800	5.1600	.0440
789	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	15.5000	.0930	.9190	.0120
790	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	1.0000	.0099	.7160	.0086
791	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	8.9100	.0660	1.8200	.0200
792	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	1.9100	.0190	.4680	.0067
793	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	1.8900	.0210	.7760	.0094
794	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	2.1100	.0220	.7020	.0077
795	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	3.9400	.0240	.6910	.0085
796	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	UNKNOWN	.1130	.0030	.0216	.0016
797	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	1.6100	.0160	.2470	.0047
798	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	1.6500	.0150	1.8300	.0190
799	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	9.0800	.0450	5.7800	.0540
800	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	6.2200	.0310	1.2600	.0140
801	WASHED HANDS	L	NO	1	45 INS	5.0	AUTO	UNKNOWN	.1440	.0026	.0368	.0029
802	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	7.1600	.0410	1.9200	.0220
803	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	6.0500	.0440	2.2300	.0280

Table 5 (Continued)

SAMPLE NUMBER	OCCUPATION	HAND SAMPLED	SMOKER	NUMBER OF FIRINGS	CALIBER	BARREL LENGTH INCHES	WEAPON TYPE	AMMUNITION	MICROGRAMS OF BARIUM	STANDARD DEVIATION BARIUM	MICROGRAMS OF ANTIMONY	STANDARD DEVIATION ANTIMONY
804	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	2.0400	.0200	1.3800	.0180
805	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	.9630	.0097	.3420	.0057
806	WASHED HANDS	R	NO	1	45 INS.	5.0	AUTO	UNKNOWN	2.1500	.0160	.5210	.0064
807	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	1.3400	.0110	.3550	.0047
806	WASHED HANDS	R	NO	1	45 INS	5.0	AUTO	UNKNOWN	2.9100	.0260	.6010	.0068
824	WASHED HANDS	R	NO	1	22 INS	6.0	AUTO	MONARCH	2.2000	.0190	.3740	.0043
825	WASHED HANDS	R	NO	1	22 INS	6.0	AUTO	MONARCH	.3780	.0055	.1190	.0024
826	WASHED HANDS	R	NO	1	22 INS	6.0	AUTO	MONARCH	1.5300	.0230	.3180	.0033
827	WASHED HANDS	R	NO	1	22 INS	4.5	REV	MONARCH	.1190	.0043	.2100	.0034
828	WASHED HANDS	R	NO	1	22 INS	4.5	REV	MONARCH	.1610	.0072	.0880	.0018
829	WASHED HANDS	R	NO	1	22 INS	4.5	REV	MONARCH	.3100	.0059	.1330	.0027
830	WASHED HANDS	R	NO	1	22 INS	6.0	AUTO	FEDERAL	6.0900	.0750	3.7800	.0029
831	WASHED HANDS	R	NO	1	22 INS	6.0	AUTO	FEDERAL	2.6700	.0440	.8350	.0065
832	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.3870	.0110	.2000	.0030
833	WASHED HANDS	R	NO	1	22 INS	4.5	REV	FEDERAL	.3450	.0070	.2660	.0036

Table 5

SUPPLEMENT

Sample No.	Occupation	Hand	Smoker	No. of Firings	Caliber	Barrel Length (in.)	Weapon Type	Ammunition	Barium µg	Barium σ	Antimony µg	Antimony σ
55	Unkn.	R	Unkn.	1	0.22	Unkn.	Rev.	Winchester	0.48	Unkn.	0.066	Unkn.
57	Unkn.	R	Unkn.	1	0.22	Unkn.	Rev.	Winchester	0.23	Unkn.	0.056	Unkn.
59	Unkn.	R	Unkn.	1	0.22	Unkn.	Rev.	Winchester	0.48	Unkn.	0.076	Unkn.
61	Unkn.	R	Unkn.	1	0.22	Unkn.	Rev.	Winchester	0.14	Unkn.	0.066	Unkn.
62	Unkn.	R	Unkn.	1	0.22	Unkn.	Rev.	Winchester	0.34	Unkn.	0.046	Unkn.
79	Unkn.	R	Unkn.	3	0.22	Unkn.	Rev.	Unkn.	0.38	Unkn.	0.136	Unkn.
84	Unkn.	R	Unkn.	6	0.22	Unkn.	Rev.	Unkn.	0.30	Unkn.	0.096	Unkn.
45	Unkn.	R	Unkn.	1	0 38	Unkn.	Rev.	Winchester	1.18	Unkn.	0.236	Unkn.
46	Unkn.	R	Unkn.	1	0.38	Unkn.	Rev.	Winchester	0.73	Unkn.	0.186	Unkn.
47	Unkn.	R	Unkn.	1	0.38	Unkn.	Rev.	Winchester	1.14	Unkn.	0.286	Unkn.
49	Unkn.	R	Unkn.	1	0.38	Unkn.	Rev.	Winchester	0.55	Unkn.	0.136	Unkn.
51	Unkn.	R	Unkn.	1	0.38	Unkn.	Rev.	Winchester	0.42	Unkn.	0.196	Unkn.
53	Unkn.	R	Unkn.	1	0.38	Unkn.	Rev.	Winchester	0.97	Unkn.	0.296	Unkn.
76	Unkn.	R	Unkn.	3	0.38	Unkn.	Rev.	Winchester	2.05	Unkn.	0.606	Unkn.
82	Unkn.	R	Unkn.	6	0.38	Unkn.	Rev.	Winchester	1.25	Unkn.	0.406	Unkn.
83	Unkn.	R	Unkn.	6	0.38	Unkn.	Rev.	Winchester	0.73	Unkn.	0.366	Unkn.
64	Unkn.	R	Unkn.	1	0.45	Unkn.	Auto	Winchester	7.75	Unkn.	1.56	Unkn.
66	Unkn.	R	Unkn.	1	0 45	Unkn.	Auto	Winchester	5.15	Unkn.	0.596	Unkn.
68	Unkn.	R	Unkn.	1	0.45	Unkn.	Auto	Winchester	5.16	Unkn.	0.616	Unkn.
70	Unkn.	R	Unkn.	1	0.45	Unkn.	Auto	Winchester	6.55	Unkn.	0.816	Unkn.
72	Unkn.	R	Unkn.	1	0.45	Unkn.	Auto	Winchester	5.55	Unkn.	1.32	Unkn.
86	Unkn.	R	Unkn.	6	0.45	Unkn.	Auto	Winchester	2.65	Unkn.	0.886	Unkn.
87	Unkn.	R.	Unkn.	6	0.45	Unkn.	Auto	Winchester	0.97	Unkn.	0.176	Unkn.

In the columns headed Standard Deviation of Barium and Standard Deviation of Antimony, the entries are based on counting statistics of the analysis only, and represent only the precision of the analytical procedure. Entries of -.0000 mean that the precision was not calculated, and represent some of the earliest work.

In many of the results from test firings the entry WASHED HANDS will be found in the column headed occupation. This indicates that the person sampled washed his hands just prior to firing.

Figures 1 - 29 are derived from the data in Tables 1 - 5. The logarithms of pairs of barium and antimony values, selected for some common property, are plotted in each figure as asterisks. Five concentric ellipses are also plotted. Each ellipse represents a solution of the density function of the bivariate normal distribution. For example, the innermost ellipse circumscribes an area containing approximately 25% of the values plotted on the figure. Moving outward, successive ellipses circumscribe areas containing approximately 50%, 75%, 90%, and 95% of all values, respectively. The construction details and exact interpretation of the ellipses are given in Appendix 3.

Results from the analysis of primers are given in Table 6, and some typical primer formulations are given in Table 7. Table 8 exemplifies the results of firing with different brands of ammunition, and this subject is discussed in a later section. The various handguns used in the firings are listed in Table 9.

Table 10 lists the statistical parameters, which were computed from data in Tables 1 - 5, and were used in the preparation of Figs. 1 - 29.

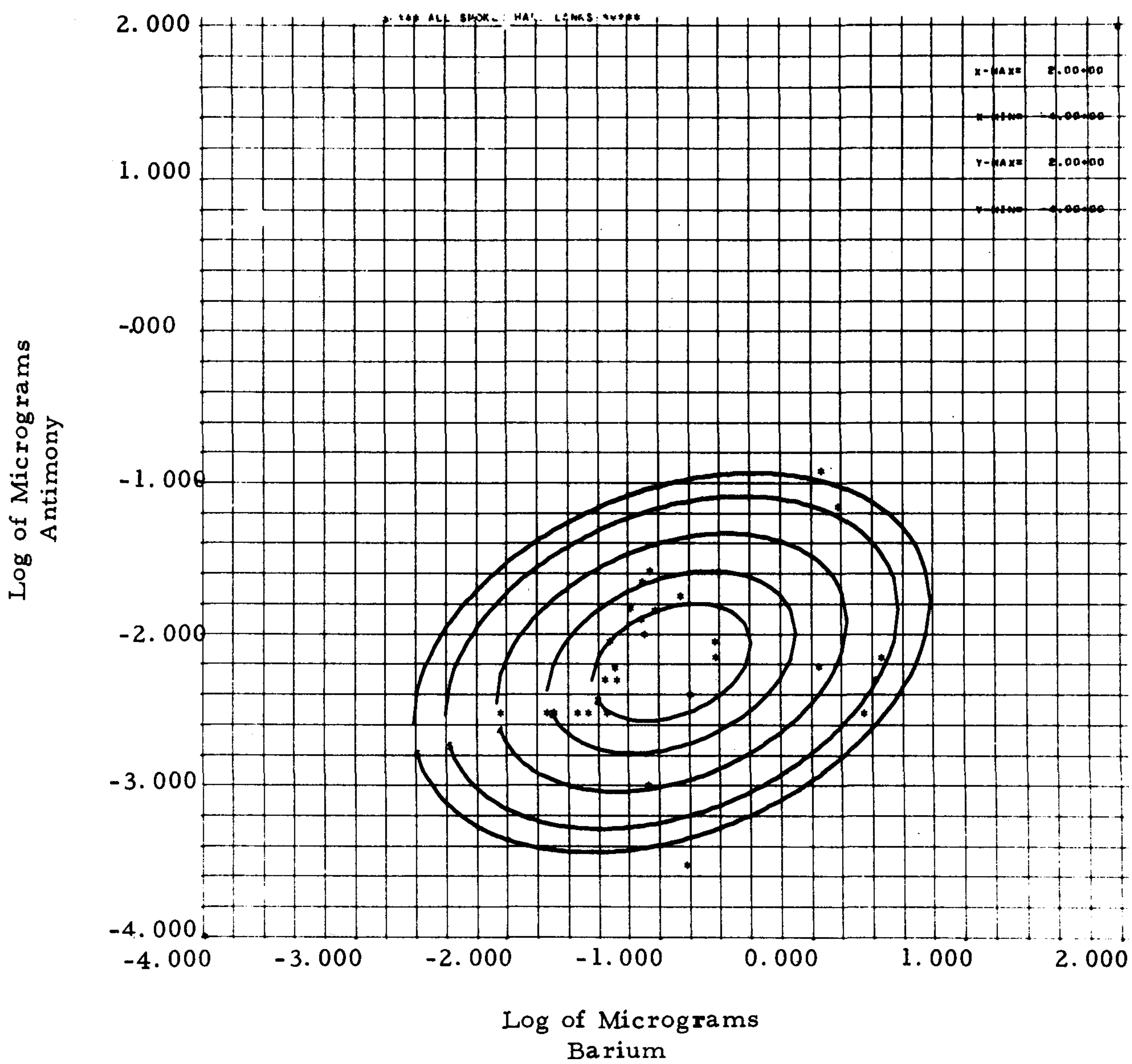


Fig. 2

Plot of Logarithms of Results from the Analysis of Handblanks Obtained from Smokers, and Associated Solutions of the Bivariate Normal Density Function

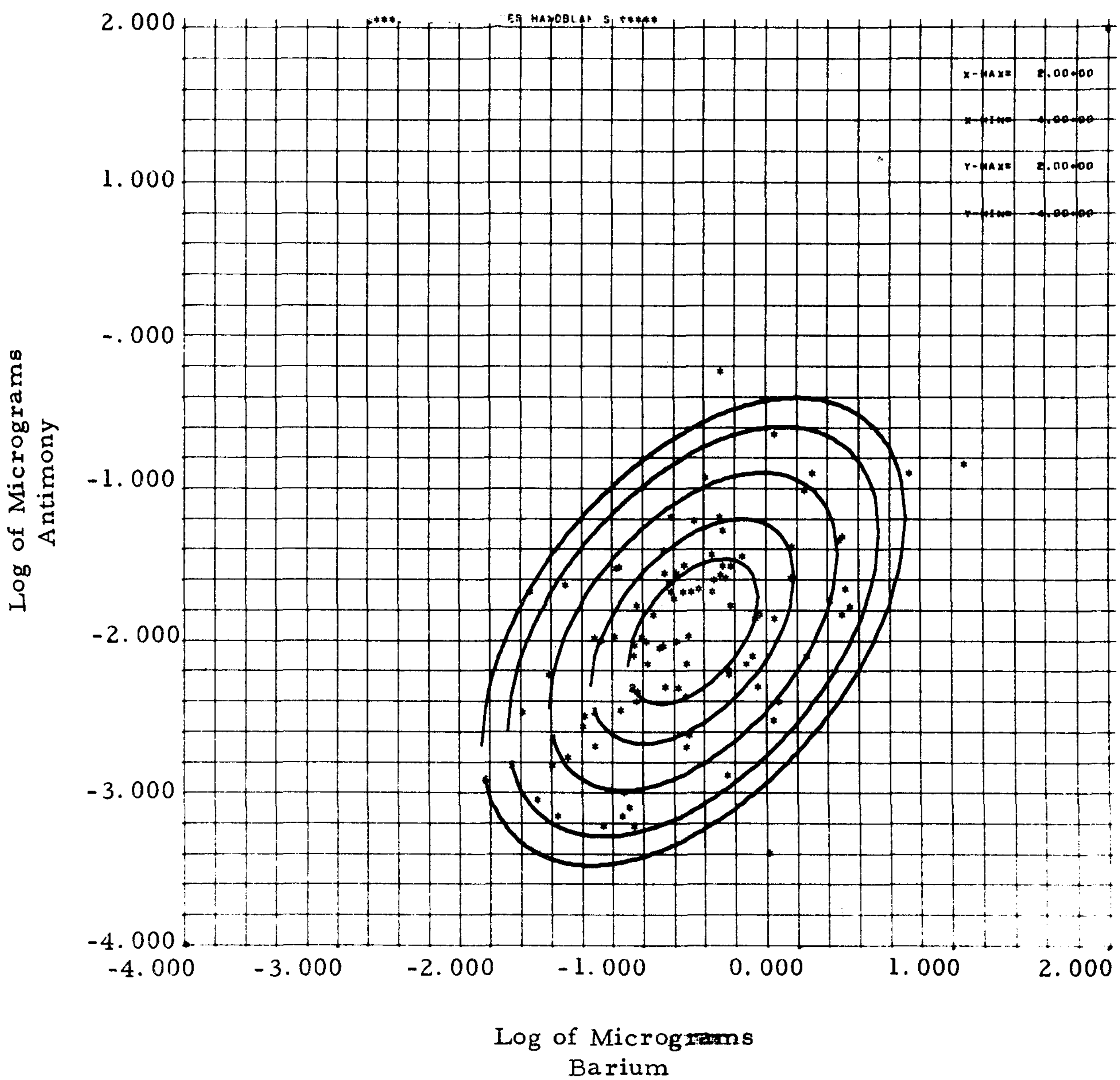


Fig. 3

Plot of Logarithms of Results from the Analysis of Handblanks Obtained from Non-Smokers, and Associated Solutions of the Bivariate Normal Density Function

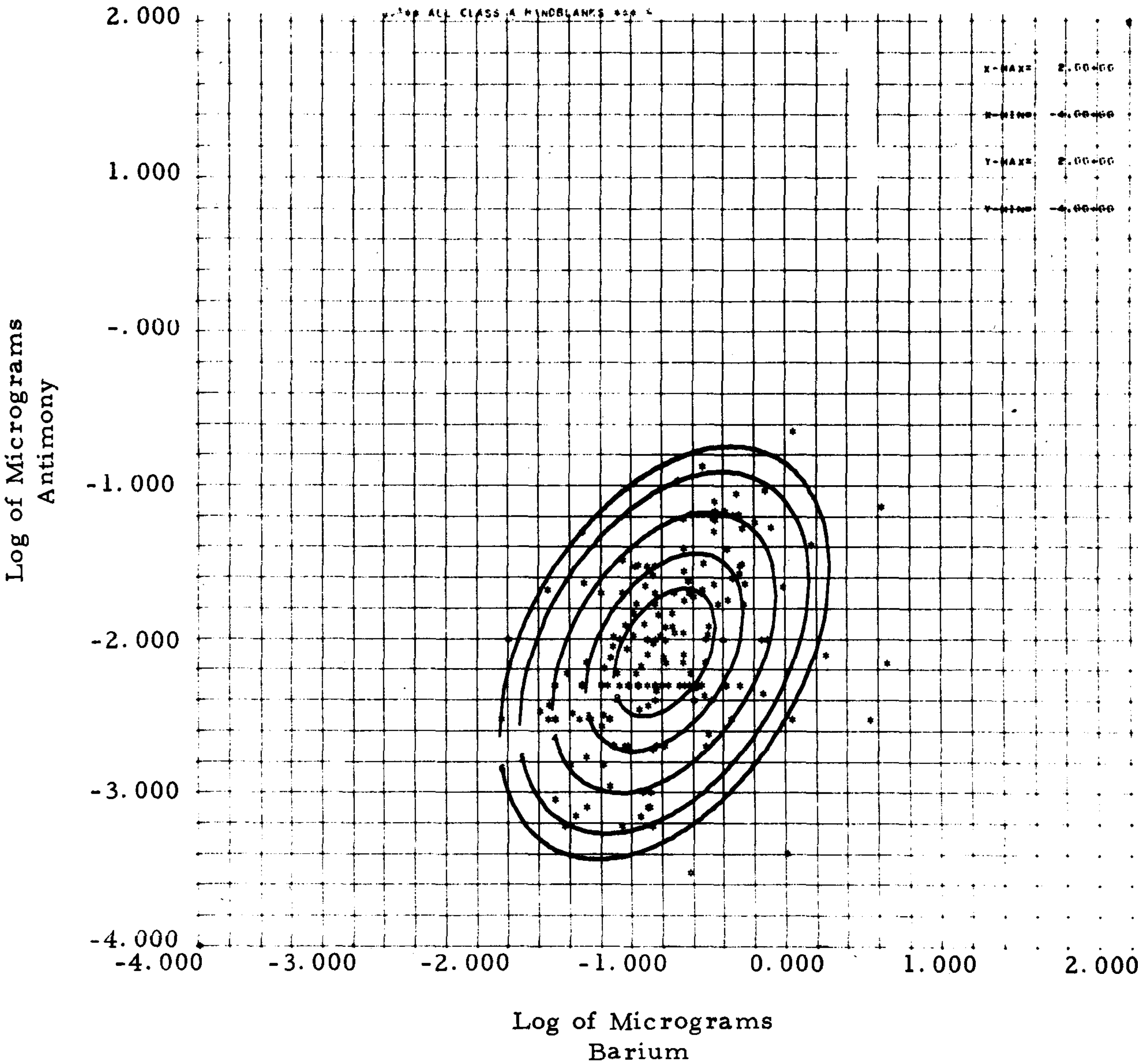


Fig. 4

Plot of Logarithms of Results from the Analysis of Class A Handblanks (see Report for Definition), and Associated Solutions of the Bivariate Normal Density Function

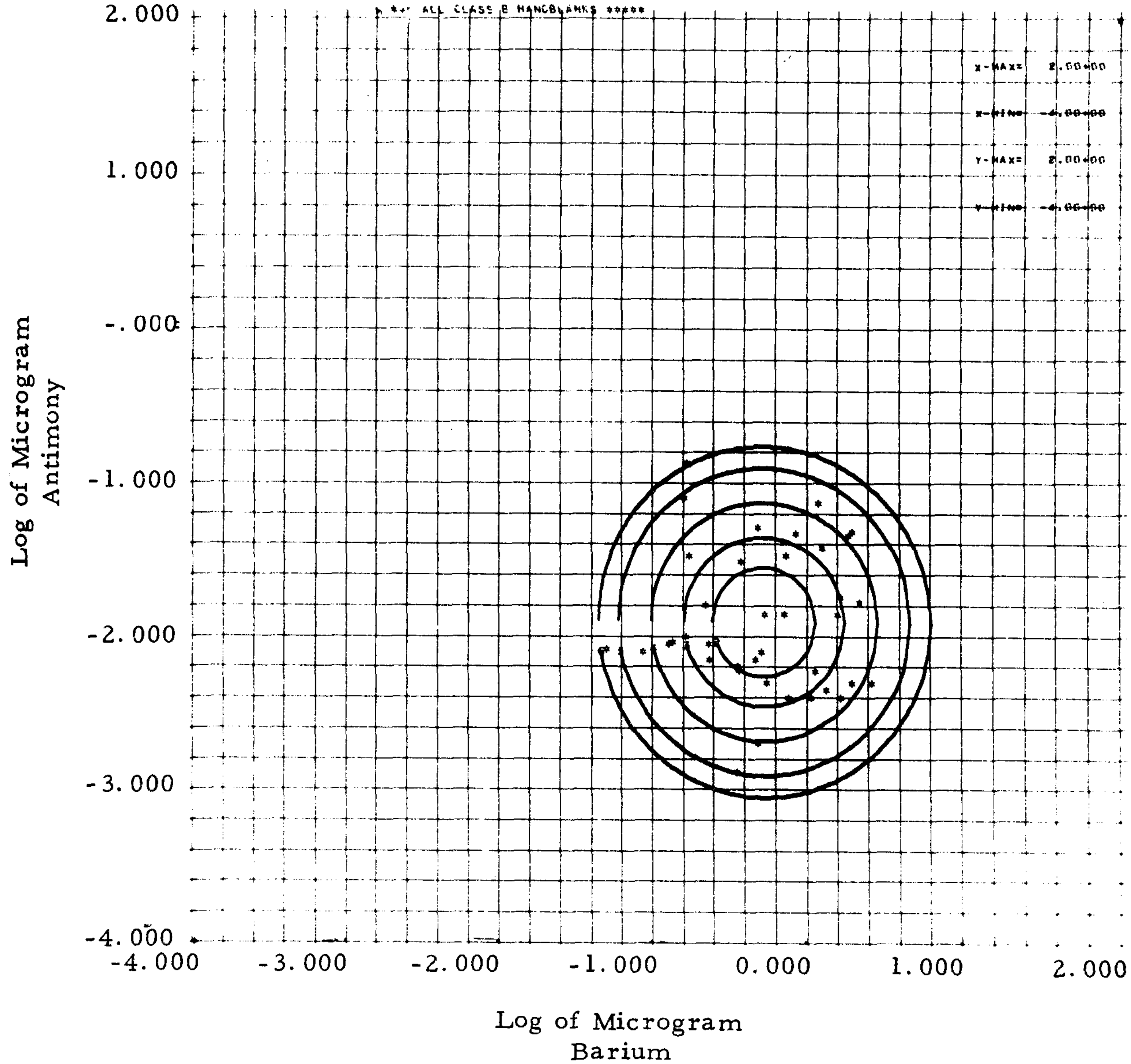


Fig. 5

Plot of Logarithms of Results Obtained from the Analysis of Class B Handblanks (see Report for Definition), and Associated Solutions of the Bivariate Normal Density Function

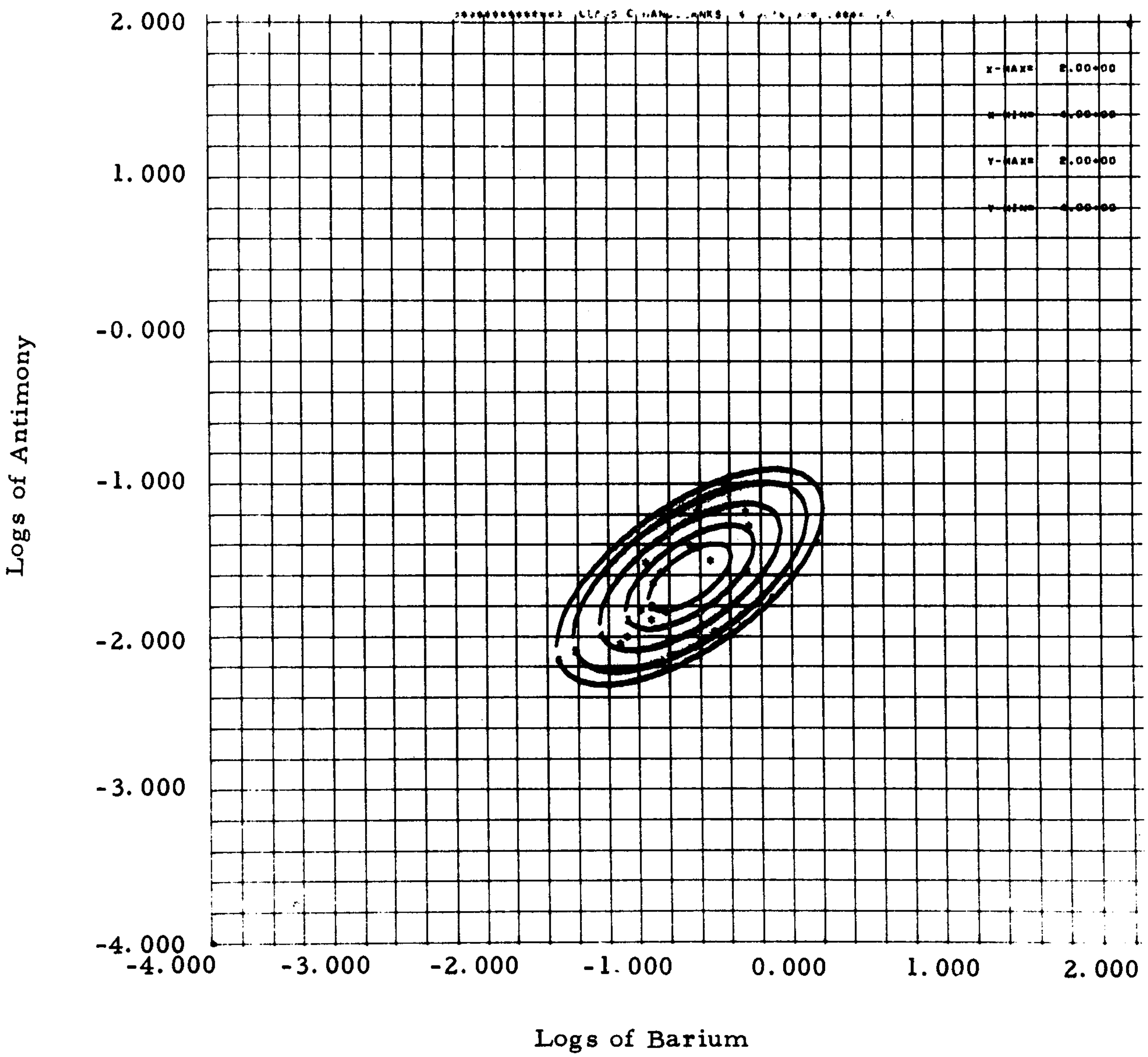


Fig. 6

Plot of Logarithms of Results Obtained from the Analysis of Class C Handblanks (see Report for Definition), and Associated Solutions of the Bivariate Normal Density Function

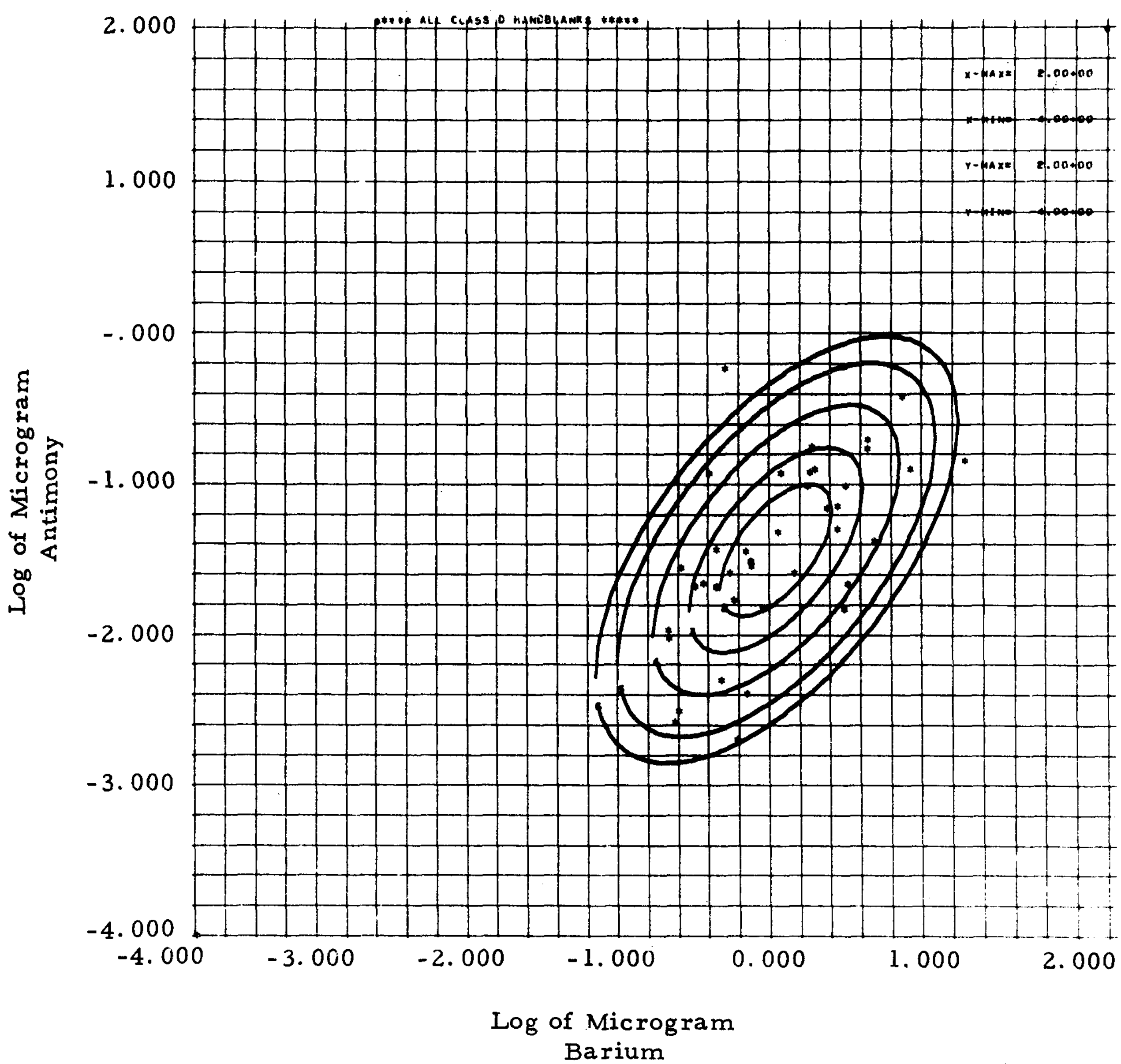


Fig. 7

Plot of Logarithms of Results Obtained from the Analysis of Class D Handblanks (see Report for Definition), and Associated Solutions of the Bivariate Normal Density Function

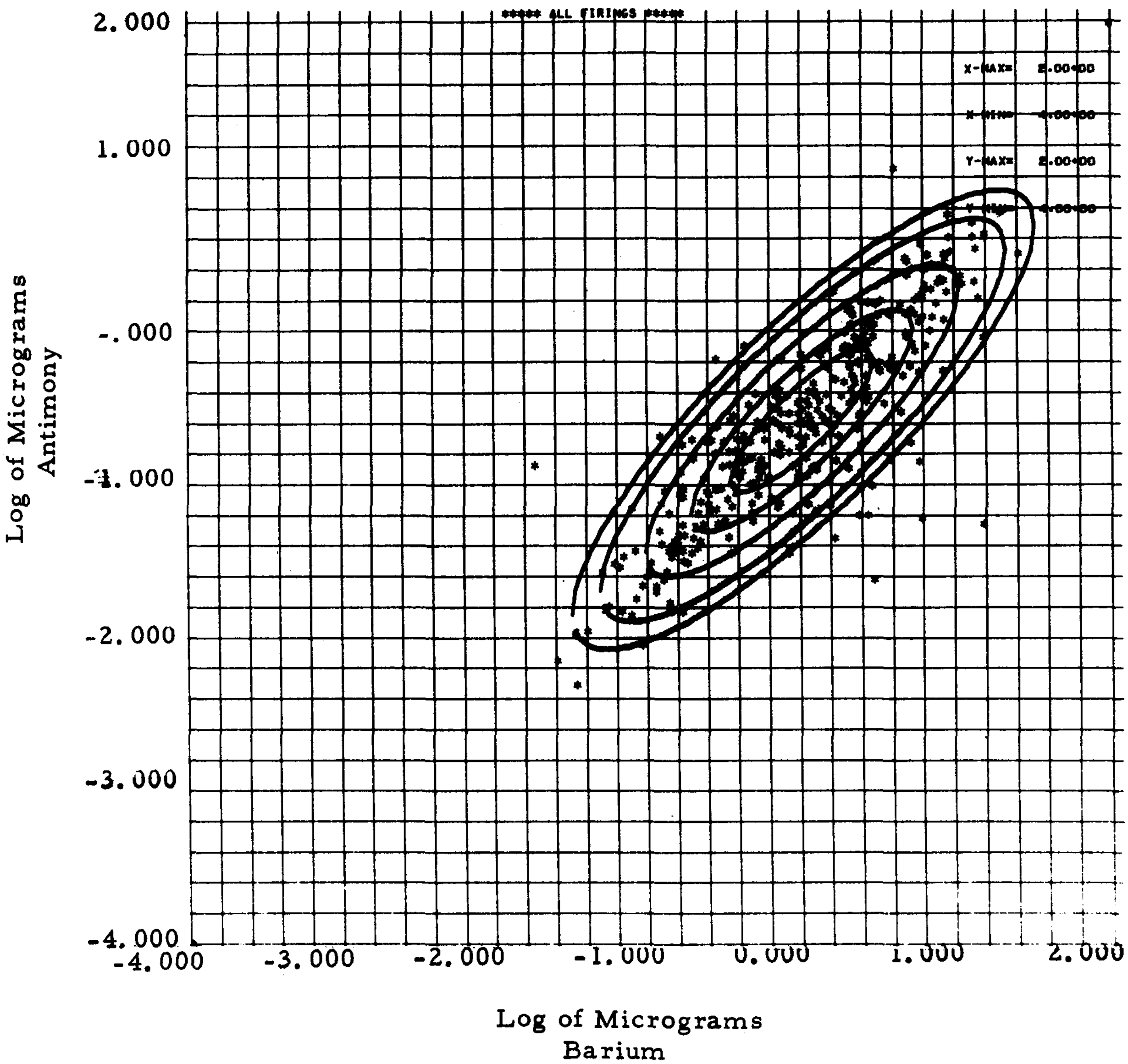


Fig. 8

Plot of Logarithms of All Results Obtained from the Analysis of Handlifts Removed after Controlled Firings, and Associated Solutions of the Bivariate Normal Density Function

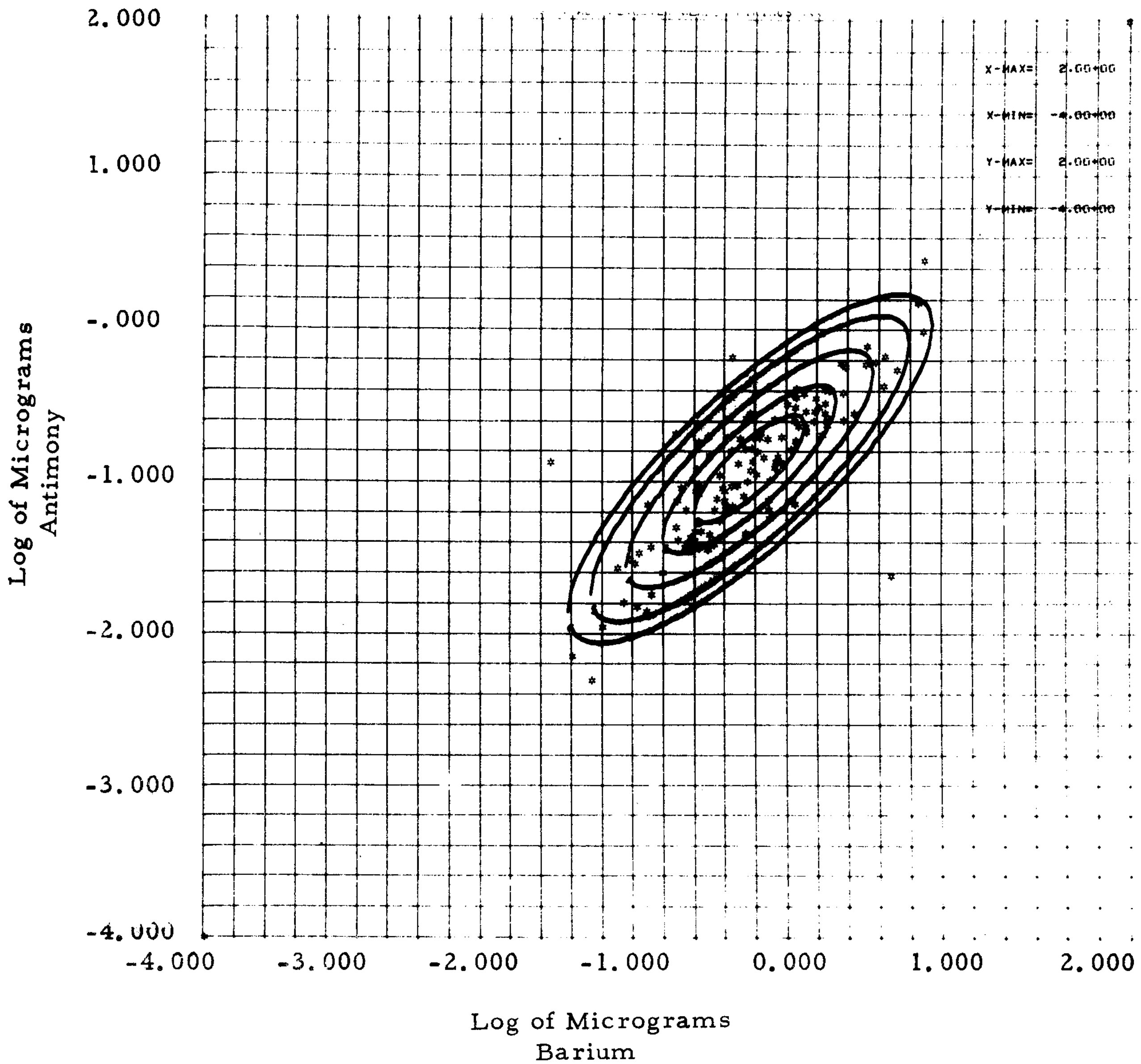


Fig. 9

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Controlled Firings of Revolvers, and Associated Solutions of the Bivariate Normal Density Function

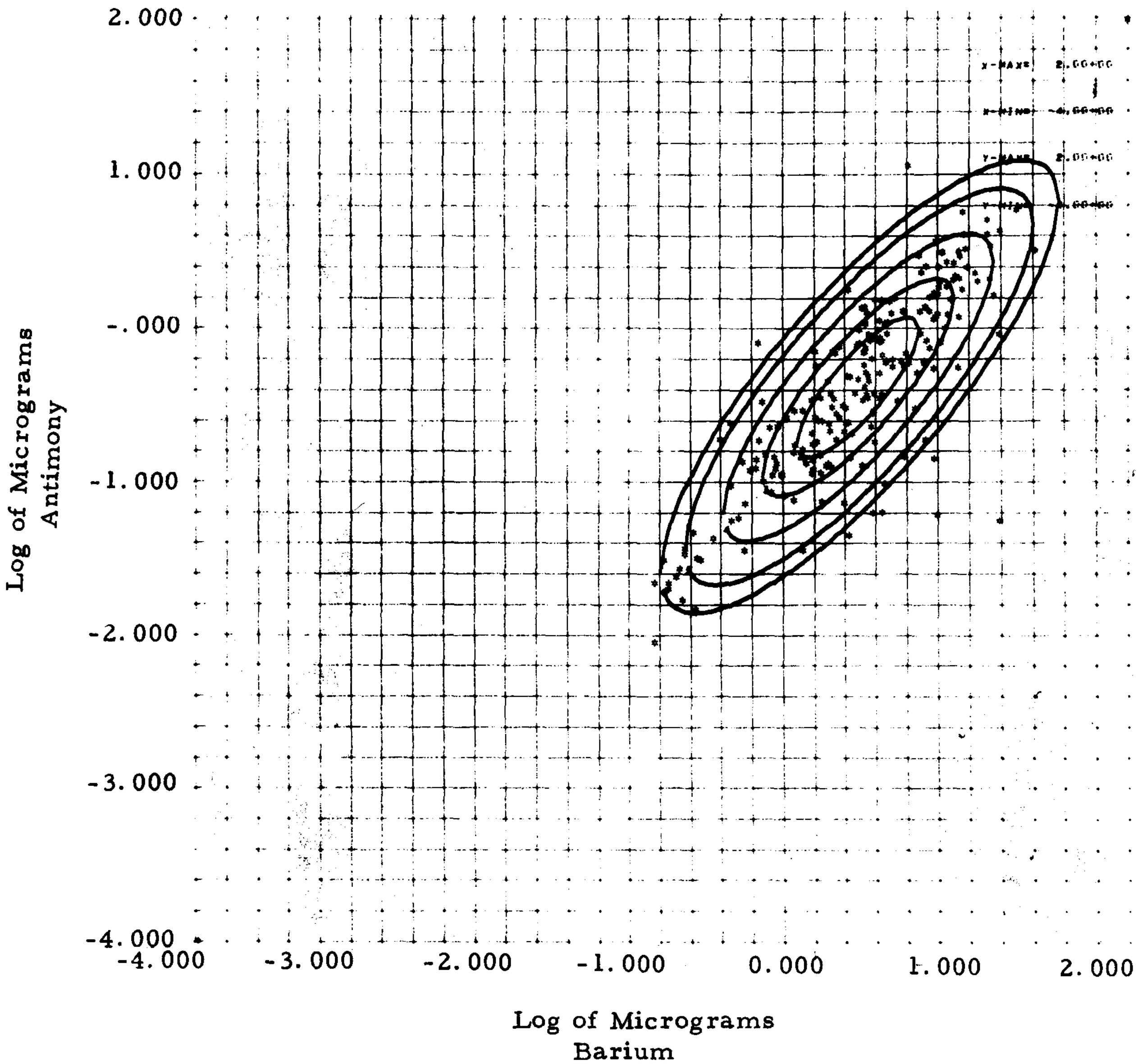


Fig. 10

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after the Controlled Firing of Automatic Pistols, and Associated Solutions of the Bivariate Normal Density Function

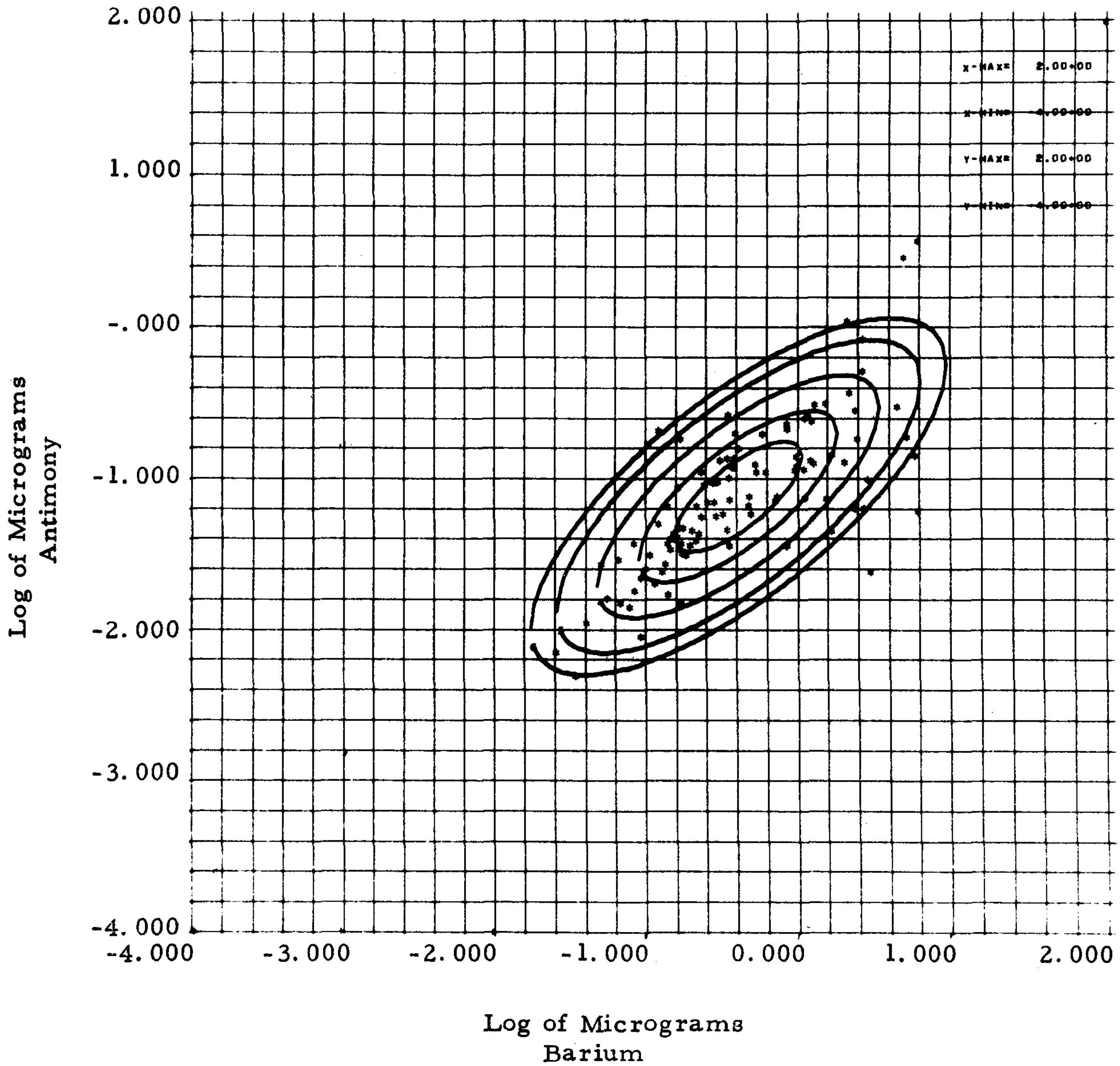


Fig. 11

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Controlled Firings of 0.22 Caliber Handguns, and Associated Solutions of the Bivariate Normal Density Function

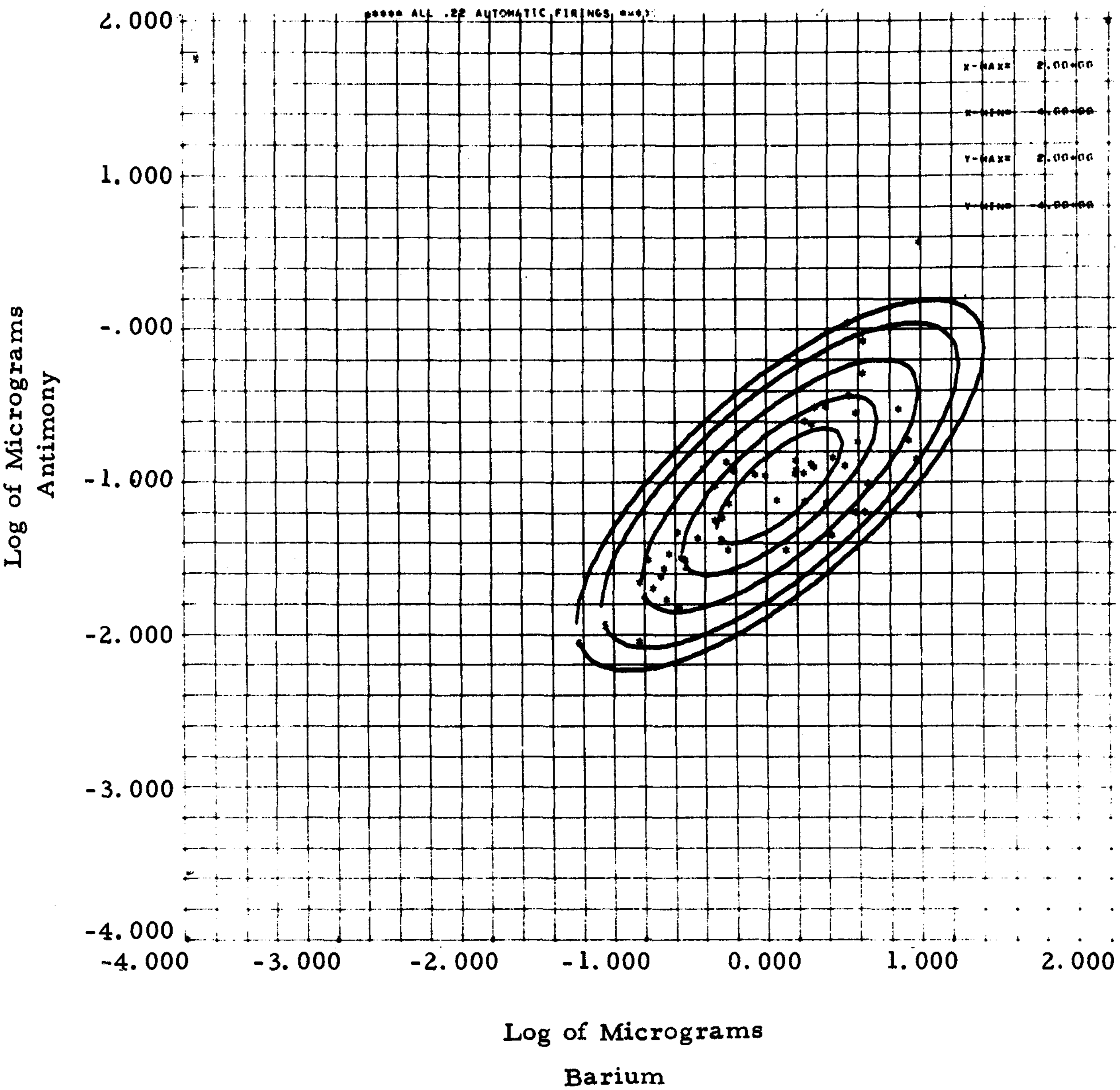


Fig. 12

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Controlled Firings of 0.22 Caliber Automatic Pistols, and Associated Solutions of the Bivariate Normal Density Function

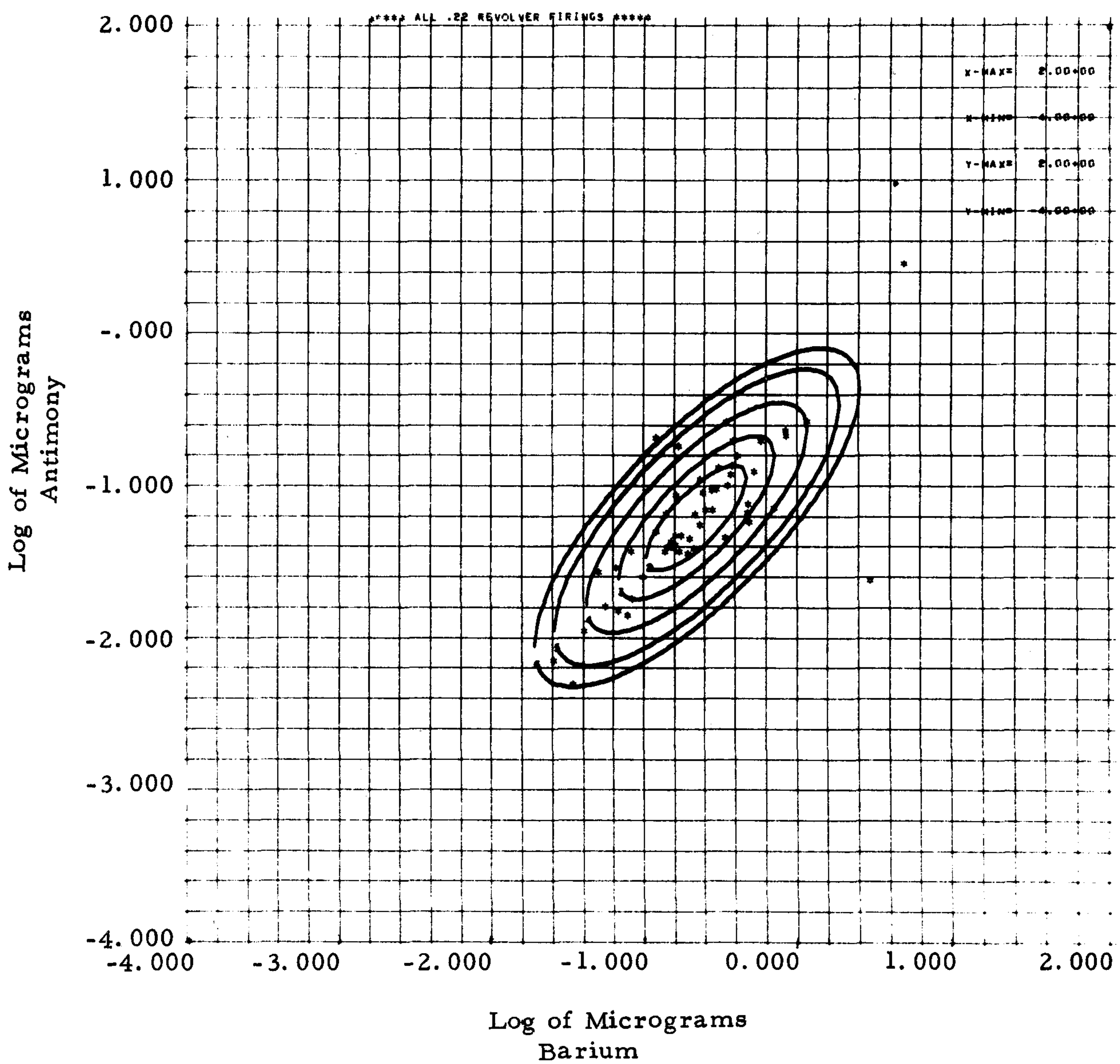


Fig. 13

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Controlled Firings of 0.22 Caliber Revolvers, and Associated Solutions of the Bivariate Normal Density Function

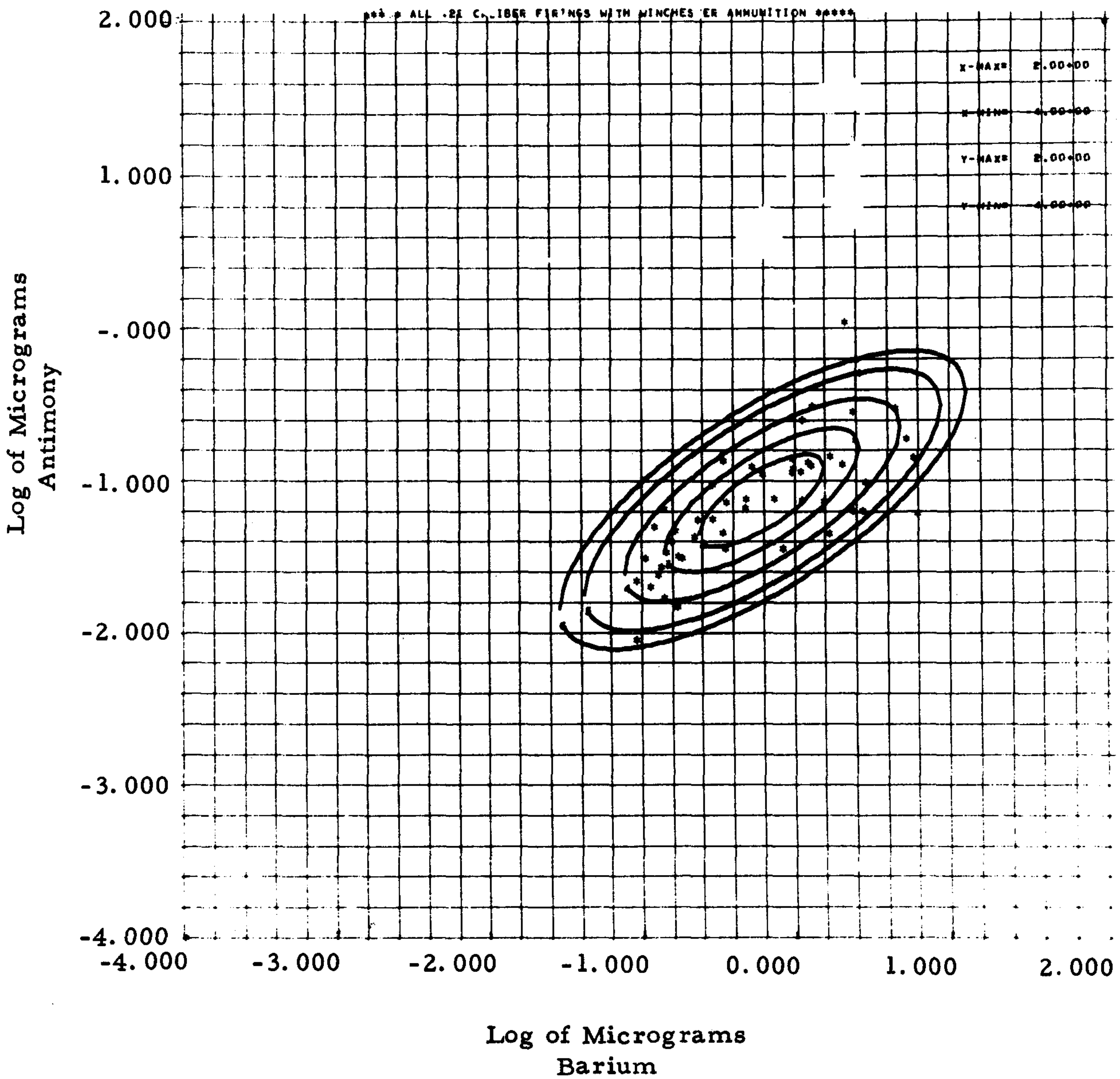


Fig. 14

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Controlled Firings of 0.22 Caliber Revolvers, and Associated Solutions of the Bivariate Normal Density Function

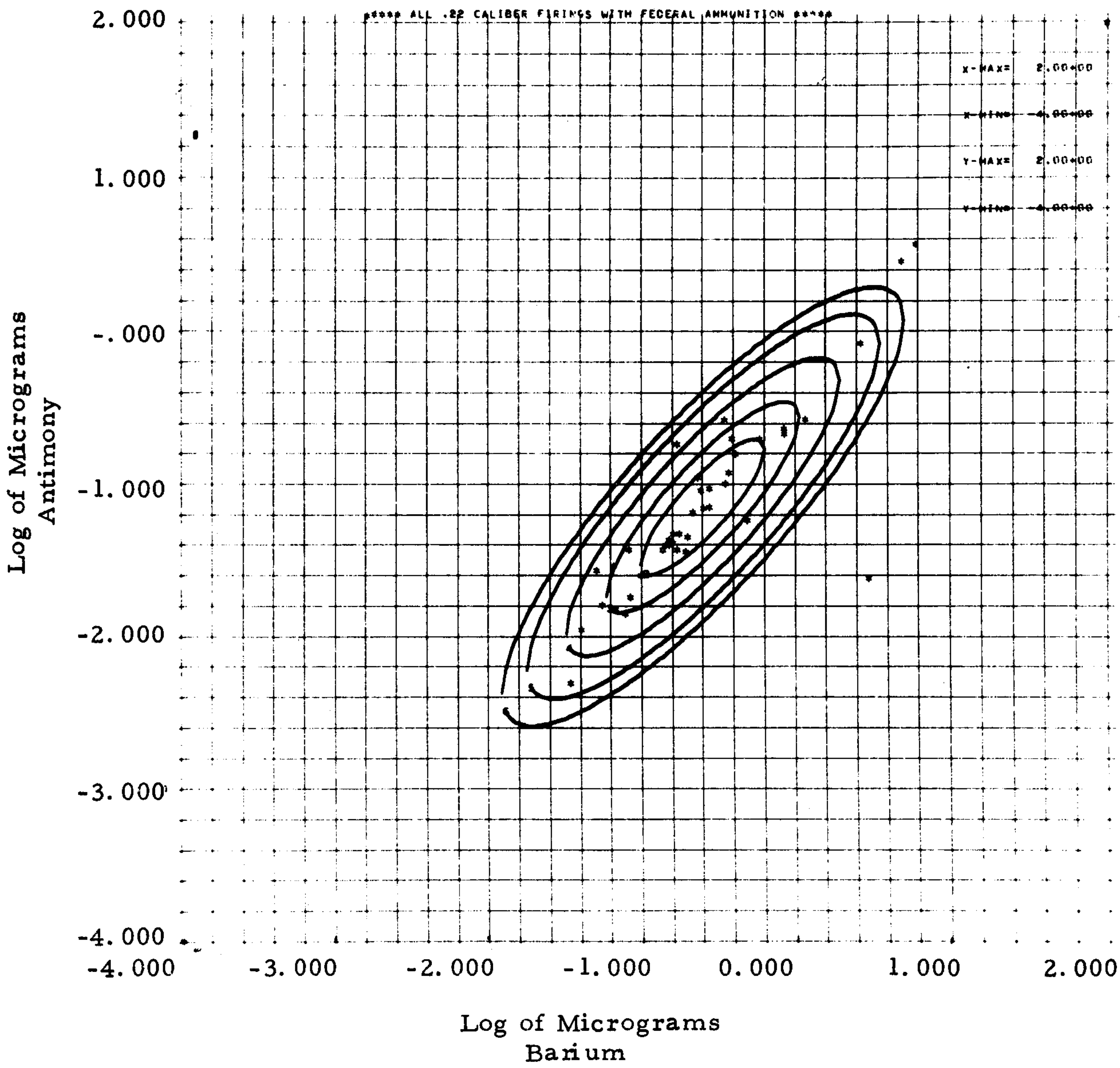


Fig. 15

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing Federal Ammunition in 0.22 Caliber Handguns, and Associated Solutions of the Bivariate Normal Density Function

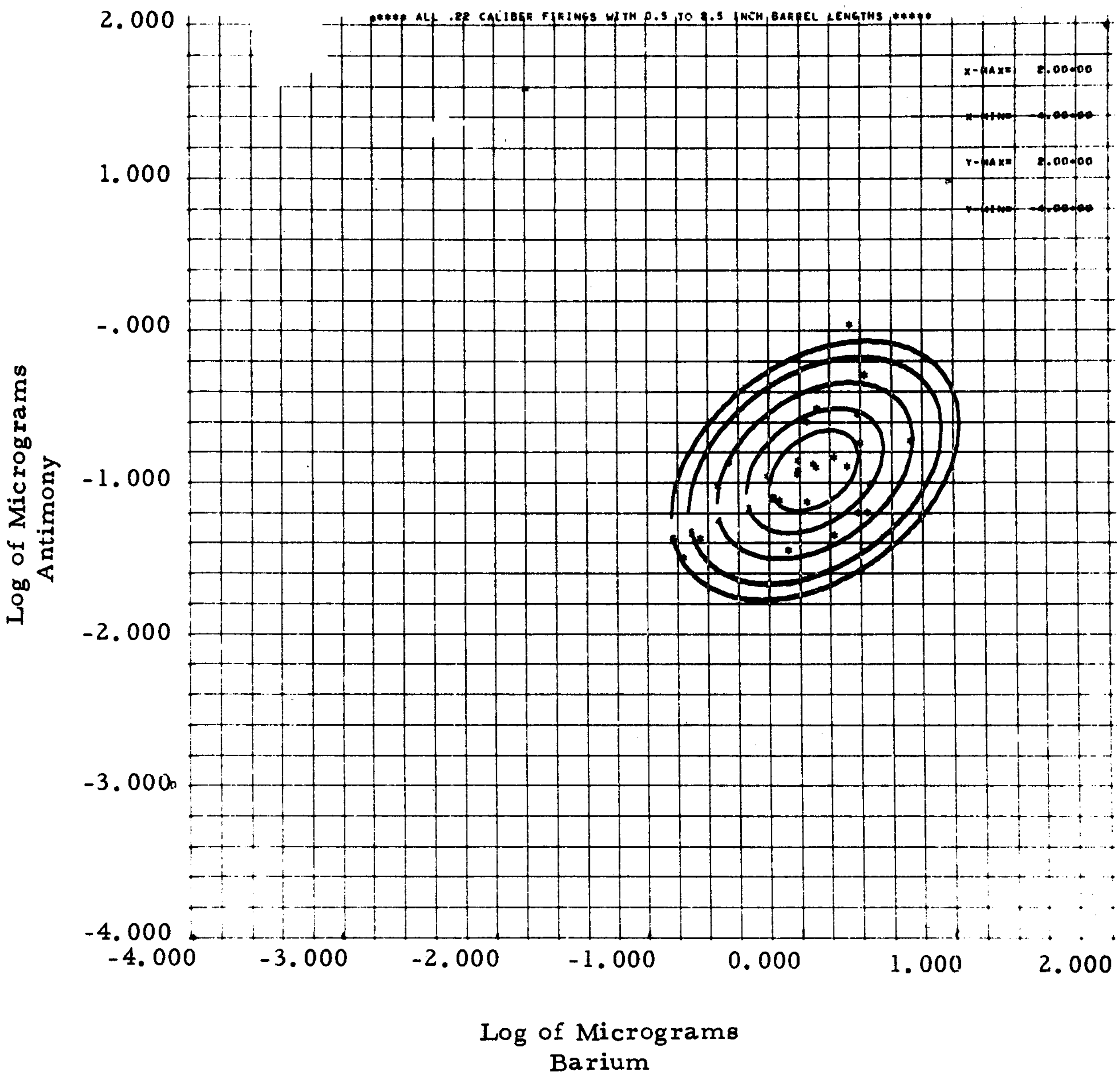


Fig. 16

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 0.22 Caliber Handguns with Barrels Less than 3.0 Inches in Length, and Associated Solutions of the Bivariate Normal Density Function

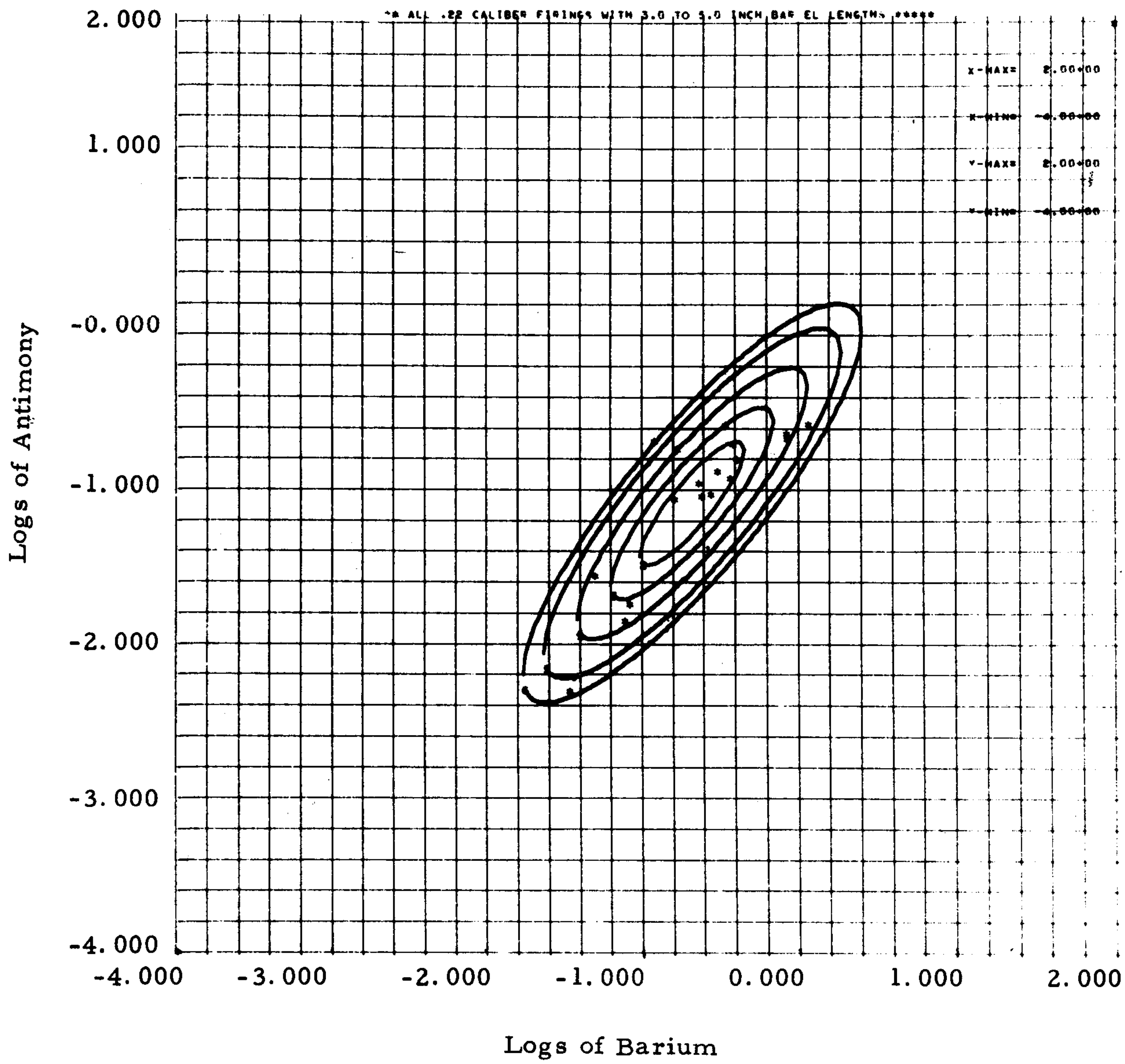


Fig. 17

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 0.22 Caliber Handguns with Barrels between 3.0 and 5.0 Inches in Length, and Associated Solutions of the Bivariate Normal Density Function

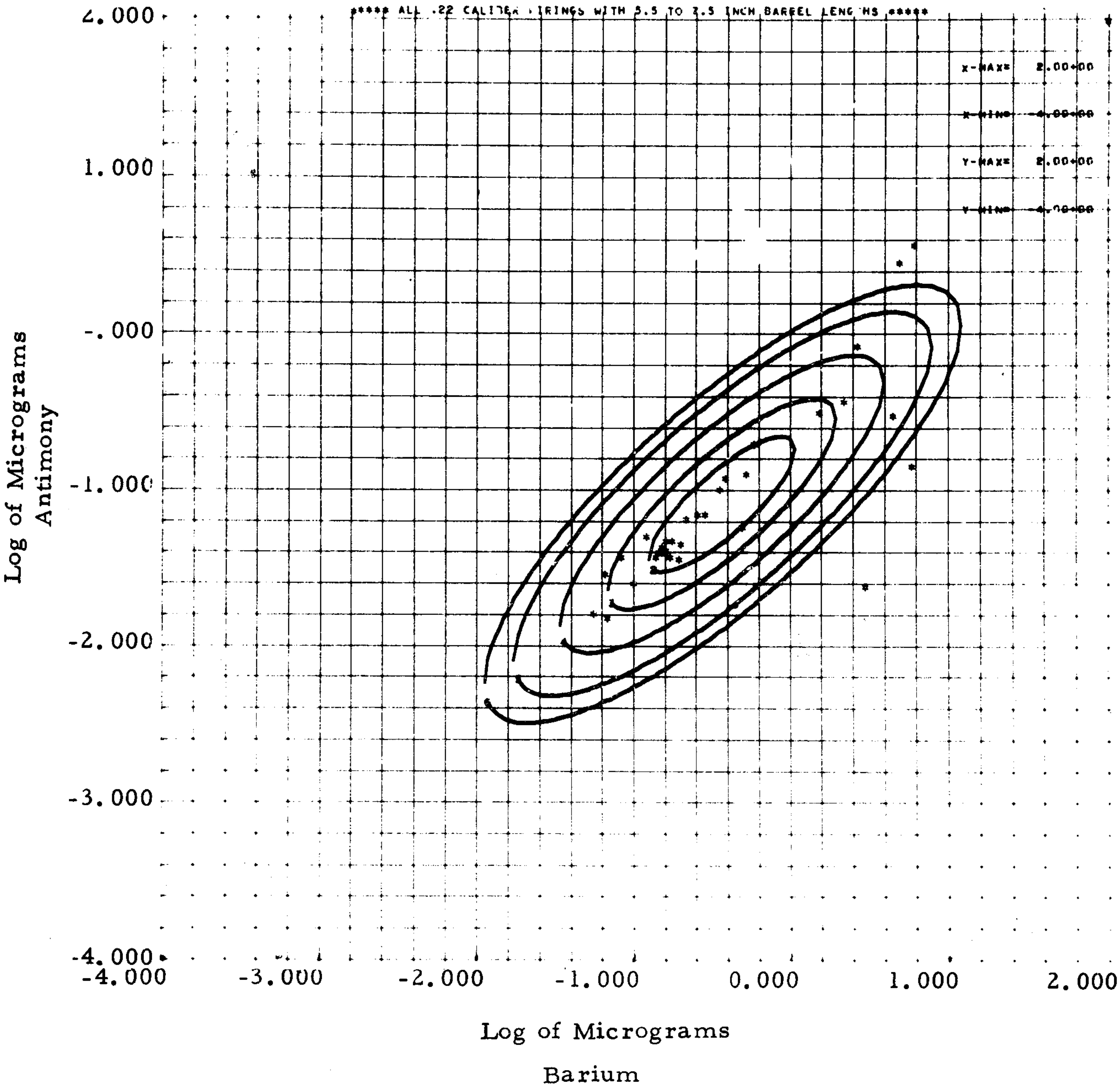


Fig. 18

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 0.22 Caliber Handguns with Barrels more than 5.0 Inches in Length, and Associated Solutions of the Bivariate Normal Density Function

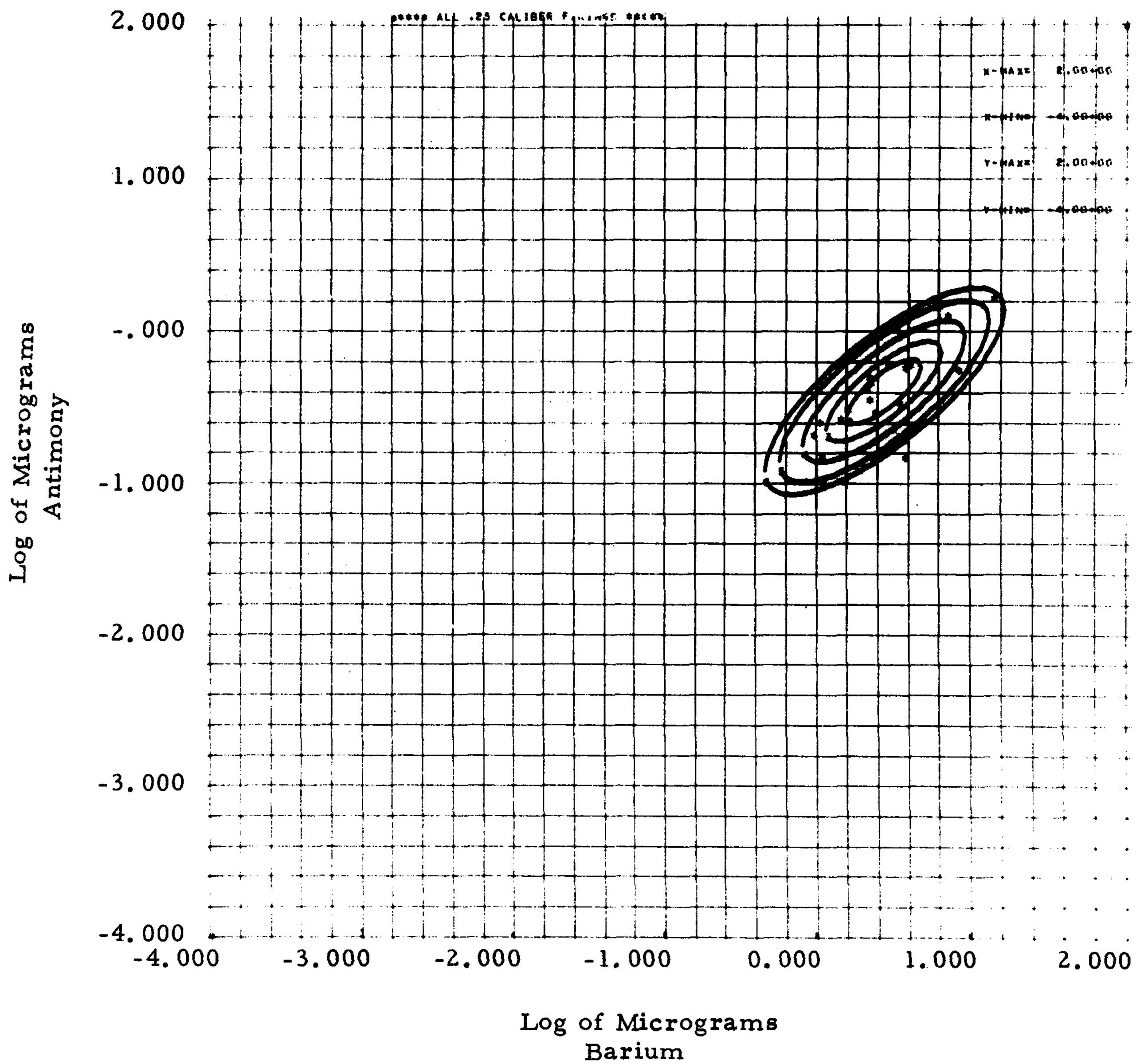


Fig. 19

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 0.25 Caliber Automatic Pistols, and Associated Solutions of the Bivariate Normal Density Function

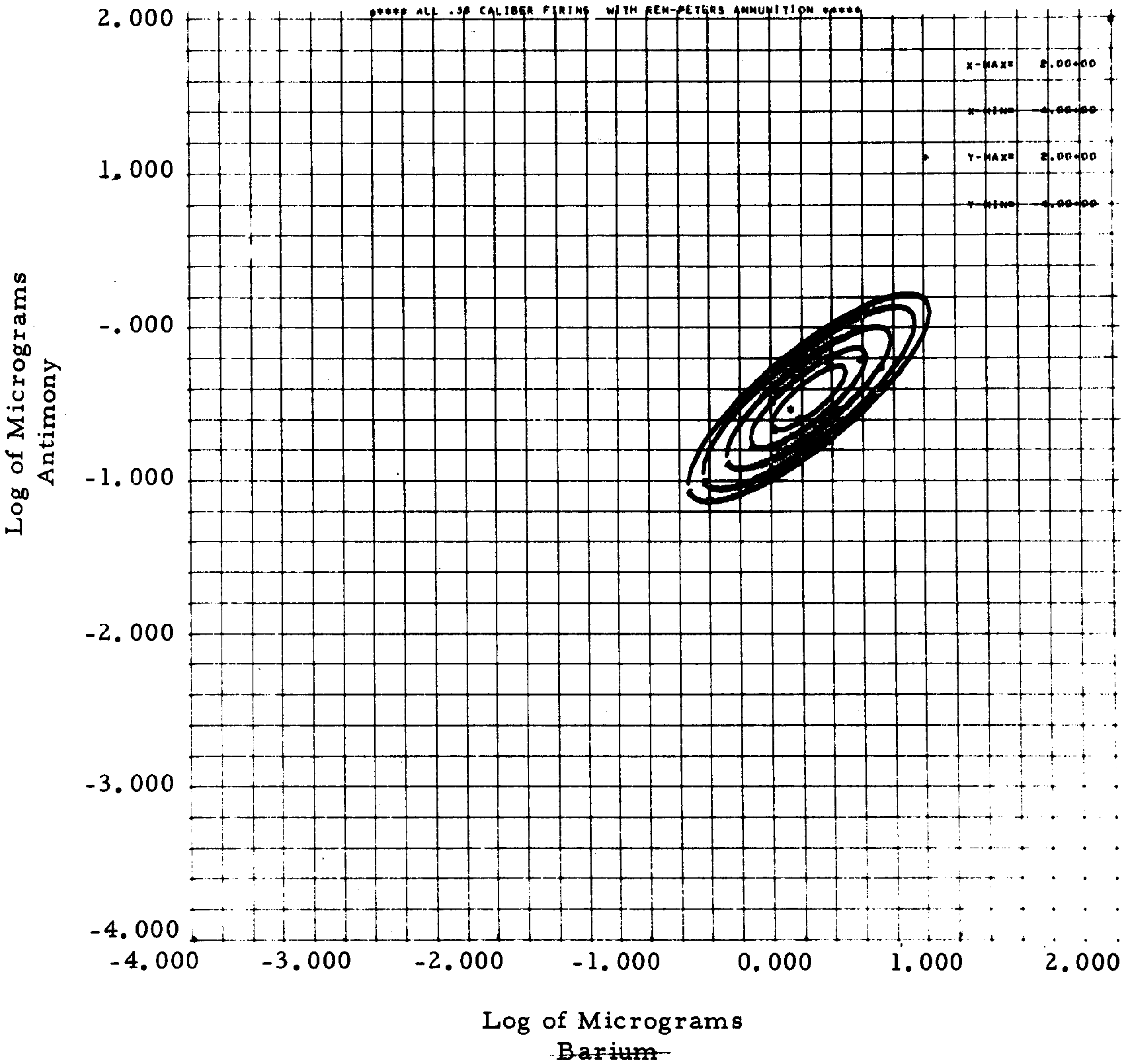


Fig. 20

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 0. 38 Caliber Revolvers, and Associated Solutions of the Bivariate Normal Density Function

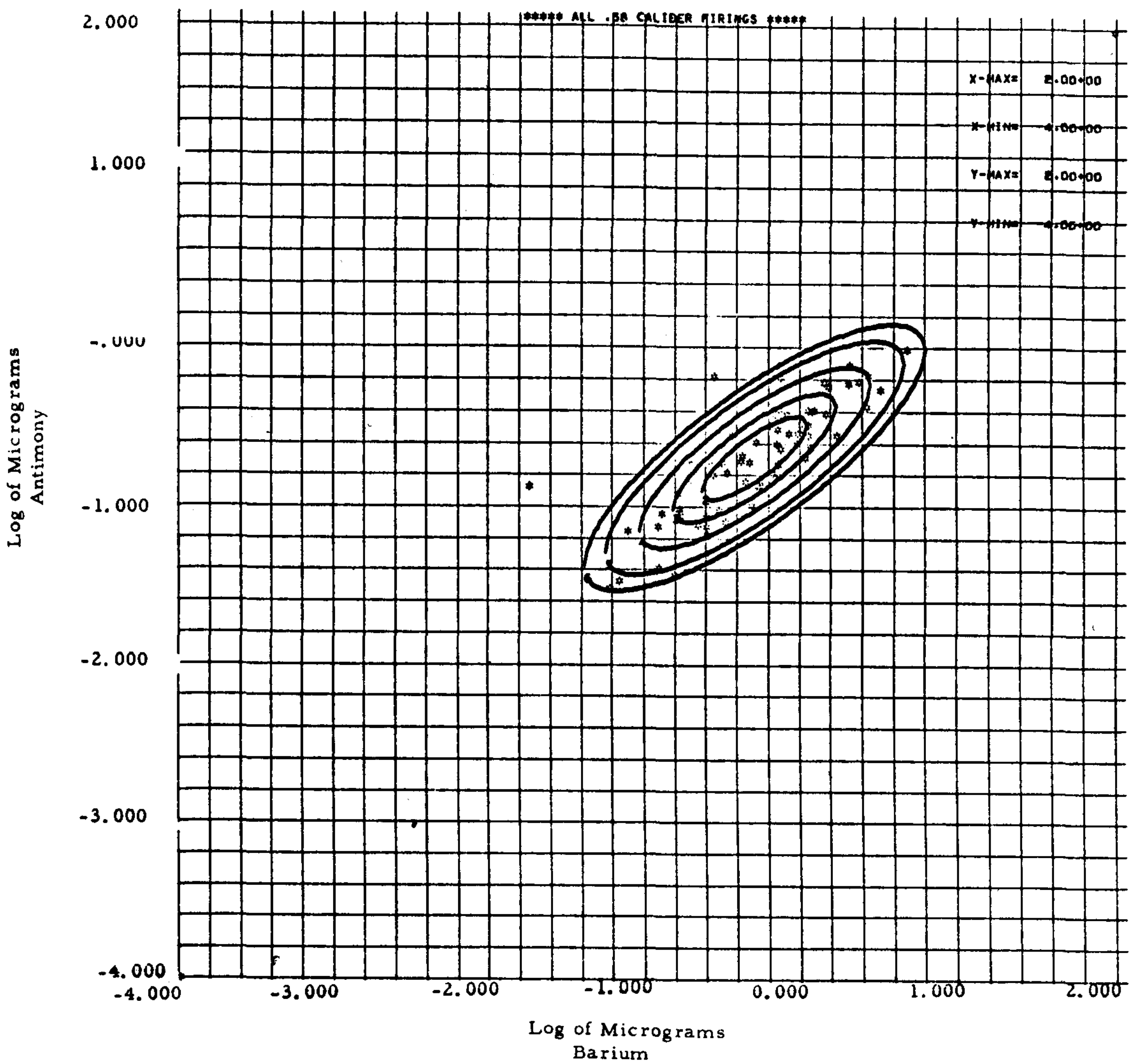


Fig 21

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing Remington-Peters Ammunition in 0.38 Caliber Revolvers, and Associated Solutions of the Bivariate Normal Density Function

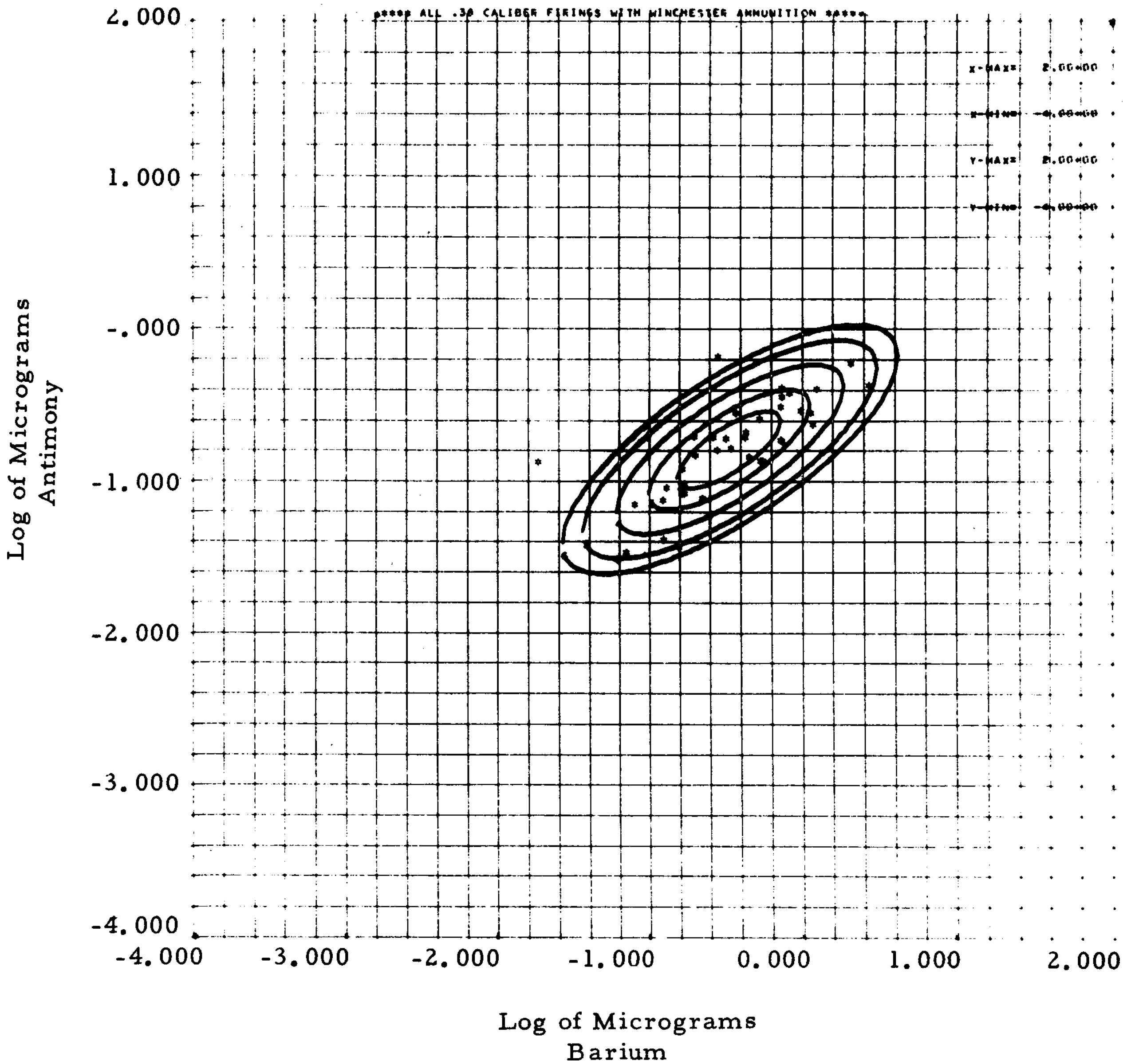


Fig. 22

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing Winchester-Western Ammunition in 0.38 Caliber Revolvers, and Associated Solutions of the Bivariate Normal Density Function

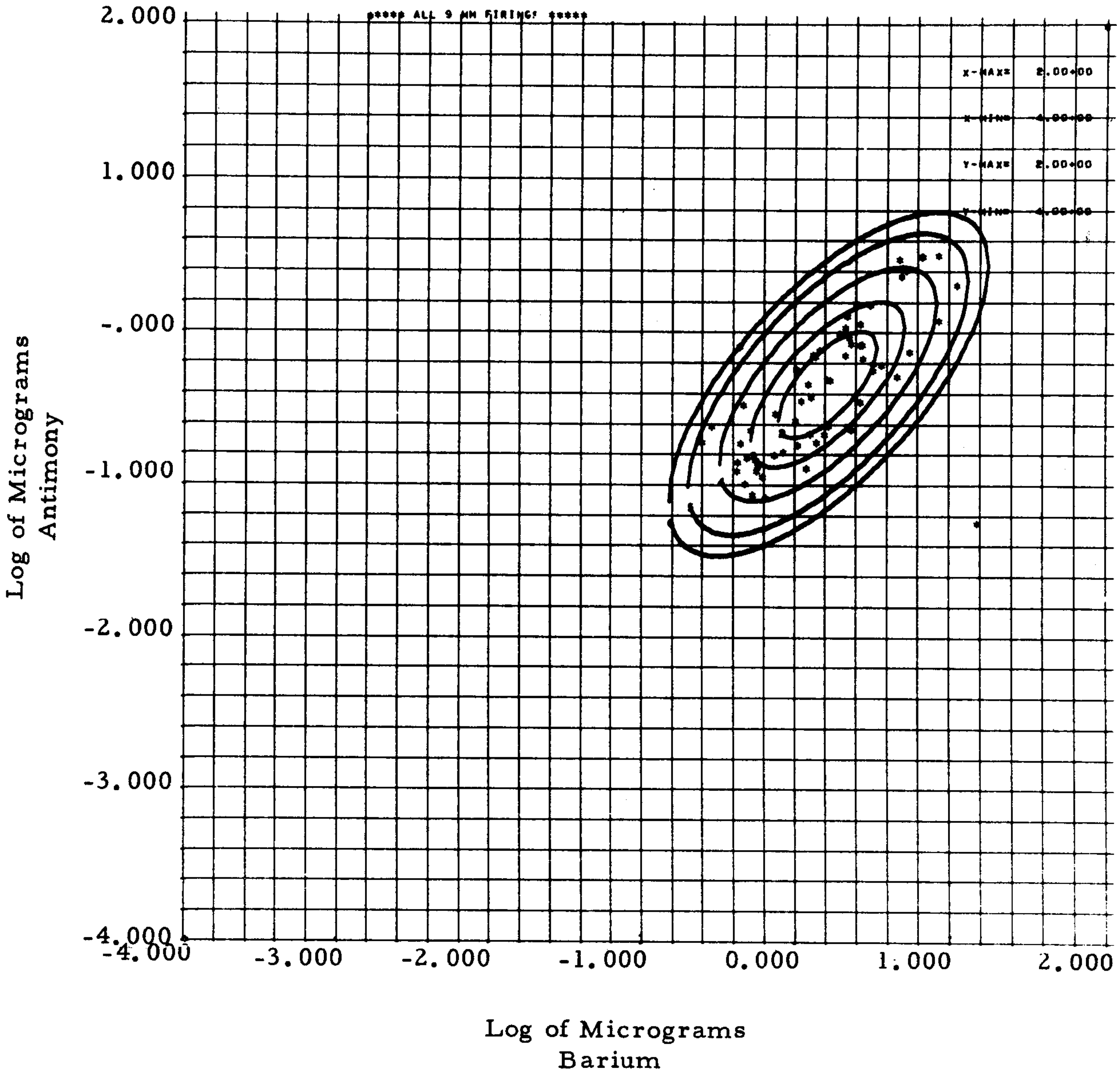


Fig. 23

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 9 mm Automatic Pistols, and Associated Solutions of the Bivariate Normal Density Function

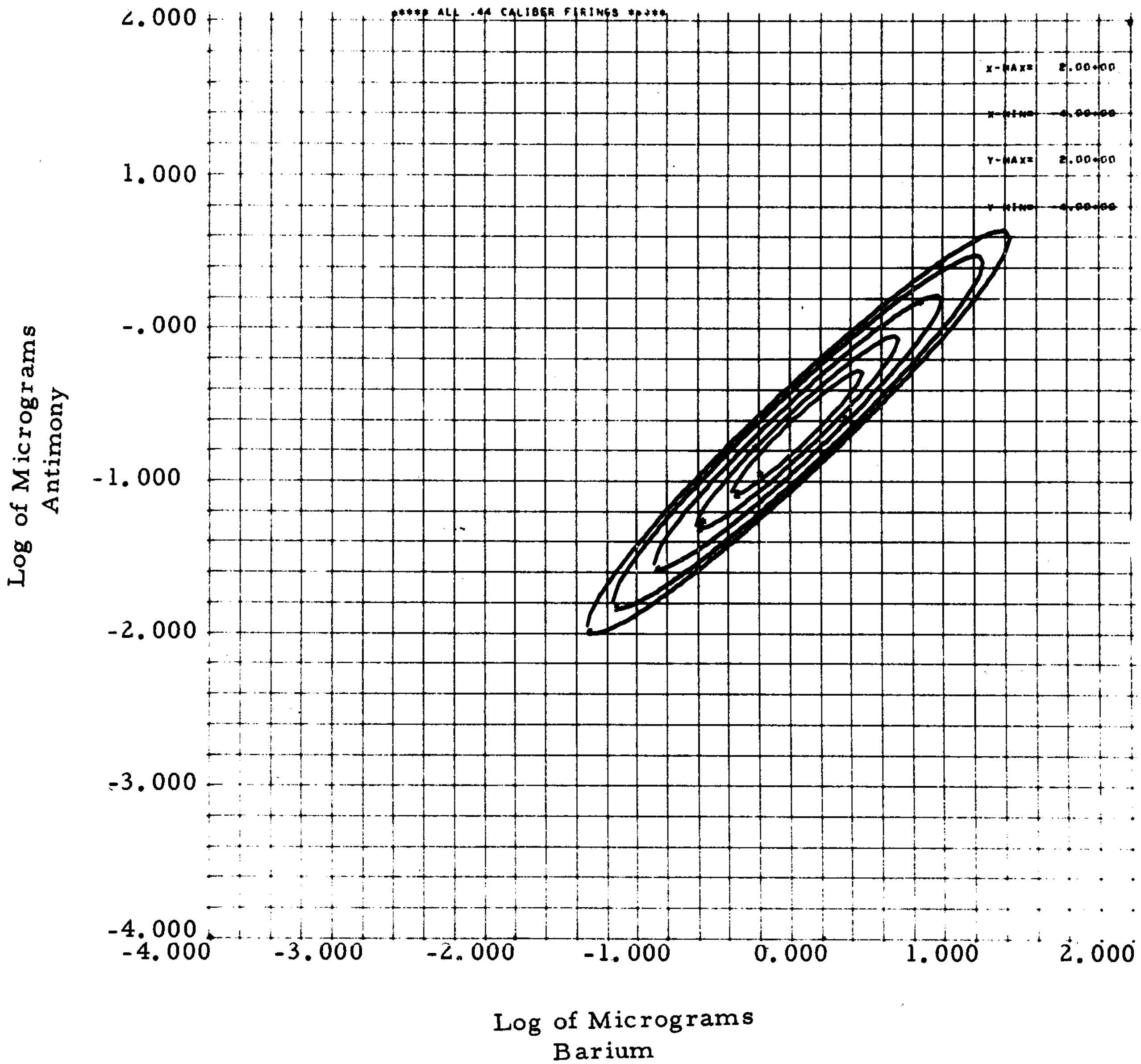


Fig. 24

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 0.44 Caliber Revolvers, and Associated Solutions of the Bivariate Normal Density Function

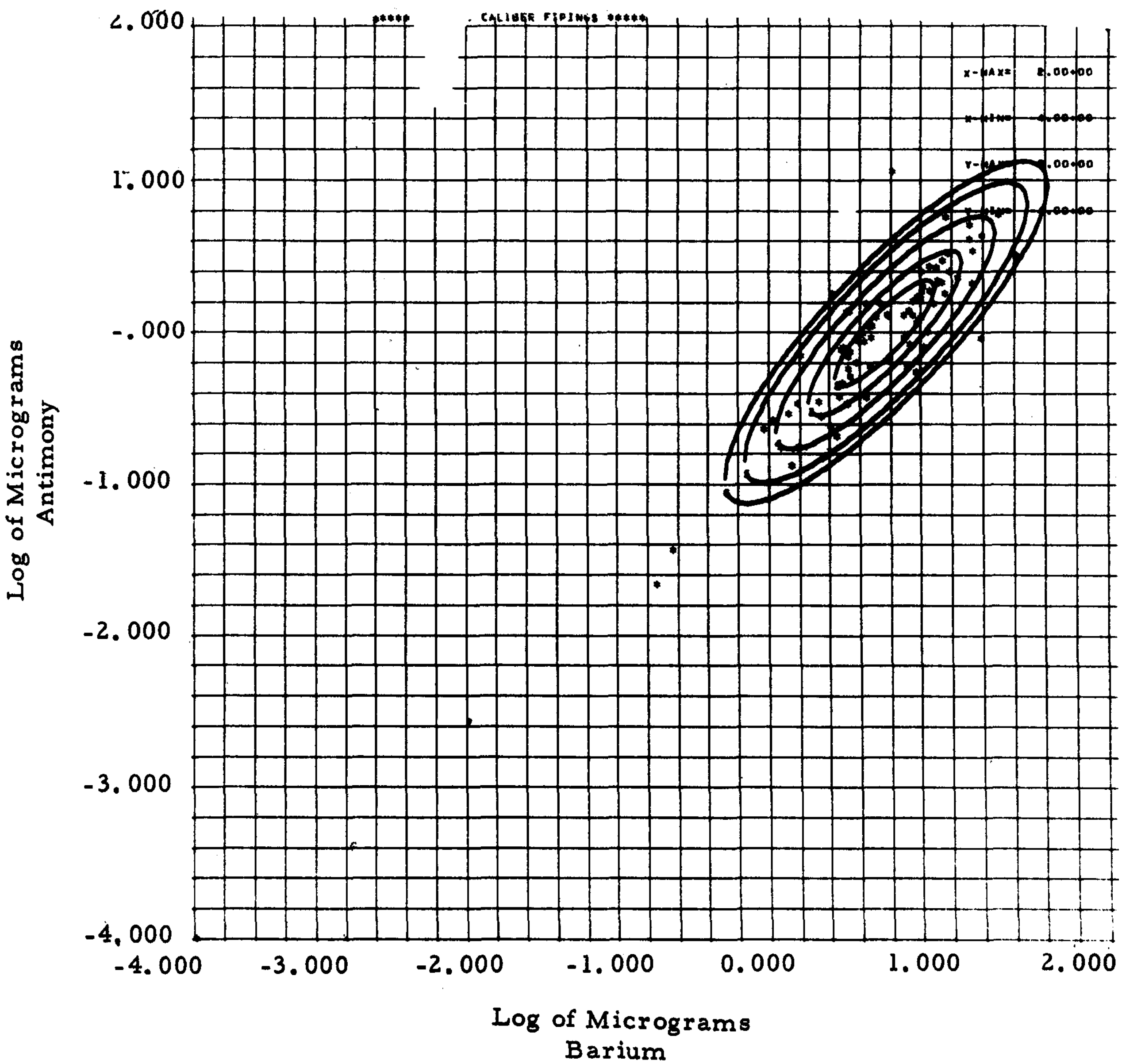


Fig. 25

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing 0.45 Caliber Automatic Pistols, and Associated Solutions of the Bivariate Normal Density Function

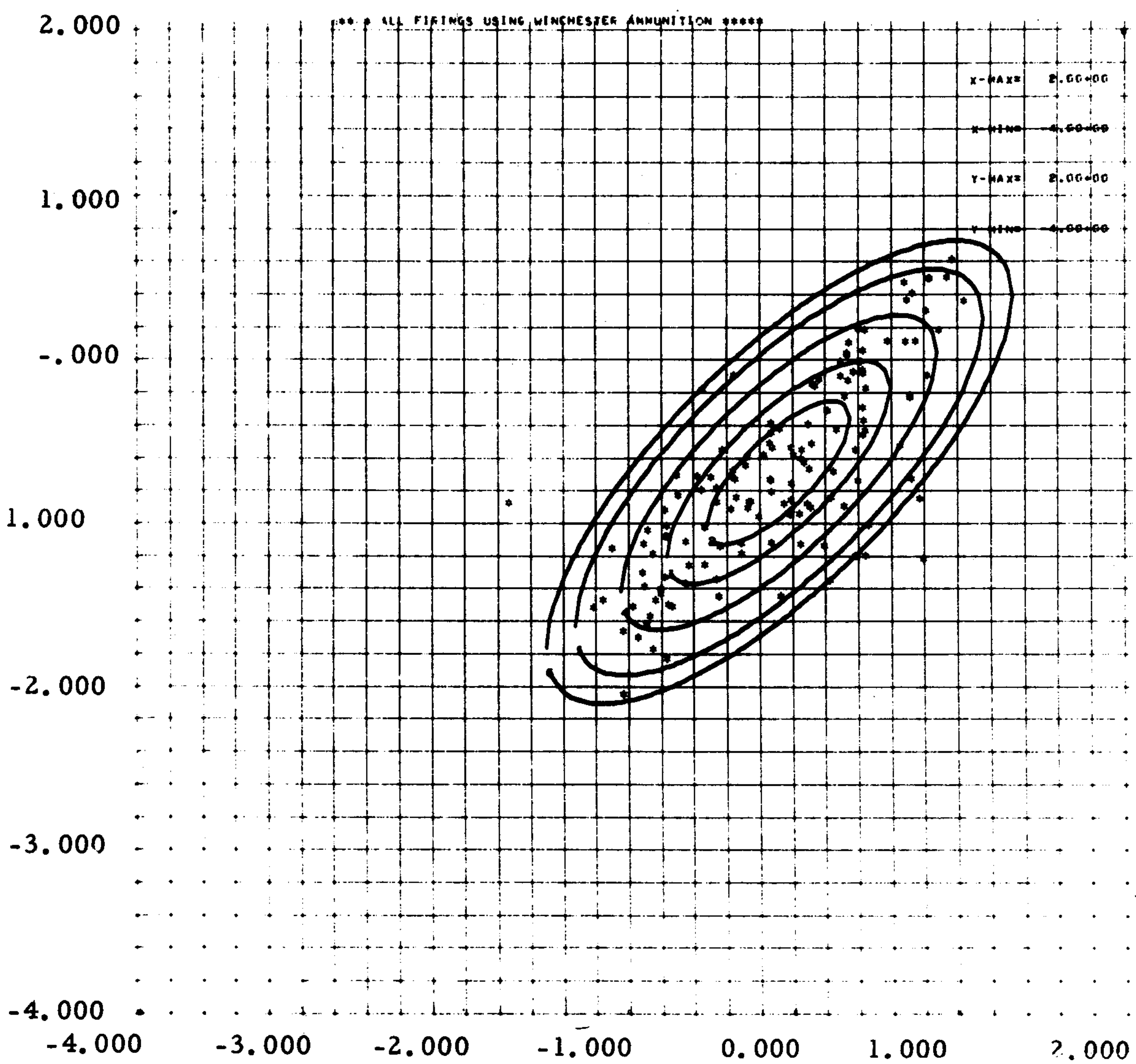


Fig. 26

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing Winchester-Western Ammunition in Handguns, and Associated Solutions of the Bivariate Normal Density Function

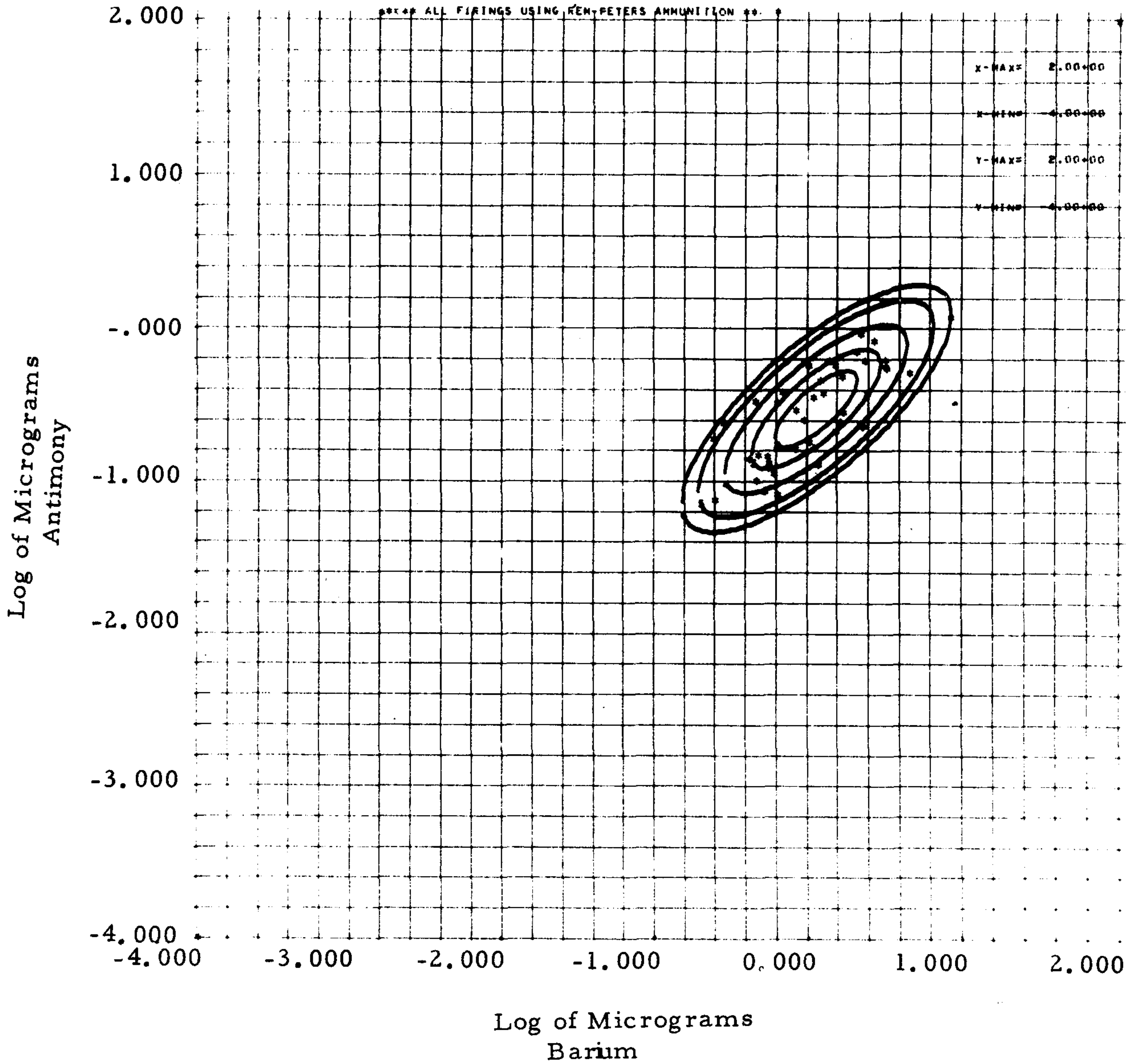


Fig. 27

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing Remington-Peters Ammunition in Handguns, and Associated Solutions of the Bivariate Normal Density Function

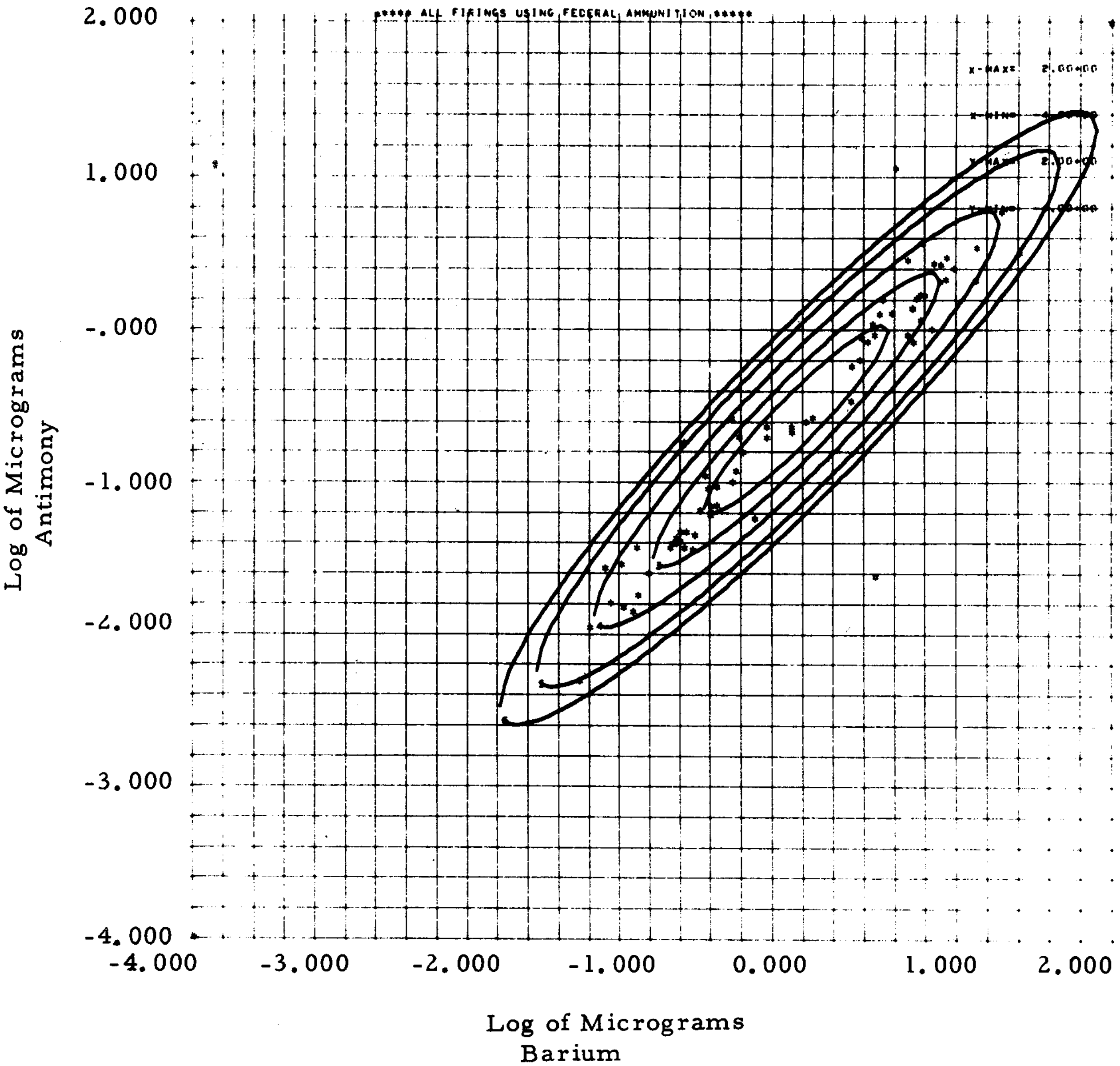


Fig. 28

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing Federal Ammunition in Handguns, and Associated Solutions of the Bivariate Normal Density Function

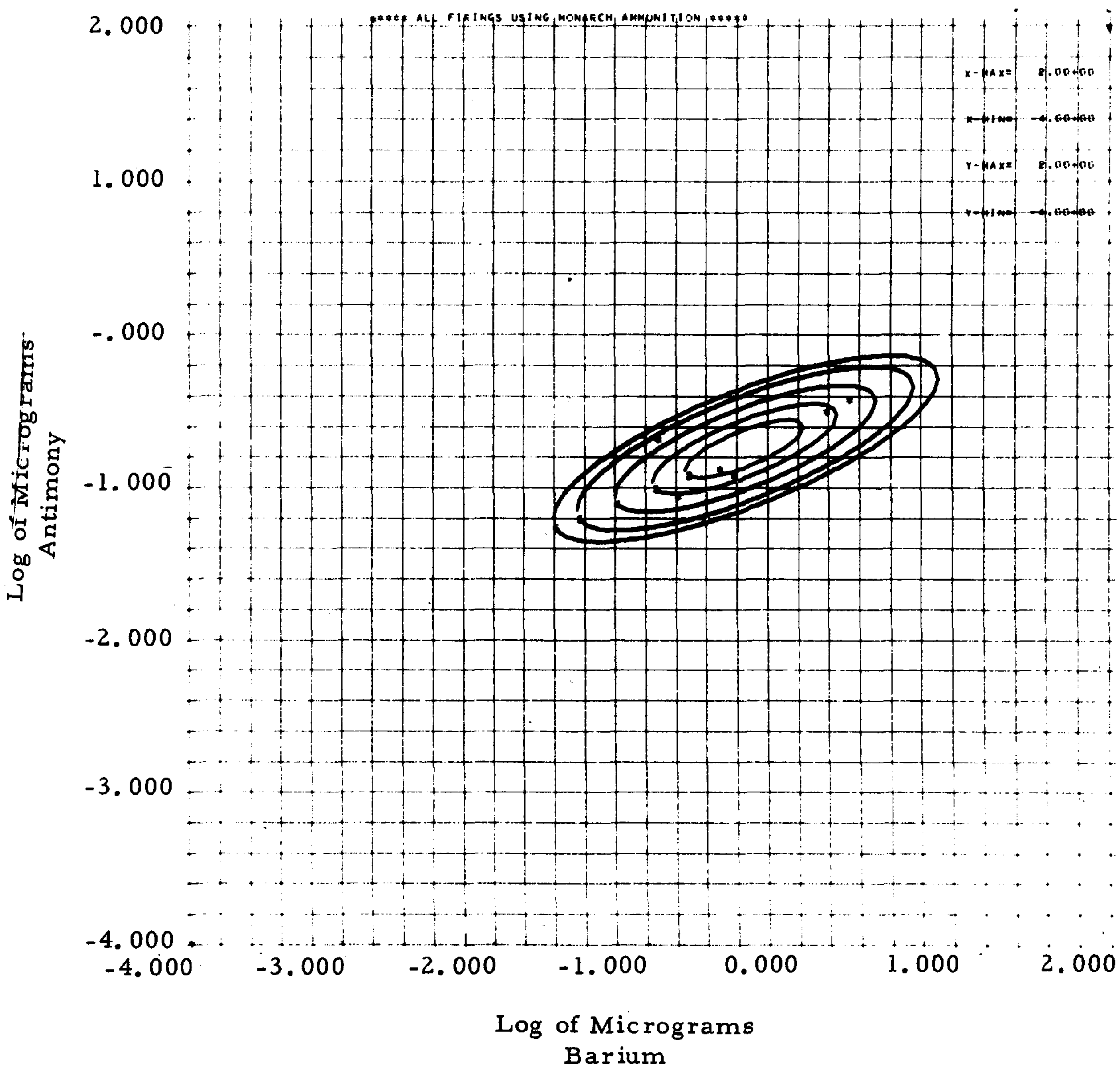


Fig. 29

Plot of Logarithms of Results Obtained from the Analysis of Handlifts Removed after Firing Monark Ammunition in Handguns, and Associated Solutions of the Bivariate Normal Density Function

Table 6

BARIUM AND ANTIMONY LEVELS IN SOME PRIMERS OF RECENT MANUFACTURE

Source of Sample	% Barium	% Antimony	Total Barium (mg)	Total Antimony (mg)	Barium/ Antimony Ratio
Remington No. 1-1/2 Primer	24.3	8.6	6.7	2.4	2.8
Winchester Large Pistol Primer	16.9	17.4	5.2	5.4	0.97
Federal No. 150 Primer	21.6	10.4	8.4	4.1	2.1
Primer from Federal 0.22 LR Cartridge	11.0	4.4	—*	—	2.5
Primer from Winchester 22S Cartridge	11.0	0.10	—	—	110.0

*Total primer weights could not be obtained due to the difficulty in removing all of the primer material from these cartridges.

Table 7

ANALYSES OF SOME TYPICAL PRIMERS

Component	Co. A (%)	Co. B (%)	Co. C (%)
Lead styphnate	38.7	39.7	42.8
Tetracene	4.4	1.1	0.91
Pentaerythritol tetranitrate (PETN)	4.4	----	-----
Nitrocellulose	-----	----	8.4
Barium nitrate	29.5	42.0	39.4
Antimony^{III} sulfide	14.4	8.7	8.1
Aluminum	6.5	----	-----
Calcium silicide	-----	6.0	-----

Table 8

BARIUM AND ANTIMONY RESULTS OBTAINED AFTER FIRING 0.22 CALIBER HANDGUNS LOADED WITH AMMUNITION FROM TWO MANUFACTURERS

Type of Handgun Fired	Type of Ammunition	Barium (μg)*	Antimony (μg)*
Automatic	Winchester-Western Super X 22LR	1.3**	0.2**
Revolver	Same as above	0.2***	0.04***
Automatic	Federal 22LR	0.3**	0.1**
Revolver	Same as above	0.1***	0.1***

*Results reported after correcting for control samples, only significant digits given.
**Mean of three samples.
***Mean of two samples.

Table 9

HANDGUNS USED IN THE STUDY

Code No.	Caliber	Barrel Length (in.)	Description
1	0.25	2.	Jr. Colt Automatic
2	0.22	6.5	Hi Standard Automatic
3	0.22	6.	S & W Revolver
4	0.22	2.5	Rosco Arms Corp. Derringer
5	0.22	2.5	Burgo Mod. 106 Revolver
6	0.22	4.	S. Ruger Revolver
7	0.22	4.5	S. Ruger Single Action Revolver
8	0.22	4.	Converted 0.45 Caliber Colt Automatic
9	0.45	5.	Colt Automatic
10	0.45	5.	Colt Military Automatic
11	0.45	5.	Military Automatic
12	0.45	5.	Colt Govt. Model Atuomatic
13	0.45	5.	Colt Govt. Model Automatic
14	0.25	2.	Rigarmi-Brescia Automatic
15	9 mm.	4.	Luger
16	9 mm	5.	Walther Automatic
19	9 mm	5.	FN Automatic
21	0.22	4.5	Ruger Single Action Revolver
22	0.22	6.	Hi Standard Automatic
23	.45	5.	Colt Automatic
24	.38	4.	S.& W Revolver
25	0.22	6.	Hi Standard Heavy Barrel Automatic

Table 10

SUMMARY OF STATISTICAL PARAMETERS DERIVED FROM LOGARITHMS OF BARIUM AND ANTIMONY RESULTS

Set	Description	$\overline{Ba}$[a]	$\overline{Sb}$[b]	σ_{Ba}[c]	σ_{Sb}[d]	χ^2_{Ba}/n[e]	χ^2_{Sb}/n[f]	α_{Ba}[g]	α_{Sb}[h]	ρ[i]	N[j]
1	All Handblanks	-0.751	-1.969	0.560	0.594	17.4/10	46.2/10	0.066	$1x10^{-6}$	0.500	260
2	Handblanks from Smokers	-0.910	-1.22	0.670	0.520	2.16/3	0.558/2	0.540	0.757	0.323	29
3	Handblanks from Non-Smokers	-0.674	-1.937	0.559	0.621	4.67/7	13.9/7	0.700	0.053	0.490	92
4	Class A Handblanks	-0.992	-2.150	0.439	0.552	3.923/6	48.1/8	0.687	$7.45x10^{-8}$	0.393	165
5	Class B Handblanks	-0.279	-1.900	0.423	0.462	3.57/3	4.92/3	0.312	0.177	-0.008	38
6	Class C Handblanks	-0.875	-1.612	0.362	0.263	1.51/1	0.476/1	0.219	0.490	0.640	16
7	Class D Handblanks	-0.176	-1.44	0.462	0.569	5.20/3	8.07/2	0.158	0.018	0.601	41
8	All Firings	-0.010	-0.580	0.619	0.616	35.0/12	11.8/12	$5x10^{-4}$	0.464	0.850	353
9	Revolver Firings	-0.440	-0.913	0.478	0.470	7.79/6	6.57/7	0.254	0.475	0.823	132
10	Automatic Pistol Firings	+0.290	-0.374	0.522	0.605	33.7/9	10.5/10	$1.x10^{-4}$	0.396	0.823	219
11	0.22 Caliber Handgun Firings	-0.391	-1.124	0.553	0.484	20.7/8	5.66/6	0.008	0.462	0.740	108
12	0.22 Caliber Automatic Pistol Firings	-0.109	-1.103	0.533	0.491	13.3/5	0.865/4	0.020	0.930	0.746	53
13	0.22 Caliber Revolver Firings	-0.662	-1.220	0.420	0.458	1.36/3	5.93/4	0.310	0.204	0.764	55
14	0.22 Caliber Handgun Firings, using Winchester Cartridges	-0.211	-1.140	0.534	0.390	8.30/4	3.10/3	0.081	0.376	0.730	53
15	0.22 Caliber Handgun Firings, using Federal Cartridges	-0.605	-0.116	0.518	0.589	5.82/2	7.89/2	0.055	0.019	852	41

Table 10 (Continued)

Set	Description	$\bar{Ba}$[a]	$\bar{Sb}$[b]	σ_{Ba}[c]	σ_{Sb}[d]	$\chi^2_{Ba/n}$[e]	$\chi^2_{Sb/n}$[f]	α_{Ba}[g]	α_{Sb}[h]	ρ[i]	N[j]
16	0.22 Caliber Handguns with Barrels Shorter than 3.0 Inches	+0.104	-0.926	0.382	0.336	1.76/1	1.51/1	0.185	0.336	0.366	27
17	0.22 Caliber Handguns with Barrels Between 3.0 and 5.0 Inches Long	-0.684	---	0.442	---	0.684	---	0.408	---	0.863	19
18	0.22 Caliber Handguns with Barrels Longer than 5.0 Inches	-0.442	-1.097	0.602	0.569	5.21/2	5.37/2	0.074	0.068	---	33
19	0.25 Caliber Automatic Pistol Firings	+0.456	-0.389	0.313	0.273	0.820/1	0.513/2	0.365	0.774	0.777	18
20	0.38 Caliber Revolver Firings	-0.291	-0.691	0.449	0.337	6.47/5	1.06/3	0.263	0.785	0.813	74
21	0.38 Caliber Revolver Firings, using Remington Ammunition	+0.060	-0.460	0.318	0.292	0.356/1	1.24/1	0.550	0.265	0.829	10
22	0.38 Caliber Revolver Firings, using Winchester Ammunition	-0.497	-0.805	0.451	0.323	3.64/3	2.49/2	0.303	0.287	0.752	39
23	9mm Automatic Pistol Firings	-0.215	-0.332	0.426	0.462	3.39/4	6.20/5	0.495	0.287	0.690	65
24	0.44 Caliber Revolver Firings	-0.160	-0.680	0.493	0.480	3.60/4	3.60/4	0.463	0.463	0.965	5
25	0.45 Caliber Automatic Pistol Firings	+0.569	-0.012	0.430	0.453	11.9/4	5.52/5	0.018	0.355	0.860	83
26	Firings of Handguns, using Winchester Ammunition	-0.093	-0.690	0.579	0.586	30.0/9	14.7/9	$4x10^{-4}$	0.100	0.762	140
27	Firings of Handguns, using Remington Ammunition	+0.0619	-0.514	0.364	0.328	0.628/2	1.81/2	0.730	0.405	0.765	42

Table 10 (Continued)

Set	Description	$\overline{Ba}$[a]	$\overline{Sb}$[b]	σ_{Ba}[c]	σ_{Sb}[d]	$\chi^2_{Ba/n}$[e]	$\chi^2_{Sn/n}$[f]	α_{Ba}[g]	α_{Sb}[h]	ρ[i]	N[j]
28	Firings of Handguns, using Federal Ammunition	-0.039	-0.586	0.790	0.827	18.9/6	17.8/6	0.004	0.007	0.942	72
29	Firings of Handguns, using Monark Ammunition	-0.367	-0.700	0.506	0.245	1.81/2	1.57/1	0.405	0.209	0.755	6

---

a $\overline{Ba}$ Mean value of the logarithm of the micrograms of barium found in a handlift. The shorthand notation, -0.xxx, implies 9.yyy-10.

b $\overline{Sb}$ Mean value of the logarithm of the micrograms of antimony found in a handlift. The shorthand notation, -0.xxx, implies 9.yyy -10.

c σ_{Ba} Standard deviation about $\overline{Ba}$.

d σ_{Sb} Standard deviation about $\overline{Sb}$.

e $\chi^2_{Ba/n}$ The value of χ^2 for the set of barium values, the assumed distribution, and n degrees of freedom.

f $\chi^2_{Sb/n}$ The same as $\chi^2_{Ba/n}$, but for antimony values.

g α_{Ba} The probability that a randomly selected set of data points would yield a greater value for χ^2

h α_{Sb} The same as α_{Ba}, but for the set of antimony values in the set.

i ρ The correlation coefficient for the pairs of barium-antimony values in the set.

j N The number of pairs of barium-antimony values in the set.

5. STATISTICAL TREATMENT OF THE DATA

5.1 PRELIMINARY EXAMINATION OF THE DATA

The data given in Table 1 - 5 were subjected to distribution tests. Barium and antimony values within each handblank and caliber classification were tested for log normal (Gaussian) distribution. Care was taken to avoid dividing concentration ranges into too few groups (which would favor an unwarranted positive test). Examples of these tests, which used the chi-square test of the hypothesis that the logarithms of the values had a normal frequency distribution, follow:

Sb
Class D Handblank
41 Samples[a]

G	E	O	$(E-O)^2/E$
1	0.3	0	0.3
2	1.1	3	7.6
3	3.2	2	0.5
4	6.5	4	0.3
5	9.3	12	0.8
6	9.3	5	2.0
7	6.5	7	0.0
8	3.2	6	2.4
9	1.1	1	0.0
10	0.3	1	1.6
	chi-square =		13.5

Sb
0.22 Caliber Firings
108 Samples[a]

G	E	O	$(E-O)^2/E$
1	0.8	2	1.8
2	3.0	5	1.3
3	8.5	14	3.6
4	17.1	28	8.3
5	24.3	28	0.9
6	24.3	20	0.8
7	17.1	6	7.2
8	8.5	2	5.0
9	3.0	1	1.3
10	0.8	2	1.8
	chi-square =		32.0

[a] G = consecutive and equal logarithmic increments of concentration.
E = expected number of observations per increment, if Gaussian.
O = observed number of observations per increment.

In the foregoing examples, the chi-square value of the class D handblank is consistent with the hypothesis, but the value for the 0.22 caliber firings is inconsistent. In fact, there is less than a 1% chance that the latter is Gaussian.

As it turned out the Sb and Ba values in a majority of classifications were not log-normally distributed when tested as described above. This did not rule out the possibility of BVN distributions, however.

Parenthetically, it may be remarked that the use of only 4 or 5 increments to contain the data usually resulted in a positive test for normal distribution. This indicated that correlation coefficients between Ba and Sb were of fair validity.

The BVN density function is given by Eq. C-2 in Appendix 3. The exponential, on expansion, takes the form: $ax^2 + 2bxy + cy^2 + 2dx + 2ey + f$. The necessary and sufficient condition for BVN distribution is that $ac - b > 0$. This was found to be true in all classifications, and thus Ba and Sb are deemed to have a BVN distribution in all cases.

Based on these findings two methods of data interpretation were employed. The decision procedure described in the section, "The Bivariate Normal Statistical Model", which is the method originally envisioned as the sole interpretation method, is described next. A second method engendered by the preliminary statistical results and certain physical considerations is then described.

5.2 DECISION PROCEDURE

For a given observation $\underset{\sim}{X} = (X_1, X_2)$, the following procedure is designed to decide between the hypothesis H_0 that the observation was obtained from a specified population of handblanks and the hypothesis H_1 that $\underset{\sim}{X}$ belongs to a given population of handgun firings. It is assumed that H_0 is represented by a bivariate normal (BVN) distribution having mean vector $\underset{\sim}{\mu}$ and covariance matrix Σ while H_1 is characterized by a BVN distribution with parameters $\underset{\sim}{\nu}$ and T.

The procedure is to reject H_0 (decide that the observation $\underset{\sim}{X}$ is a firing) if

$$\underset{\sim}{X}(T^{-1} - \Sigma^{-1})\underset{\sim}{X} \quad - \quad 2(\underset{\sim}{\nu}^1 T^{-1} - \underset{\sim}{\mu}^1 \Sigma^{-1})\underset{\sim}{X} < k \tag{1}$$

where k is chosen so that the probability α of rejecting H_0 when it is true is a specified number (e.g., $\alpha = 0.01$). This choice of k results in a corresponding probability β of accepting H_0 when it is false.

The set of points (x_1, x_2) which satisfy the inequality (1) is called the critical region C_k. The error probabilities α and β can be expressed as integrals over the critical region:

$$\alpha = \iint_{C_k} f_0(x_1, x_2) dx_1 \, dx_2 \quad ,$$

$$\beta = \iint_{D_k} f_1(x_1, x_2) dx_1 \, dx_2 \quad ,$$

or

$$\beta = 1 - \iint_{C_k} f_1(x_1, x_2) dx_1 \, dx_2 \quad ,$$

where f_0 and f_1 are the BVN densities associated with H_0 and H_1, respectively, and D_k is the set of points (x_1, x_2) which do not belong to the critical region C_k.

The problem is first transformed so that the critical region C_k is determined by the inequality

$$r x_1^2 + s x_2^2 < c + k$$

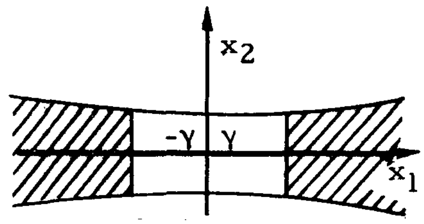
where r, s, c are functions of $\underset{\sim}{\mu}$, $\underset{\sim}{\nu}$, Σ, T.

These are four cases:

1. $r > 0$, $s > 0$ — critical region is interior of ellipse
2. $r < 0$, $s < 0$ — critical region is exterior of ellipse
3. $r < 0$, $s > 0$ — critical region is between branches of a hyperbola having a horizontal orientation as shown in the sketch.

   If $c + k > 0$, $\gamma = 0$ and if

   $c + k < 0$, $\gamma = \sqrt{\frac{c + k}{r}}$



4. $r > 0$, $s < 0$ — similar to case 3 except that the hyperbola has a vertical orientation and $\gamma = \sqrt{\frac{c + k}{s}}$ or $\gamma = 0$.

The first two cases are treated by using a computer program (CALTAB) to transform the ellipse into a circle centered at the origin. The corresponding transformations are also applied to the BVN distributions involved. A set of tables can then be used to determine k and β for a given value of α.[15]

There are no tables available to aid in the solution of the problem for cases 3 and 4, and consequently, a numerical integration scheme must be used. A computer program (BVN), described in Appendix IV, was written for this purpose.

The results of the calculation of the error probabilities α and β are given in Table 11. Diagrams illustrating the critical regions for these choices of α and β for the various comparisons of handblanks and firings are shown in Figs. 30-38.

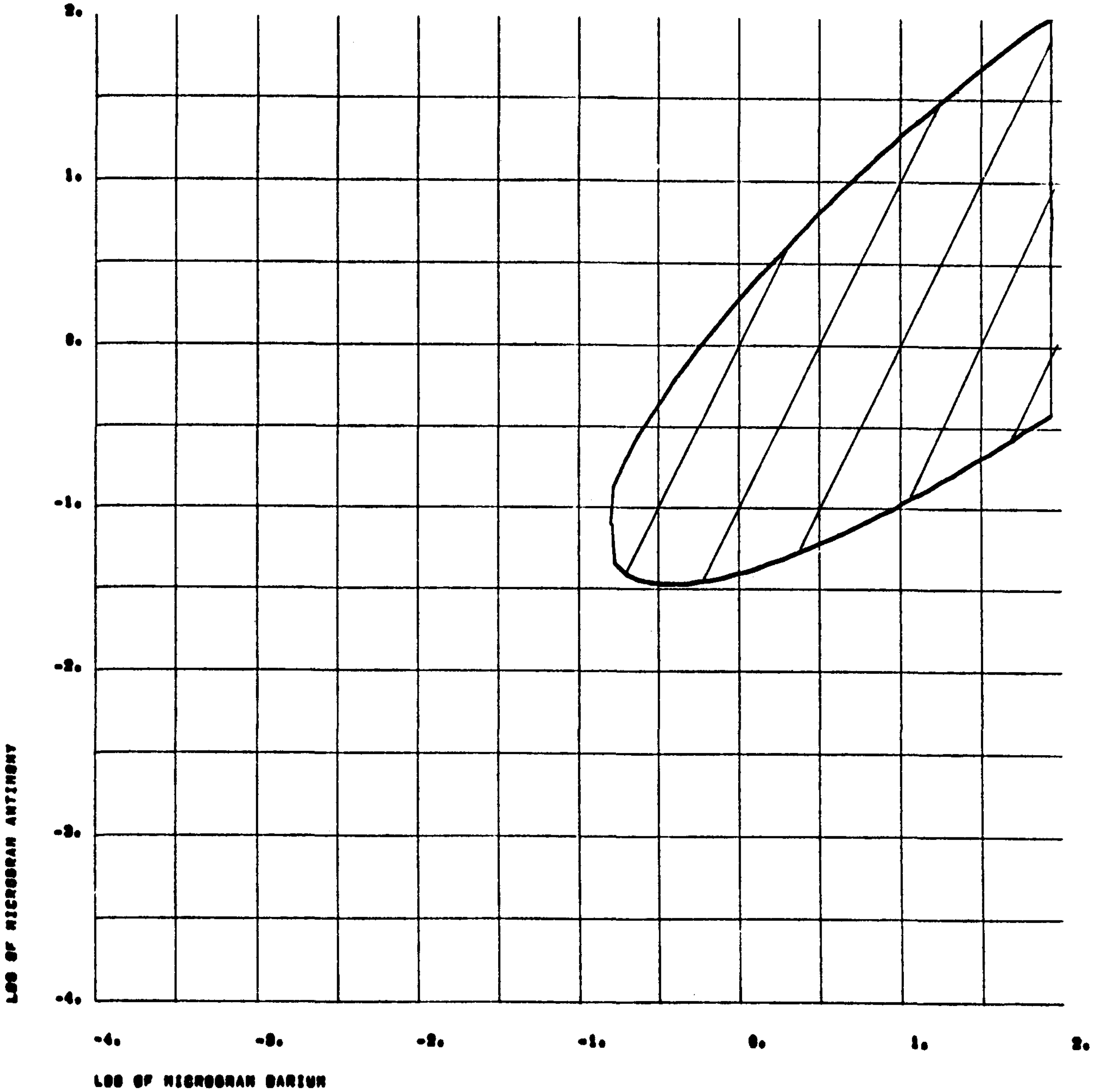
5.3 A SIMPLIFIED INTERPRETATION METHOD[21]

It has come to light that the bulk of Ba and Sb in gunshot residues deposited on the hand is contained in a small number (10-20) of relatively large (10-50 μ) particles. Furthermore, it appears that some particles are Ba-rich and others are Sb-rich. Thus the lack of log-normal distribution of Ba and Sb values is not inconsistent with a BVN distribution, if one assumes the number of particles follows a Gaussian distribution and the

Table 11

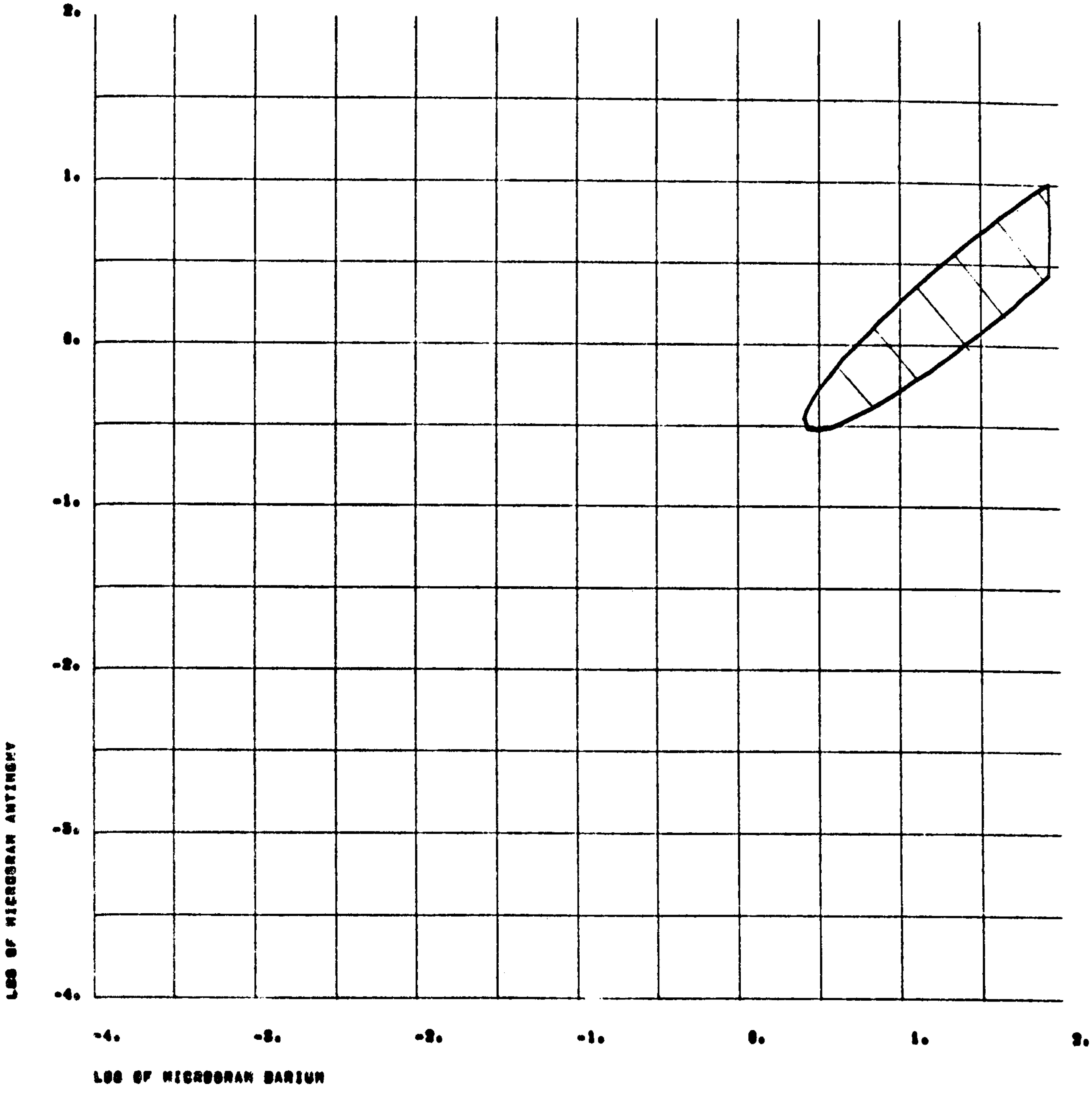
ERROR PROBABILITIES FOR GUNSHOT RESIDUE DECISION PROCEDURE

H_0	H_1	k	α	β	Critical Region
A handblanks	0.22 rev	3.125	0.014	0.751	Hyperbolic (partial, γ = 11.88)
A handblanks	0.22 auto	1.563	0.007	0.519	Hyperbolic (partial, γ = 3.34)
A handblanks	0.25 auto	11.25	0.011	0.046	Elliptic (interior)
A handblanks	0.38 rev	1.563	0.008	0.483	Hyperbolic (partial, γ = 40.49)
A handblanks	0.45 auto	20.312	0.008	0.001	Elliptic (interior)
A handblanks	9 mm	15.625	0.007	0.034	Elliptic (interior
B handblanks	0.22 rev	-14.063	0.010	0.465	Hyperbolic (partial, γ = 2.55) vertical
B handblanks	0.22 auto	-15.63	0.010	0.662	Hyperbolic (partial, γ = 1.12)
B handblanks	0.25 auto	-20.188	0.013	0.842	Elliptic (interior)
B handblanks	0.38 rev	-10.938	0.011	0.828	Hyperbolic (partial, γ = 1.73
B handblanks	0.45 auto	-10.938	0.006	0.840	Hyperbolic (partial, γ = 2.46) vertical
C handblanks	0.22 rev	15.741	0.007	0.819	Elliptic (exterior)
C handblanks	0.22 auto	12.5	0.010	0.704	Elliptic (exterior)
C handblanks	0.25 auto	28.125	0.015	0.007	Elliptic (interior)
C handblanks	0.38 rev	0.0	0.005	0.542	Hyperbolic (partial, γ = 2.74)
C handblanks	0.45 auto	25.0	0.006	0.001	Elliptic (exterior)
C handblanks	9 mm	25.0	0.005	0.018	Elliptic (exterior)
D handblanks	0.22 rev	-4.063	0.009	0.954	Elliptic (interior)
D handblanks	0.22 auto	-2.344	0.011	0.965	Hyperbolic (partial, γ = 1.32)
D handblanks	0.25 auto	-8.339	0.010	0.436	Elliptic (interior)
D handblanks	0.38 rev	-3.486	0.010	(0.999)	Elliptic (interior)
D handblanks	0.45 auto	2.643	0.013	0.263	Elliptic (interior)
D handblanks	9 mm	2.125	0.008	0.554	Elliptic (interior)



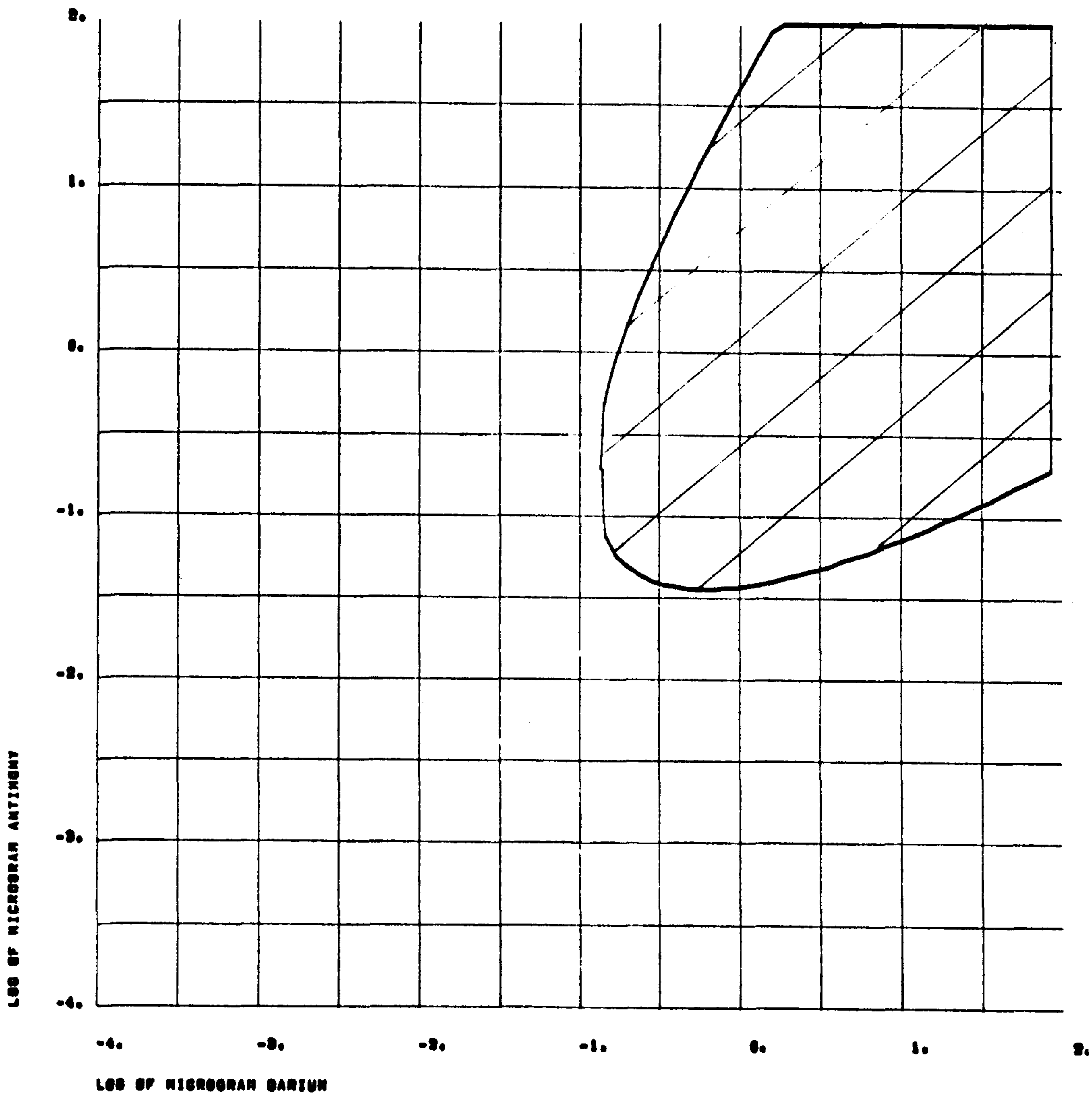
(Critical region at the one percent confidence level)

Fig. 30. Critical region for .25 caliber firings — Class A handblanks



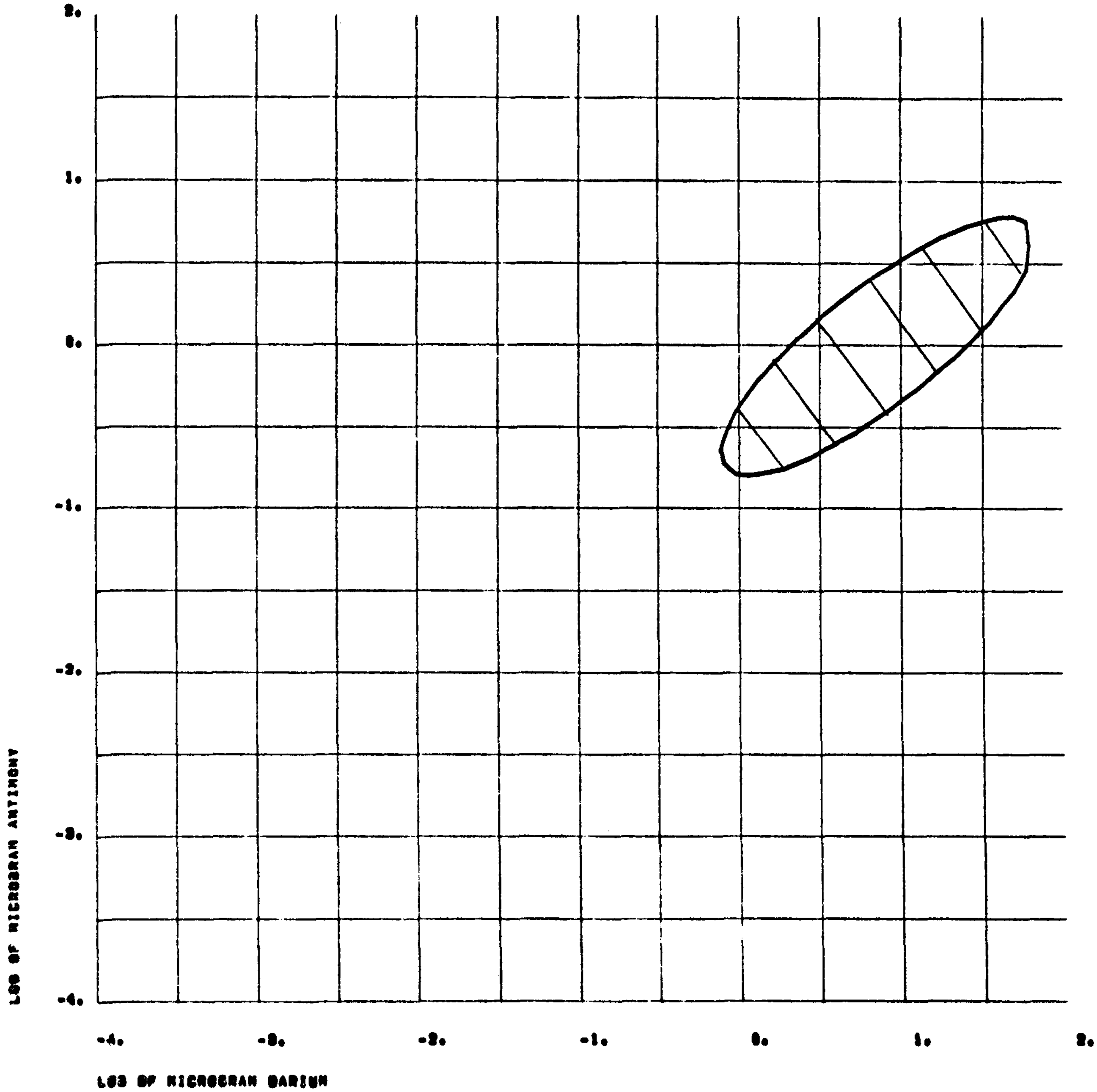
(Critical region at the one percent confidence level)

Fig. 31. Critical region for .25 caliber firings — Class B handblanks



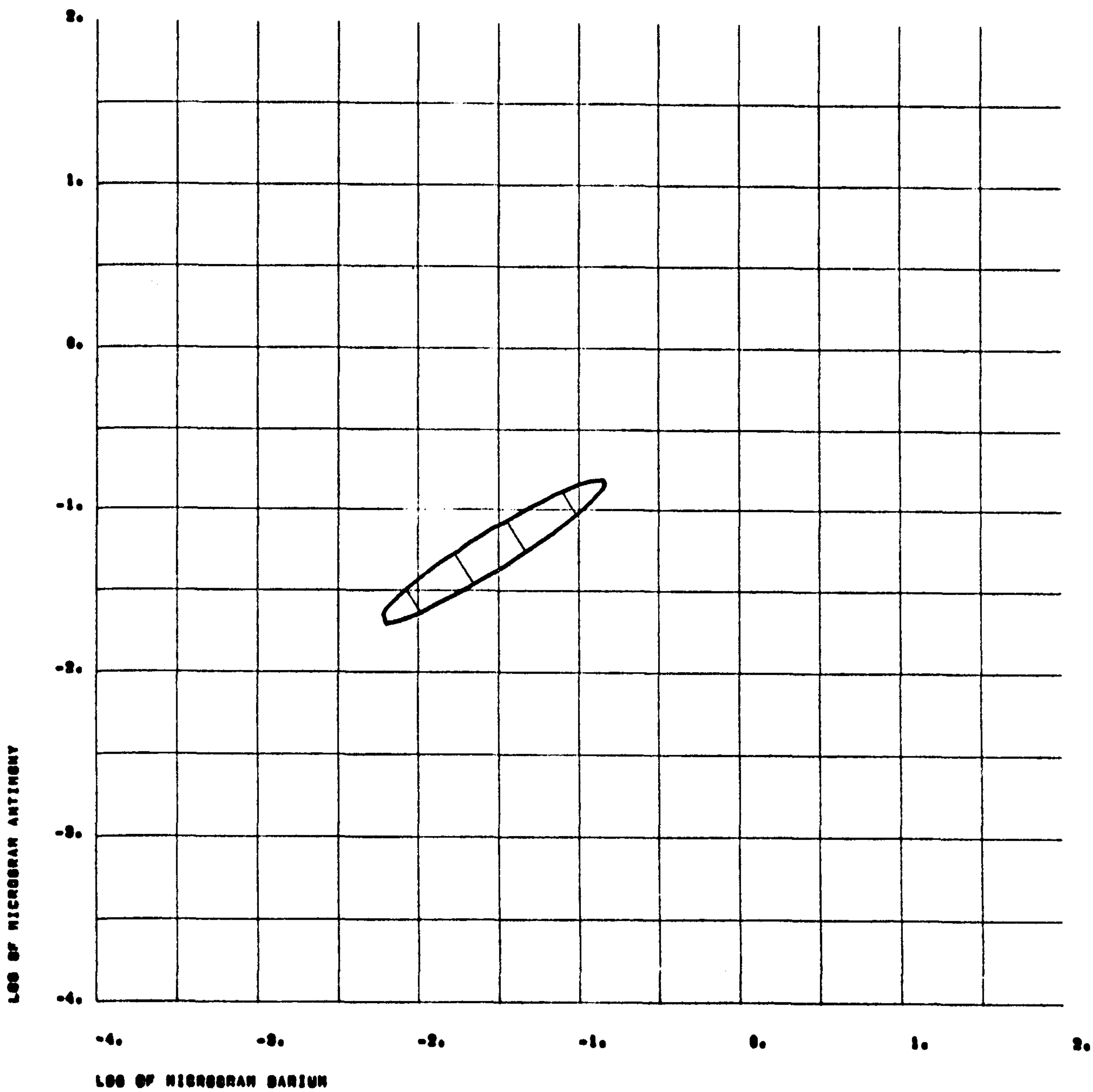
(Critical region at the one percent confidence level)

Fig. 32. Critical region for .25 caliber firings — Class C handblanks



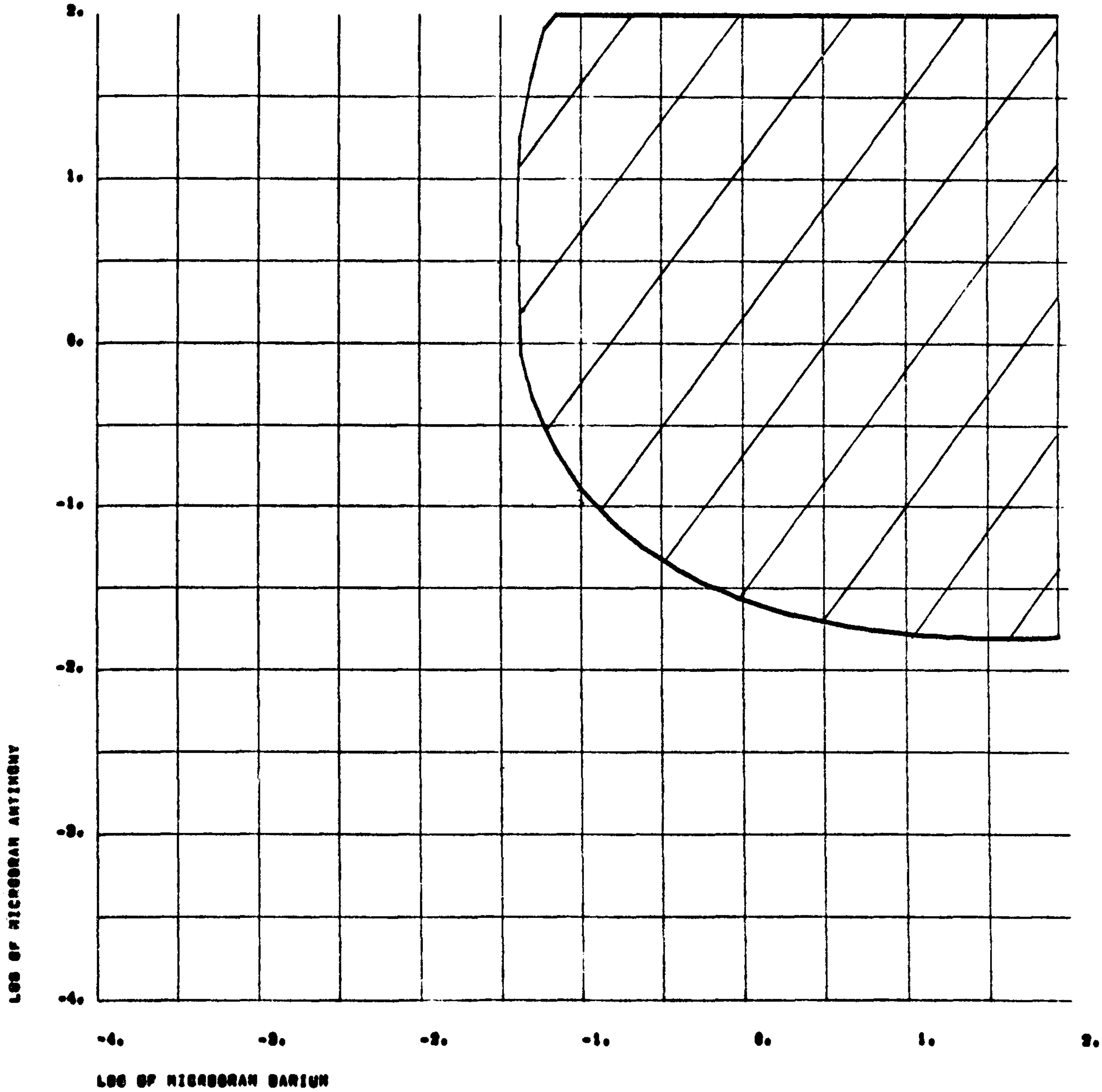
(Critical region at the one percent confidence level)

Fig. 33. Critical region for .25 caliber firings — Class D handblanks



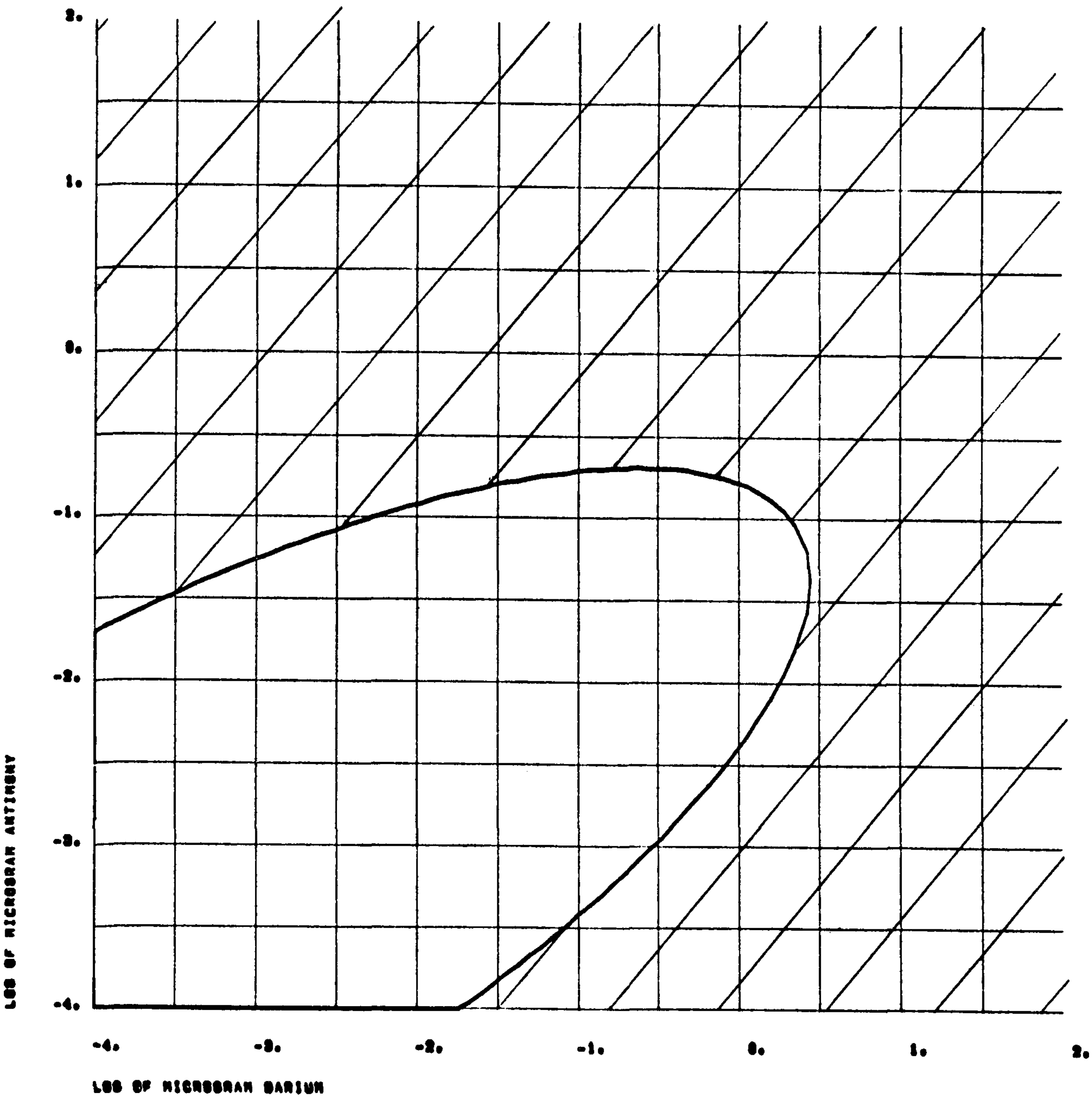
(Critical region at the one percent confidence level)

Fig. 34. Critical region for .38 caliber firings — Class D handblanks



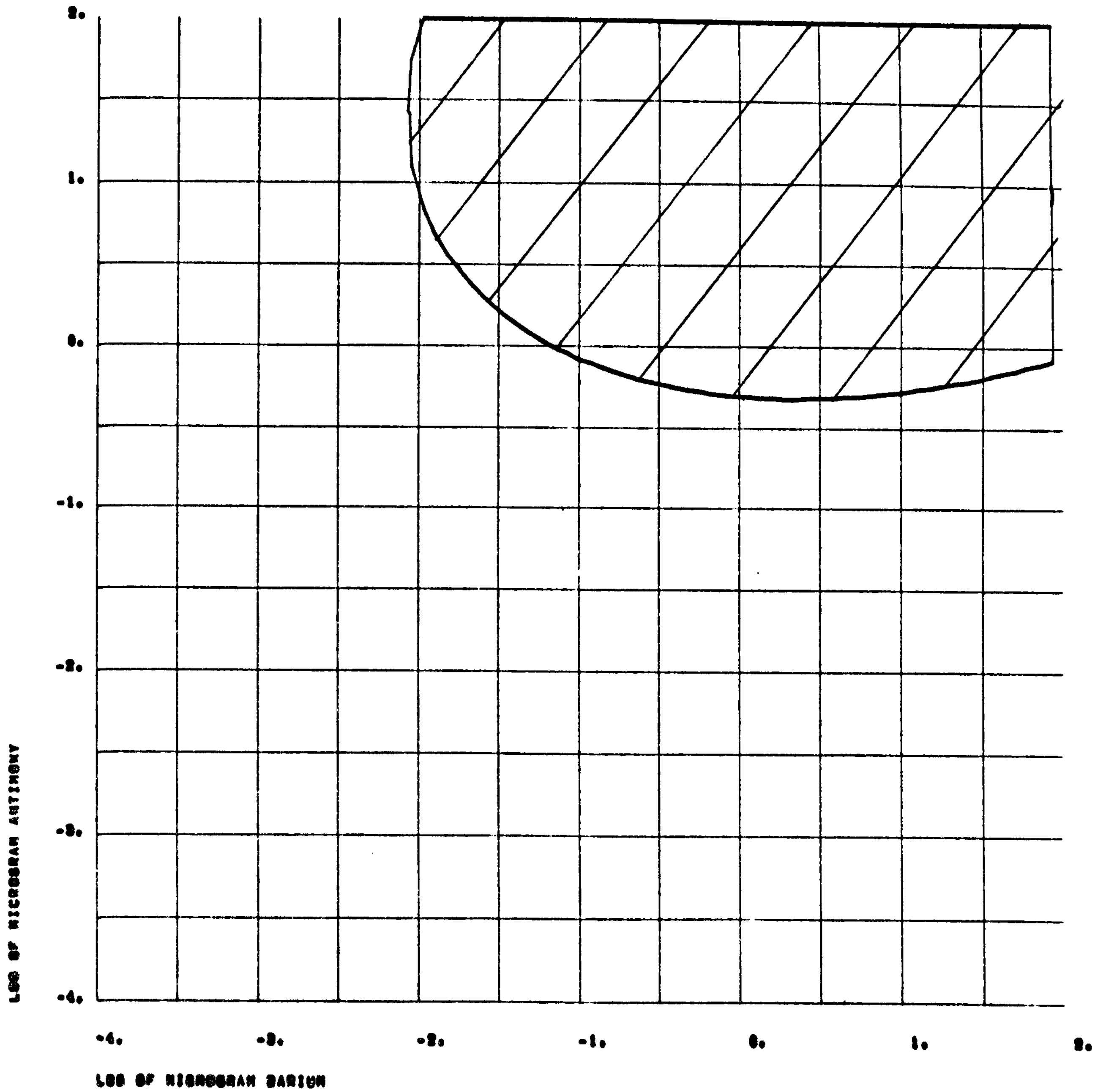
(Critical region at the one percent confidence level)

Fig. 35. Critical region for .45 caliber firings — Class A handblanks



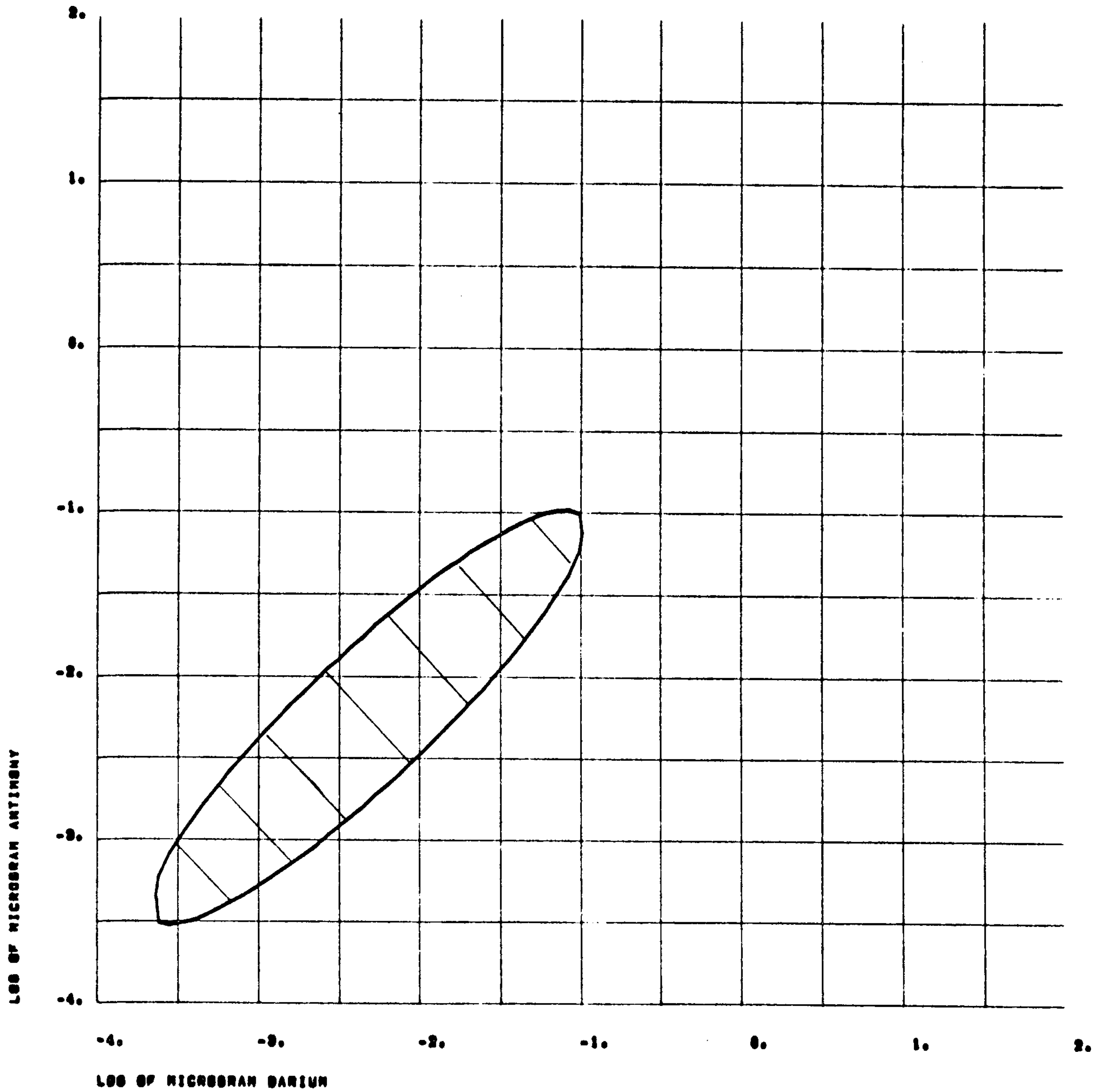
(Critical region at the one percent confidence level)

Fig. 36. Critical region for .45 caliber firings — Class C handblanks



(Critical region at the one percent confidence level)

Fig. 37. Critical region for .45 caliber firings — Class D handblanks



(Critical region at the one percent confidence level)

Fig. 38. Critical region for 2 caliber revolver firings – Class D handblanks

Ba/Sb ratio is a thermodynamic function. Inasmuch as Ba and Sb compounds have different thermodynamic properties, it is plausible that the differences in pressure-temperature-time cycles between different weapon-cartridge combinations can be responsible for the somewhat unexpected statistical features of the results.

The foregoing considerations suggested a simplified approach to the interpretation of the data listed in Tables 1 - 5 . In view of difficulties encountered in implementing the previously described decision procedure — especially difficulties in computing error probabilities in critical regions with hyperbolic bounds — it was decided to investigate the simplified procedure. This was done on a strictly manual (noncomputerized) basis.

All of the Ba values were multiplied by 100 and the Sb values were multiplied by 1000. This, in effect, normalized the data, since the overall average of Ba/Sb ratios was nearly 10 (actually 9.53); and it simplified to the listing of logarithms of the values. Henceforth in this section the word "value" will refer to the logarithm of an enlarged datum.

The values from Tables 1 - 5 were codified in accordance with the following code:

Code	Range of Values	Code	Range of Values
A	0 - 0.3	H	2.1 - 2.4
B	0.3 - 0.6	I	2.4 - 2.7
C	0.6 - 0.9	J	2.7 - 3.0
D	0.9 - 1.2	K	3.0 - 3.3
E	1.2 - 1.5	L	3.3 - 3.6
F	1.5 - 1.8	M	3.6 - 3.9
G	1.8 - 2.1		

The bivariate frequency distributions were plotted as shown in Table 12, wherein the concentration code was used. It can be seen that the "regression" pattern of each classification follows a slope of about -45° in every case. The data in Table 5 Supplement were not included in this treatment initially; however, as will be seen, these data scarcely alter the probabilities to be obtained.

Table 12

BIVARIATE FREQUENCIES

Class A Handblank

Ba \ Sb	A	B	C	D	E	F	G	H
A		4		1	1			
B	4	7	7		1	1		
C	5	10	16	4	4	2		
D	5	3	13	14	10	1	1	
E		3	10	4	7	4	4	1
F			1	2	5	2	1	
G	1	1		1				1
H		1						
I			1				1	

Class B Handblank

Ba \ Sb	A	B	C	D	E	F	G	H
A								
B								
C				1				
D				3				
E			1	2	1	1	1	1
F	1	1	4	2	1	1		
G			3	1		2		
H			3	1	2	3	1	
I			1					

Class C Handblank

Ba \ Sb	A	B	C	D	E	F	G	H
A								
B								
C				4	3			
D				1		1	1	
E				1	1			
F						1	2	
G						1		
H								
I								

Class D Handblank

Ba \ Sb	A	B	C	D	E	F	G	H	I	J
D		1		2						
E		1	1		5	1	1			
F		1	1	1	5	1				1
G					1	1	3	1		
H				1	1	1	3	1		
I						1		2	1	
J								1		
K										

0.22 Caliber Firings

Ba \ Sb	A	B	C	D	E	F	G	H	I	J	K	L
A												
B			1									
C				3	2			1				
D			1	1	8	6						
E				1	1	11	8	3	1		1	
F						3	6	5	1			1
G						2	6	6				
H						3	3	3	3			
I					2		1			2		
J						1		2				1

0.45 Caliber Firings

Ba \ Sb	E	F	G	H	I	J	K	L	M
D	1				1				
E									
F				1					
G				2	3	1			
H				2	7	6	3		
I		1			2	3	9		
J						2	12	10	1
K						1		3	3
L								1	1

0.25 Caliber Firings

Ba \ Sb	H	I	J	K
G	2	1		
H		7		
I	1	1	3	
J			1	1
K			1	

0.38 Caliber Firings

Ba \ Sb	D	E	F	G	H	I	J	K
A	1							
B								
C		1						
D			2	3				
E				10	4		1	
F				2	8	3		
G			1		5	13	1	
H						2	4	
I						1	2	1

9 mm Firings

Ba \ Sb	G	H	I	J	K	L	M
E		2					
F	5	6	1	1			
G	1	4	4	1			
H		5	4	7	2		
I			1	7	3	2	
J			1	1	1	3	1
K						1	

0.44 Caliber Firings

Ba \ Sb	F	G	H	I
F			1	
G				
H	1			1
I		1	1	

The total frequency along each +45° diagonal was obtained, a step consistent with the previously mentioned physical and mathematical considerations. These totals were found to have a Gaussian distribution for all classifications, except class A handblanks (which was found to be fitted to two overlapping Gaussian curves) and class C handblanks (for which there are a very small number of samples). Also, the fitting of a Gaussian curve to the 0.44 caliber firing classification is somewhat dubious due to the small number of samples.

The test for Gaussian distribution is exemplified in the following case, where the total frequency along each 45° diagonal of the class B handblanks of Table 12 are compared with the expected totals in a normal distribution of 38 observations:

E, Expect	O, Found	$(E-O)^2/E$
0.3	0	0.3
1.1	2	0.7
3.0	5	1.3
6.1	6	0.0
8.6	6	0.7
8.6	6	0.7
6.1	4	0.7
3.0	5	1.3
1.1	3	3.3
0.3	1	0.2
		Σ = 9.2 = chi-square

The hypothesis that the observed frequences are normally distributed is not rejected, since the difference between the two is not significant according to the calculated chi-square number.

The expected, normal distributions can be viewed as the smoothed distributions of the observed data by virtue of the foregoing, favorable tests. These smoothed distributions, expressed as percent of occurrence, are given in Table 13. It will be noted that along each +45° diagonal in Table 12 the numerical sum of the Sb code and Ba code is constant, where it is considered that A = 1, B = 2, C = 3, etc. This numerical constant is designated by a Roman numeral in Table 13. For example, Roman numeral VII specifies the (Sb, Ba) diagonal (A, F), (B, E), (C, D), (D, C), (E, B), (F, A) that appears in Table 12.

The probabilities given in Table 13 enabled the computation of the probability that any particular combination of Sb and Ba values resulting from the analysis of a handlift represents a handblank (lack of firing), where the handblank classification and caliber of weapon are known. This point of view is consistent with traditions of American jurisprudence in that it tests the assumption that the person, from whom a handlift was taken, is innocent. The array of these probabilities associated with each handblank classification (A, B, and D) in conjunction with 0.22, 0.25, 0.38, 0.45, and 9 mm weapons is given in Table 14.

The interpretation described, which is consistent with the various physical and mathematical considerations, has the virtue of simplicity of application. The results of a given handlift analysis may be simply categorized and the probable innocence (of firing) can be read directly from Table 14.

The revision of Table 14 to include Table 5 Supplement data affects the probabilities very little for 0.38 caliber and 0.45 caliber cases and not at all for 0.22 caliber cases. The revised probabilities for 0.38 caliber and 0.45 caliber cases are given in Table 15.

Table 13

SMOOTHED DISTRIBUTION OF OBSERVATION PROBABILITIES, IN PERCENT, FOR EACH 45° DIAGONAL IN TABLE 12

Diagonal Category	Handblank Class A	B	D	Firings, Weapon Caliber 0.22	0.25	0.38	0.45	9 mm
II	0.6							
III	3.3							
IV	9.4	0	0	0				
V	14.2	0.1	0.4	0.3				
VI	12.6	0.7	0.9	0.6		0		
VII	10.8	2.8	2.2	1.3		0.4		
VIII	12.0	7.9	4.5	2.5		0.9		
IX	13.2	15.9	7.8	4.3		2.2		0
X	11.0	22.6	11.5	6.8		4.5		0.4
XI	7.3	22.6	14.7	9.4		7.8	0	0.9
XII	3.5	15.9	15.8	11.6	0	11.5	0.4	2.2
XIII	1.2	7.9	14.7	13.1	0.7	14.7	0.9	4.5
XIV	0.4	2.8	11.5	13.1	2.8	15.8	2.2	7.8
XV	0.3	0.7	7.8	11.6	7.9	14.7	4.5	11.5
XVI	0.1	0.1	4.5	9.4	15.9	11.5	7.8	14.7
XVII	0	0	2.2	6.8	22.6	4.5	11.5	15.8
XIX			0.9	4.3	22.6	4.5	14.7	14.7
XX			0	2.5	15.9	2.2	15.8	11.5
XXI				1.3	7.9	0.9	14.7	7.8
XXII				0.6	2.8	0.4	11.5	4.5
XXIII				0.3	0.7	0	7.8	2.2
XXIV				0	0		4.5	0.9
XXV							2.2	0.4
XXVI							0.9	0
XXVII							0.4	
XXVIII							0	

Table 14

PROBABILITY (IN PERCENT) THAT Sb AND Ba VALUES FALLING IN A GIVEN CATEGORY REPRESENT A HANDBLANK, WHERE OCCUPATIONAL HANDBLANK CLASS AND WEAPON CALIBER ARE SPECIFIED

Diagonal Category	0.22 Cal., and Handblank Class			0.25 Cal., and Handblank Class			0.38 Cal., and Handblank Class			0.45 Cal., and Handblank Class			9 mm, and Handblank Class		
	A	B	D	A	B	D	A	B	D	A	B	D	A	B	D
II															
III															
IV	>99.5														
V	97.0	25.0	57.0												
VI	96.0	54.0	60.0				>99.5	>99.5	>99.5						
VII	89.0	69.0	63.0				96.0	88.0	85.0						
VIII	83.0	76.0	64.0				93.0	90.0	83.0						
IX	76.0	79.0	66.0				86.0	88.0	78.0				>99.5	>99.5	>99.5
X	62.0	77.0	63.0				71.0	83.0	72.0				96.0	98.0	97.0
XI	44.0	73.0	61.0				48.0	74.0	66.0	>99.5	>99.5	>99.5	89.0	96.0	94.0
XII	23.0	58.0	58.0	>99.5	>99.5	>99.5	23.0	58.0	58.0	90.0	98.0	98.0	61.0	88.0	89.0
XIII	9.1	38.0	53.0	63.0	92.0	96.0	7.6	35.0	50.0	57.0	90.0	94.0	21.0	64.0	77.0
XIV	3.0	18.0	47.0	25.0	50.0	80.0	2.5	15.0	42.0	15.0	56.0	84.0	4.9	26.0	60.0
XV	2.5	5.7	40.0	3.6	8.1	50.0	2.0	4.6	35.0	6.3	14.0	64.0	2.5	5.9	41.0
XVI	1.1	1.1	32.0	0.6	0.6	22.0	0.9	0.9	28.0	1.3	1.3	36.0	0.7	0.7	24.0
XVII	<0.5	<0.5	24.0	<0.1	<0.1	8.9	<0.1	<0.1	22.0	<0.5	<0.5	16.0	<0.1	<0.1	11.0
XVIII			17.0			3.8			17.0			5.7			5.7
XIX			14.0			2.5			15.0			2.5			3.4
XX			<0.5			<0.5			<0.5			<0.5			<0.5

Table 15

PROBABILITY (IN PERCENT) THAT Ba AND Sb VALUES FALLING IN A GIVEN CATEGORY REPRESENTS A HANDBLANK, WHERE OCCUPATIONAL HANDBLANK CLASS AND WEAPON CALIBER ARE SPECIFIED[a]

Diagonal Category	0.38 Cal., and Handblank Class			0.45 Cal., and Handblank Class		
	A	B	D	A	B	D
VI	>99.5	>99.5	>99.5			
VII	97	90	88			
VIII	92	89	83			
IX	83	86	75			
X	67	80	68			
XI	46	72	63	>99.5	>99.5	>99.5
XII	24	59	58	95	99	99
XIII	9.4	41	56	60	91	95
XIV	3.2	19	49	15	55	84
XV	2.3	5.3	38	5.9	13	62
XVI	0.8	0.8	26	1.3	1.3	37
XVII	<0.1	<0.1	18	<0.1	<0.1	19
XVIII			12			7.8
XIX			11			3.6
XX			<0.5			<0.5

[a] Table 5 Supplement Data Included

6. DISCUSSION AND CONCLUSION

The two methods of interpreting the gunshot residue data give somewhat different ways of judging the analytical data from a given handlift, although they have the same sense when it is considered that a firing usually must be proven in court beyond a reasonable doubt. Both methods clearly indicate those results that may be taken to have >99% chance of being due to a handblank and those that have >99% chance of being due to a firing. The critical areas defined in the decision procedure are analogous to the middle diagonal categories in Tables 14 and 15, and it can be seen in Table 11 that the decision procedure probabilities of interpreting a true firing as a handblank are generally greater than the probabilities of accepting a true handblank as a firing when results fall in the relevant critical area. Needless to say a jury would likewise be constrained to favor the defendant accused of a shooting in any case where the results fell into the diagonal category XII or less in Table 14.

Both interpretation methods have a degree of reliability commensurate with the sample sizes available in the various categories. The fact that 0.38 caliber and 0.45 caliber probabilities were not seriously perturbed (and the fact that 0.22 caliber probabilities were not at all affected) by the addition of Table 5 Supplement data to the original Table 5 data in the simpler interpretation method supports this contention for that method. The decision method uses the same data and is mathematically more rigorous: therefore, despite the use of some parameters (Table 10) not based on univariate Gaussian distributions, this method should be just as, if not more, reliable.

The results of both interpretations show that there are distinct differences between calibers in over-all probability of being able to reject the hypothesis that data indicate a handblank. When class A handblanks are considered, ~25% of 0.22 caliber firing will be distinctly recognized as such from handlift analysis (where the cartridge brand is unspecified). By contrast ~90% of 0.25 caliber firings will be so indicated.

Referring to the fourth continuation page of Table 5, it is evident that the brand of 0.22 caliber bullets will influence the ability of TNAA to specify whether or not a person fired the weapon. The reason is that there is one U.S. manufacturer who makes one caliber of bullets that have primers devoid of antimony. It is interesting that antimony in excess, on the average, of the average class A handblank level was found subsequent to firing such cartridges. This was found to be due to the presence of Sb in bullet lead, fragments of which are deposited on the hand during a firing. Most of the bullet leads of that brand of cartridge had ~1% wt Sb. Thus, despite the lack of Sb in the primers, there is still a finite chance of detecting a firing.

While it might be argued that a larger data base would be desirable, the essential objectives of the study have been met, the utility of TNAA in the detection of gunshot residues has been defined, and the sets of probabilities germane to the most frequently encountered cases have been defined. The TNAA method constitutes the best and most reliable method of definitively identifying gunshot residues that is available to the criminalist at this time.

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APPENDIX 1

1. METHOD OF ANALYSIS

Through the years of its use in this Laboratory, the procedure to determine levels of barium and antimony in handlift samples has changed in minor details. The version given here is that used at this time. It is given in considerable detail to aid other workers who might be interested in doing similar work. Following the description of the method are discussions of alternate procedures and the question of interferences.

1.1 IRRADIATION PARAMETERS

Irradiations are conducted in the rotary specimen rack of the TRIGA Mark I nuclear reactor at Gulf General Atomic. The rack rotates at the rate of one revolution per minute about the midline of the reactor core, smoothing out flux perturbations in the plane of rotation. The samples and standards are shimmed, if necessary, so that all are the same vertical distance above the floor of the rack. Since flux perturbations in both the horizontal and vertical axis are compensated for, no flux monitors are required, saving considerable time and effort when large numbers of samples are to be analyzed. While the rotary specimen rack can accomodate forty samples in one horizontal plane, no more than sixteen samples have been irradiated simultaneously in this study to minimize the loss of activity of 83-minute ^{139}Ba (described more fully below).

The thermal neutron flux in the rotary specimen rack is about 1.8 x 10^{12} neutrons/cm^2-sec. Thirty-minute irradiations yield activities adequate for the detection of as little as 0.01 micrograms of barium and 0.002 micrograms of antimony under the counting parameters employed. This is more than sufficient for the purpose of the analysis.

1.2 RADIOCHEMICAL PROCEDURE

While the paraffin used in this study is quite low in organic contaminants, perspiration transferred to the paraffin in preparing handlifts (see Appendix 2) contains sufficient sodium, chlorine, copper, and manganese to require that radiochemical separations be performed to isolate the barium and antimony cavities. The following scheme is used:

1. Solutions Required
   a. Copper carrier. Usually prepared by dissolving copper wire in nitric acid. The final solution is to contain ~ 2.0 mg Cu^{+2}/ml.
   b. Barium carrier. Usually prepared by dissolving barium nitrate in distilled water to yield a final concentration of about 10 mg/ml of barium.
   c. Antimony carrier. Prepared by dissolving spectrographic grade metal in hydrochloric and nitric acids. The solution used contains about 10 mg/ml of antimony.
   d. Barium standard. The carrier solution is standardized by a standard quantitative procedure. An aliquot is precipitated as the sulfate, filtered, ignited and weighed. Dilutions of the standardized solution are made to a final concentration of 50-100 micrograms/ml.
   e. Antimony standard. An aliquot of the carrier solution is diluted to a final concentration of about 10 micrograms/ml.
   f. Dithizone solution. Dissolve 300 mg dithizone in 100 ml of chloroform. Baker dithizone has been used without further purification. Bottles of dithizone are stored in a dessicator and the solution made immediately before use.

2. Procedure

a. Extraction of inorganic ions. Place the following in a 150 or 250 ml beaker.

1. 1.00 ml of copper carrier solution
2. 2.00 ml of antimony carrier solution
3. 1.00 ml of barium carrier solution
4. 3.5 ml of concentrated hydrochloric acid
5. 0.5 ml of concentrated nitric acid
6. ~100 mg of sodium chloride
7. ~15 ml of distilled water
8. Paraffin sample

Place a glass cover over the beaker and boil on a hot plate for at least 5 minutes. Swirl occasionally. Cool the beaker in an ice bath until the paraffin solidifies. Then transfer the aqueous solution to a 50 ml centrifuge tube.

b. Barium separation. While the solution is still warm add 10 drops of concentrated sulfuric acid and stir vigorously. Barium sulfate precipitate should form within one minute. The precipitation will be slow if the solution is cold. Centrifuge and transfer the supernatant liquid to another centrifuge tube. Wash the precipitate three times with about 15 ml aliquots of distilled water, being careful to disperse the precipitate during each washing and to wash down the lip of the tube. Centrifuge between washings. After the last washing the precipitate is transferred to a 2-dram polyethylene vial for counting. Chemical yields average 85%.

c. Antimony separation. Use a 50% aqueous solution of sodium hydroxide to adjust the pH of the solution to 1.5 - 2.0 using narrow-range pH paper or two drops of 0.04% metacresol purple indicator. Allow the solution to cool.

Transfer to a separatory funnel and extract twice with 5 ml aliquots of dithizone. Discard the organic layer. Continue washing with chloroform until the organic layer is colorless. If a pink tinge is seen in the organic layer after the first chloroform wash, check the pH of the aqueous layer, re-adjust the pH if necessary, and add 5 ml of dithizone solution, then continue washing with chloroform.

Transfer the aqueous phase to a 40 ml centrifuge tube. Do not include any chloroform, which may cause bumping later on. Add 3 ml of concentrated hydrochloric acid and about 50 mg of thioacetamide. Place the tube in a boiling water bath and heat until a deep red precipitate of Sb_2S_3 has formed and coagulated.

If the solution is not red after about 10 minutes add another portion of thioacetamide. Centrifuge and discard the supernatant liquid. Add about 10 ml of concentrated hydrochloric acid and warm the tube until the red precipitate has dissolved. Add about 20 ml of distilled water to the tube and centrifuge strongly to remove the colloidal sulfur. Transfer the supernatent liquid to a new centrifuge tube and add about 20 ml of water and 2 ml of chromous chloride solution. Place the tube in a boiling water bath for about 30 minutes and leave overnight. A disposable pipet is used to transfer the sample to a 2-dram polyethylene vial for counting. The chemical yield is about 70%.

d. Preparation of the barium standard. About 3 ml of standard is irradiated with each set of samples. After irradiation, 1.00 ml is pipetted into a 2-dram polyethylene vial and a few drops of concentrated sulfuric acid is added. Water is added to adjust the liquid level in this vial to equal that for the samples.

e. Preparation of the antimony standard. Since chromous chloride solution will not reduce antimony to the metal in the presence of nitric acid, the antimony standard solution is first precipitated as the sulfide with thioacetamide, then treated according to the procedure described in c, above.

f. Comments on the chemicals used. Only analytical grade reagents were used without further purification, unless otherwise indicated. Both "Oxorbent" and Fisher chromous chloride solutions have been used. The Fisher material uses mineral oil to prevent air oxidation, which must be removed and replaced with diethyl ether.

g. An ordinary laboratory centrifuge will not remove all of the colloidal sulfur remaining after the antimony sulfide has been dissolved with hydrochloric acid. If the chemical yield is determined by reirradiating the sample, (see below) the sulfur is harmless. If a gravimetric method is used, careful technique and repeated centrifugings are required to remove the last traces of sulfur.

1.3 DETECTION OF INDUCED ACTIVITY

1. Counting Procedure for Barium

To achieve better sensitivity and to minimize errors due to differing sample geometries, both the barium and antimony are counted in well detectors. Standard 3 in. x 3 in., well-type, NaI(Tl) detectors are used, coupled to 400 channel pulse height analyzers. When large numbers of samples are analyzed simultaneously, three similar systems are used. In general, the factor limiting the number of samples to be analyzed simultaneously is the requirement that less than two half-lives (166 minutes) elapse between the end of the irradiation and the end of count of the last sample. Count times are adjusted to the activity of the sample being counted, but do not exceed 15 minutes. Analyzer gain is 3.75 keV/channel and the 160 keV γ-ray of 83 minute ^{139}Ba is the analytical indicator.

2. Counting Procedure for Antimony

The same equipment described above is used for determing the antimony content of the sample, using the 564 keV γ-ray of 2.8 day ^{122}Sb as the analytical indicator. The analyzer gain is adjusted to 7.5 keV/channel for this measurement. The counting time is adjusted for the activity of each sample, but in no case is longer than 60 minutes.

3. Notes on the counting procedure

   a. Both barium sulfate and antimony metal are relatively dense and settle to the bottom of the 2-dram polyethylene vials in a few minutes. The precipitate should not be disturbed while placing the sample in the detector.

   b. To eliminate errors due to the effect of γ-ray self-attenuation in samples and standards, the liquid levels in all vials prepared for counting should be nearly the same.

1.4 REIRRADIATING FOR YIELD

It has been found to be very convenient to reirradiate the samples after counting to determine the chemical yield. The procedure used is to irradiate the samples in the pneumatic transfer system of the TRIGA Mark I nuclear reactor for between 10 and 15 seconds. About 70 samples can be irradiated in 30 minutes. After irradiation the exterior of the vials are rinsed to remove any transferrable radioactivity and the samples are counted sequentially for about 0.2 minutes each (counting times are adjusted so that at least 10,000 counts are found in the net photopeak area). No flux monitors are used, or required. The sample geometry has already been adjusted as described above and the stability of the neutron flux during reactor operation has been shown to be very good.

1.5 CALCULATIONS FOR DETERMINING THE BARIUM AND ANTIMONY CONTENT OF THE SAMPLES ARE CONVENTIONAL

The net photopeak area due to the analytical indicator is determined for the standard and the samples. This is expressed in counts/minute and appropriate decay corrections made. Corrections for the chemical yield are applied. (See Reference 13 for a detailed discussion of the principles involved.) The corrected counts/minute derived from the known weight of the element irradiated as a standard is then compared to that from each sample. In large-scale studies it has been found very convenient to use a high-speed computer to do these calculations. The SHERRY, or SHERRY 2 computer programs, written at this Laboratory, are employed; using the Model 1108 UNIVAC computer at this facility. All of the calculations required for determining the barium and antimony content of 20 samples can be performed for about $10.

1.6 CALCULATIONS FOR DETERMINING THE CHEMICAL YIELD BY REIRRADIATING THE SAMPLE

Since the antimony standard is carried through several chemical reactions, the yield is not quantitative and a chemical yield for the standard appears necessary to complete the calculation for the amount of antimony in the sample. As a matter of fact, the chemical yield for the standard is unnecessary. A derivation proving this is given.

Define the following terms:

X and Y are the activities, corrected for saturation and decay and expressed as net counts in the photopeak per unit time, experimentally obtained for the sample and standard, respectively, after the first irradiation and chemical separation.

x^1 and y^1 are the activities, expressed in the same terms, determined after the samples are irradiated.

k_x and k_y are constants with values ≥ 1, which are the reciprocals of the chemical yields for the sample and standard after reirradiation.

Then

$$\frac{x}{y} = \frac{k_x X}{k_y Y} \qquad (1)$$

where x and y are the amounts of the element present in the sample and standard, respectively.

If the carrier is equilibrated with the radioactive nuclei of the element, one can write

$$\frac{x^1}{y^1} = \frac{k_y}{k_x} \qquad (2)$$

Then from Eqs. 1 and 2:

$$x = y\left(\frac{y^1}{x^1}\right)\left(\frac{X}{Y}\right) \qquad (3)$$

The absolute amount of the carrier present does not appear in Eq. 3.

1.7 DISCUSSION OF THE ANALYTICAL SCHEME AND SOME VARIATIONS

1. The barium separation is very rapid and requires little comment. In a few of the hundreds of samples analyzed, residual sodium-24 activity has been observed, probably originating from inadequate washing of the precipitate.

2. The antimony separation procedure, including the dithizone extraction step for the elimination of copper is fairly involved. Activity ascribed to the positron-emitter, copper-64, has been observed on occasion, requiring the use of spectrum stripping to eliminate the resulting shoulder on the 564 keV γ-ray photopeak. Detection of the 412 keV photopeak of gold-198 is rather common and has been associated with handlifts from wearers of gold rings and watches. The possibility of confusing the 559 keV γ-ray of 27-hour arsenic-76 with that originating from antimony has been eliminated by verifying the presence of the 686 keV γ-ray from antimony-122, and in some cases by measuring the apparent half-life.

The fact that 60-day antimony-124 emits a γ-ray with 603 keV energy has been considered. All of the samples in a series are counted within five hours of the time that a standard is counted and counting begins on the day after irradiation. The error introduced by the presence of the longer-lived isotope is negligible under these conditions.

3. Antimony ions can exist both in the III and V valence state. Exchange between these states is slow in hydrochloric acid solutions. An experiment was performed to determine the extent to which exchange occurred under the conditions of this procedure.

One ml of 20 microgram/ml Sb^{III} solution was irradiated, then oxidized to the V state with ceric sulfate. The excess ceric ion was then reduced with hydroxylamine hydrochloride. The resulting tracer solution was carried through the procedure, using Sb^{III} carrier. Each precipitate and discarded solution was checked for activity. Eighty percent of the total activity was found in the antimony sulfide precipitate, the remainder was distributed in a fairly equal fashion in the discarded supernatent liquids and the sulfur precipitate.

One can conclude from these results that the addition of nitric and/or sulfuric acid promotes exchange between Sb^{III} and Sb^{V}, and therefore no error due to lack of equilibration of these states occurs.

4. In early work the barium and antimony yields were determined gravimetrically. This procedure worked satisfactorily except that care is required to eliminate sulfur from the antimony precipitate.

APPENDIX 2

1. COMPONENTS

1.1 PARAFFIN

It was shown in very early work that "Parowax", a product of the American Oil Company, contains barium and antimony in such low concentration that contamination from this source can be ignored. On numerous occasions different batches of this material have been analyzed and the barium and antimony levels are consistently very low. While it is probable that similar products manufactured by other companies have the same freedom from impurities, they have not been analyzed. Parowax is nationally distributed and sold for use in home canning. It is conveniently packaged in quarter-pound slabs. All of the work reported in this study employed this material.

1.2 BRUSHES

Various inexpensive varnish brushes have been used. These brushes were all "natural bristle" brushes in one or two-inch size. Blanks obtained by dipping new brushes in molten paraffin and transferring the paraffin to clean empty polyethylene vials have consistently been very low.

On early work the same brush was used repeatedly in taking consecutive samples, with no apparent transfer of residues to the molten paraffin bath. In later work brushes were used once, then discarded (see Section 4 on Taking of Handlifts for a discussion of this point).

1.3 POLYETHYLENE VIALS

Four-dram vials, products of the Olympic Plastic Co., with snap tops were used to contain the samples. These vials are prepared by washing once with soapy water, once with dilute nitric acid, three times with distilled water, and twice with acetone. The acetone is used to reduce the drying time and thus shorten the exposure of the vials in an open container. After drying, the vials are sealed in a clean plastic bag for use.

1.4 PLASTIC GLOVES

Various polyethylene and synthetic rubber disposable gloves have been used.

2. TESTS OF COMPONENTS

The best proof that the components employed do not contain significant amounts of barium or antimony is that is is possible to repeatedly obtain actual samples, which when analyzed contain very low levels of these elements.

2.1 OTHER COMPONENTS

A hotplate, thermometer, clean beaker, marking pencil, and paper napkins are used.

3. TAKING OF HANDLIFTS

One or two 1/4 lb slabs of paraffin are placed in a beaker and melted on the hotplate. The temperature is adjusted to about 120°F. The person to be sampled is asked to place his hand over a paper napkin, palm down and fingers extended. A brush is dipped into the paraffin and stroked over the back of the hand. Strokes are made with the brush almost parallel to the skin and paraffin is flowed, rather than brushed, onto the skin. The tendency of some persons to press the brush into the skin led to the policy of not returning the brush to the paraffin, but rather replacing it with an unused brush. With practice, sufficient paraffin can be carried on one 2 in. varnish brush to complete one handlift.

After the paraffin has solidified, droplets which have run out of the area to be sampled (see below), are removed and discarded. Occasionally a bristle will be found embedded in the paraffin. It is removed. The person is then asked to make a fist. This loosens the paraffin and it is removed. Disposable gloves are always worn. The soft paraffin is crumpled and placed into a premarked vial. The vial is closed and not opened until after it has been irradiated.

The degree to which the molten paraffin adheres to the skin varies. It is apparently a function of the amount of oil on the hand. On one occasion a surgeon who had just finished an operation was sampled and it was found extremely difficult to remove the paraffin from his hand. Probably the pre-operation washing had completely depleted his skin oil. Also, during repeated testing of the same hand, it was found that the paraffin becomes progressively more difficult to remove since the hand must be washed between firings.

Experiments have been performed to test the efficacy of paraffin in removing particles from the hand. Finely, powdered graphite was lightly dusted on a hand, which was then covered with paraffin. About half (estimated from visual inspection) of the graphite was removed. A smaller fraction is removed if the graphite is pressed into the skin with the other hand. This is undoubtedly one source of the variability observed when consecutive samples are obtained from firings of the same weapon.

4. GUNSHOT RESIDUE KIT

A kit has been prepared for use by investigative personnel which contains the items described above in a compact form. In addition, a set of instructions and a mailing container for the samples are included.

APPENDIX 3

THE BIVARIATE NORMAL DISTRIBUTION

In the discussion that follows, X_1 and X_2 will denote the common logarithms of the amounts of Ba and Sb, respectively, determined by sampling the hand, followed by the NAA procedure. Each observation can be thought of as an ordered pair, or two-dimensional vector (X_1, X_2), and it will be assumed that the random vector $\underset{\sim}{X} = (X_1, X_2)$ follows a bivariate normal distribution.[14]

This distribution is characterized by a mean vector $\underset{\sim}{\mu} = (\mu_1, \mu_2)$ and a covariance matrix Σ, where

$$\Sigma = \begin{pmatrix} \sigma_{11} \sigma_{12} \\ \sigma_{21} \sigma_{22} \end{pmatrix}, \text{ and } \sigma_{12} = \sigma_{21} . \tag{1}$$

The bivariate normal distribution has a density function, f, given by

$$f(X_1, X_2) = \frac{\exp\left[-\frac{1}{2} Q(x_1, x_2)\right]}{2\pi\left[\sigma_{11}\sigma_{22}(1 - \rho^2)\right]^{\frac{1}{2}}} , \tag{2}$$

where

$$\rho = \sigma_{12}/(\sigma_{11}\sigma_{22})^{\frac{1}{2}} \tag{3}$$

is the correlation between X_1 and X_2, and

$$Q(X_1, X_2) = \frac{1}{2(1 - \rho)^2} \left[\frac{(x_1 - \mu_1)^2}{\sigma_{11}} - \frac{2\rho(x_1 - \mu_1)(x_2 - \mu_2)}{(\sigma_{11}\sigma_{22})^{\frac{1}{2}}} + \frac{(x_2 - \mu_2)^2}{\sigma_{22}} \right] . \tag{4}$$

The probability that the point X falls in any region of the (X_1, X_2) plane is obtained by integrating f over that region. Moreover, it can be shown[14] that

$$\mu_i = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x_i f(x_1, x_2) dx_1 dx_2 \quad , \; i = 1, 2 \tag{5}$$

and

$$\sigma_{ij} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x_i - \mu_i)(x_j - \mu_j) f(x_1, x_2) dx_1 dx_2 \tag{6}$$

for i, j = 1, 2. Thus, μ_i is the mean, or expected value, of x_i and σ_{ii} is the variance ($\sqrt{\sigma_{ii}}$ is the standard deviation) of x_i.

A means of visualizing the shape of this distribution is provided by the geometric properties of the surface determined by the density function, or, alternatively, the level curves of the surface, i.e. the set of points in the (X_1, X_2) plane determined by the equations,

$$Q(X_1, X_2) = c \quad . \tag{7}$$

For various choices of positive numbers, c, these are concentric ellipses centered at the point $\underset{\sim}{\mu}$. The probability attributed to the exterior of such an ellipse is equal to e^{-c}. In case $\rho = o$, the major and minor axes of the ellipses are paralleled to the coordinate axes.

Finally, a most important property of this distribution, is that the random variables, X_1 and X_2, are independent if and only if $\rho = o$.

For each group of data the sample mean vector, $\underset{\sim}{X}$, and sample covariance matrix, S, were computed in the usual way. Specifically, the measurements $\underset{\sim}{X}(1), \ldots\ldots, \underset{\sim}{X}(n)$ consist of pairs:

$$\underset{\sim}{X}(k) = \begin{bmatrix} X_1(k) \\ X_2(k) \end{bmatrix} \quad , \tag{8}$$

where $X_1(k)$ and $X_2(k)$ are the (common) logarithms of the amounts of barium and antimony, respectively, found in the $k^{\underline{th}}$ handlift by the NAA procedure, for $k = 1, \ldots\ldots, n$. The number of measurements, n, is different for each of the groups. The sample means are then defined by

$$X_i = \frac{1}{n} \cdot \sum_{k=1}^{n} X_i(k) \tag{9}$$

for $i = 1, 2$, and the elements of the sample covariance matrix are given by

$$s_{ij} = \frac{1}{n-1} \cdot \sum_{k=1}^{n} (X_i(k) - \overline{X}_i)(X_j(k) - \overline{X}_j) \tag{10}$$

for $i = 1, 2$, and $j = 1, 2$. Since the sample mean vector and covariance matrix are defined as

$$\underset{\sim}{\overline{X}} = \begin{bmatrix} \overline{X}_1 \\ X_2 \end{bmatrix}, \text{ and}$$

$$S = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix},$$

respectively, the sets of equations (9) and (10) can be written in vector-matrix form as

$$\underset{\sim}{\overline{X}} = \frac{1}{n} \cdot \sum_{k=1}^{n} \underset{\sim}{X}(k) \text{ and} \tag{11}$$

$$S = \frac{1}{n-1} \cdot \sum_{k=1}^{n} (\underset{\sim}{X}(k) - \underset{\sim}{\overline{X}})(\underset{\sim}{X}(k) - \underset{\sim}{\overline{X}})' \tag{12}$$

respectively, where denotes transpose. From the sample covariance matrix, the sample correlation, r, is computed by:

$$r = s_{12}/(s_{11}s_{22})^{\frac{1}{2}} \quad . \qquad (13)$$

For each group, the calculated sample mean vector and covariance matrix were used as estimates of the corresponding parameters of the theoretical bivariate normal distribution that is assumed to describe the probabilistic mechanisms governing the observations. The extent of agreement between the theoretical model and the actual data is illustrated for each group in Figs. 1 to 29 of this report. In each figure, several ellipses of concentration, corresponding to level curves (points of constant value) of the associated bivariate normal density function, have been superimposed on a scatter diagram of the actual data points in the group. For example, the 50 percent ellipse of concentration contains an area (centered at the mean vector $\underset{\sim}{\overline{X}}$) to which the theoretical distribution attributes a proability of 0.50. Hence, if there is good agreement between the model and the measurements, one would expect about half of the data points to fall within this ellipse. Similar remarks apply to the other ellipses.

All of the diagrams are plotted on the same scale, in order to facilitate comparisons of the size and shape of the estimated theoretical distributions among the various groups of data.

Several different tests of the descriptive mathematical model were carried out, based upon the chi-square goodness-of-fit criterion. These tests are adaptations of standard techniques to measure the extent of agreement between a set of data and a probability distribution which is assumed to describe the data. The general method is to divide the population of interest into several regions, and then compare the observed number of data points in each region with the number which would be expected to be found in that region according to the assumed distribution and the given sample size. The key idea underlying this class of methods is that a statistic (i. e. a function of the observations) can be constructed which has an approximate chi-square distribution provided that the observations are governed by the assumed distribution. It should be noted that, on the average, the accuracy of this type of goodness-of-fit test increases as the sample size increases. Moreover, close agreement between the data and the model does not necessarily imply theoretical evidence for the validity of the model. Such agreement can be interpreted, however, as empirical justification for the use of the model to approximate the physical situation.

For each of the categories of data, a goodness-of-fit to the bivariate normal (BVN) distribution was performed using the chi-squared distribution. In each case, the results indicated that the assumption that the data is governed by a BVN distribution is indeed valid. The regions used in the tests were determined from the theoretical ellipses of concentration.

APPENDIX 4

THE COMPUTER PROGRAM (BVN)

INTRODUCTION

The BVN computer program is designed to obtain values for the parameters k and β, given a desired α and the hypotheses H_o and H_1. This is accomplished by performing a series of double numerical integrations over a sequence of critical regions until a value of k is obtained for which the computed α approximates the desired α. When this k is obtained, one more double integration is performed to calculate β.

DESCRIPTION

For each case being analyzed, a desired value of α is input, followed by the parameters of the bivariate normal (BVN) distributions describing H_o and H_1. Also input are two guesses of bounds on the parameter k; these are called k_l and k_u. A series of coordinate transformations is performed until the critical region can be defined as a portion of the region lying between the two branches of a hyperbola whose equation is either

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$

or

$$\frac{y^2}{b^2} - \frac{x^2}{a^2} = 1 \quad .$$

Note: In this section (x, y) will be used to designate the coordinate variables rather than (x_1, x_2).

The next step performed is to integrate the transformed BVN describing H_o over two critical regions whose parameters are described by

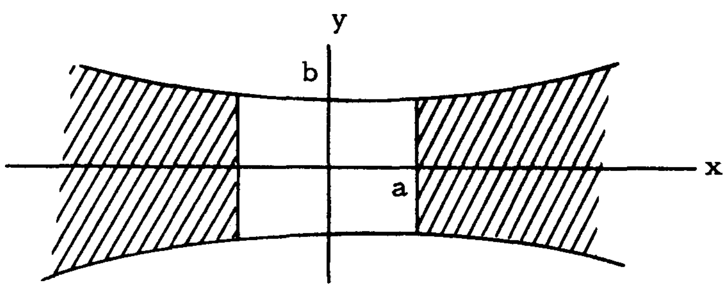
k_l and k_u respectively. k enters into the calculation of a and b in the following manner:

$$a^2 = \left| \frac{c + k}{r} \right|$$

and

$$b^2 = \left| \frac{c + k}{s} \right|$$

If $c + k > o$, the critical region is simply the area between the two branches of the hpperbola. If $c + k < o$, the critical region is the cross hatched area of the region pictured below:



(or this region rotated 90°).

For k_l and k_u, the integrals of the BVN over the critical regions are called α_l and α_u, respectively. If the input α is such that $\alpha_l < \alpha < \alpha_u$ or $\alpha_u < \alpha < \alpha_l$ the calculation continues. If neither of these conditions is met, the calculation is terminated with α_l and α_u printed to help in selection of more appropriate k_l and k_u for another run. When either condition is met, a new k,

$$k_n = \frac{k_l + k_u}{2}$$

is selected and a corresponding α_n computed. It is assumed that α is a monotonic function of k and thus α_n lies between α_l and α_u. α_n is compared with α, α_u and α_l and the appropriate interval either (α_l, α_n) or (α_n, α_u) is selected and the interval halving procedure continued by chosing a new k_n and a new α_n. This process is continued until

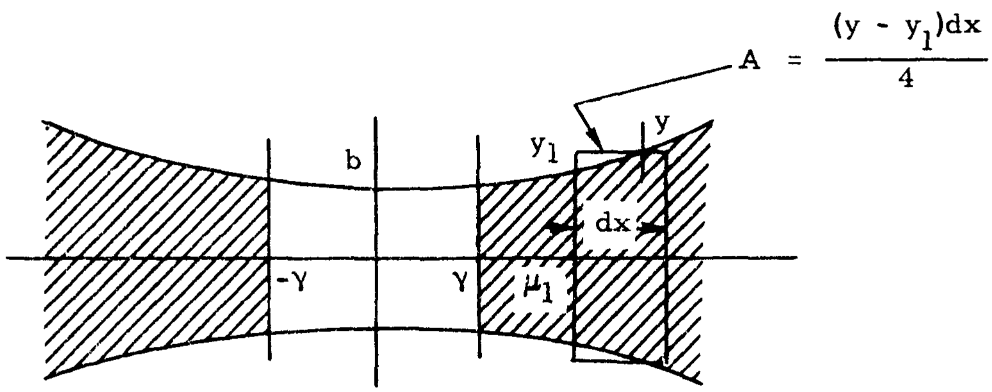
$$\left| \alpha_n - \alpha \right| \; 0.005 \quad .$$

The k_n corresponding to this α_n is then considered to be the correct k. The value of β is determined by integrating the BVN associated with H_l over the region defined by k, and subtracting the value of this integral from 1.0.

INTEGRATION PROCEDURE

For each k value selected, the integration procedure involves approximating the area between the branches of the hyperbola by a series of rectangular strips, integrating over each of these strips. The procedure is the same whether the branches of the hyperbola intersect the x axis or the y axis; for simplicity of description we assume the latter case.

If $\mu_1 < 0$, an additional transformation is made to force $\mu_1 > 0$. A value of $x = x_1$ is chosen such that either $x_1 = \mu_1$ or $x_1 = \gamma$ if $\gamma > \mu_1$. $\gamma = 0$ if $c + k \geq 0$ and $\gamma = a$ if $c + k < 0$.



/ / / / / critical region

A width for a rectangular strip, dx, is chosen such that $4A < dx \cdot 2y\delta$. A and y are shown in the diagram and δ is a small number (presently $\delta = 0.005$). A double integration is performed over the rectangular region of width dx and height 2y. Another strip is then chosen immediately to the right of the preceding strip with the same dx. This dx is tested to ensure that $4A < dx \cdot 2y\delta$. If dx is too large, it is halved until the inequality is satisfied. The integral over the new region is calculated and added to the previous sum. Integration is performed over successive regions moving to the right until S, the contribution from a single region is zero or until

$$S < Z\epsilon$$

where Z is the sum of all S and ϵ is 0.01.

If $\gamma > \mu_1$, the same integration process is then initiated starting at $-\gamma$ and proceeding to the left. If $\gamma < \mu_1$, rectangular regions are constructed to the left of μ_1, moving left to γ, and then starting at $-\gamma$ moving left. In all cases $S = 0$ or $S < Z\epsilon$ terminates the process.