A. Seamster,[1] B.Sc.; T. Mead,[1]; J. Gislason,[1] B.Sc.; K. Jackson,[2] B.Sc.; F. Ruddy,[2] Ph.D.; and B. D. Pate,[1] Ph.D.

Studies of the Spatial Distribution of Firearms Discharge Residues

The technique of determining the circumstances of the discharge of a firearm through measurement of the inorganic residue from combustion of the primer has been substantially detailed [*1–23*]. The principal components of this residue are usually lead (Pb), antimony (Sb), and barium (Ba); the latter two elements may be determined, in the trace quantities encountered, by neutron activation analysis [*5,9–11*]; all three may be determined by atomic absorption spectrometry [*12,13,21,22*].

Primer residue is found near the point of impact of the bullet on a target, on floor and wall surfaces near the bullet trajectory and the weapon, and on the hands of a weapon firer. The assay of the total amount of residue on a firing hand may be attempted if the hand surfaces are swabbed or rinsed with appropriate solutions [*15,17,18*]. However, the results are subject to some uncertainty (beyond that occasioned by washing, delays in sampling and the like) because the three elements in question are also found on hands of persons who have not fired (particularly in certain occupation groups) in quantities comparable to the variable amounts found in firearms discharge residues [*1,5*]. Thus, it seems to be important to attempt to preserve any other residue signatures which may exist, for example, in the form of the variation of residue intensity over the hand or other surfaces.

Such intensity patterns have been demonstrated around bullet holes in paper and fabric targets [*2,8*] and on collectors adjacent to a firing site [*8*], most successfully by neutron irradiation followed by autoradiography of the induced Sb and Ba radioactivity [*2,8*]. Information on firing distances can be deduced in this way [*3,4*]; however, this technique may not always be practicable if (as has been usually the case thus far) a clothing or wall-covering specimen must be subjected to a nuclear reactor irradiation.

These considerations indicate a clear need for a technique capable of lifting firearms discharge residues from a variety of surfaces via a lifting material which itself should contain a low background of the elements being studied. Previous studies have employed a range of materials [*7,14,16*]. The present authors were privileged to receive, while their work was in progress, a report by Goleb and Midkiff [*23*] on a comparison of the efficiency of residues lifting by paraffin, cellulose film, and common adhesive tape. The present article describes the application of Ace® Lifting Tape, commonly employed by law enforcement personnel in fingerprint applications.

Received for publication 11 Nov. 1975; revised manuscript received 6 Jan. 1976; accepted for publication 23 Jan. 1976.

[1] Chemistry Department, Simon Fraser University, Burnaby, British Columbia, V5A 1S6, Canada.
[2] Nuclear Radiation Center, Washington State University, Pullman, Wash. 99163.

Experimental Techniques and Results

Lift Efficiency

Ace® lifting tape was obtained from the Institute of Applied Science, Chicago, Ill. Firearms discharge residues were lifted by peeling the protective backing from the tape, pressing the tape firmly onto the surface carrying the residue, peeling off the tape with forceps, and pressing it (glue side down) in contact with polyethylene film to sandwich the lifted residue. To reduce the antimony background in subsequent measurements, the polyethylene film thickness was reduced to 0.005 in. (0.13 mm).

The film did not tear during the lifting, and, owing to the good adhesive qualities of the glue coating the tape, the lifted residue was accompanied by surface debris, including hairs in the case of skin lifts. The efficiency with which residue was lifted from paper or cloth targets was investigated by means of energy-dispersive X-ray fluorescence analysis, comparisons being made of the residue found on the target surface before and after a lift or of the residue found on the target surface before a lift and on the tape after the lift. Lift efficiencies ranged from 30 to 70%, even from very coarse woolen fabric. The data of Goleb and Midkiff [*22*] suggest that lift efficiencies from skin surfaces may have been higher than those from paper and fabric surfaces.

Residue Detection

Two techniques have been used to detect firearms discharge residue in the lifted specimen: autoradiography and neutron activation analysis. The Ace® lifting tape plus polyethylene sandwich was irradiated in a thermal neutron flux of either 1.0×10^{12} or 5.6×10^{12} neutrons$\cdot$cm$^{-2}\cdot$s^{-1}, together with standards containing known quantities of antimony. (These latter were either aliquots of an Sb solution absorbed on to a Biosil® matrix or weighed quantities of National Bureau of Standards orchard leaves material.) The irradiated specimens were then stored for time periods chosen to optimize the ratio of the activity of 2.7-day ^{122}Sb relative to the other residual radioactivity generated in the lifted debris. Typically, irradiation times were from 20 min to 8 h, depending on the amount of Sb in the samples, while storage times after irradiation ranged from 0 to 24 h, depending on the amount of radioactivity other than Sb encountered and on the contrast required in autoradiographs subsequently made. These times generally had the result that the 83-min ^{139}Ba, generated from the barium content of the firearms discharge residue, had largely decayed before measurements were made. It proved impossible to optimize factors such as the contrast obtained in autoradiographs for both antimony and barium at the same time; however, since spatial distribution signatures of residue were sought, the distribution of one element was expected to provide the desired information. Antimony was chosen for convenience; however, changes in times would permit optimization for and measurement of Ba.

In principle, the use of epithermal neutrons for the irradiations should also have improved the ratio of the activity intensity of radioantimony to the intensity of other interfering activities (after the variation of cross sections with neutron energy). In practice, manipulation of irridation and storage times proved more effective.

For autoradiography, the irradiated sandwich was pressed to Polaroid® Type 57 film for a time period chosen to give optimum intensity to the resulting autoradiograph (generally from 30 min to 5 h). For neutron activation analysis, all or selected portions of the irradiated sandwich were placed at known distances from a 60-cm^3 coaxial Ge(Li) gamma-ray spectrometer of known efficiency. Comparison of peak areas produced in the resulting spectra by the gamma rays from the decay of ^{122}Sb with corresponding areas in spectra obtained from Sb standards irradiated in the same neutron flux at the same time permitted the extraction of quantitative data on the Sb content of the specimen (Table 1).

TABLE 1—*Antimony content of hand lifts (results obtained by neutron-activation analysis).*

Subject	Hand Area	Antimony in Complete Lift, ng	Antimony in Selected Area, ng	Antimony in Selected Area, %[a]
Fired once	web-back	37.1	2.10	5.66
Fired once	web-palm	67.6	0.940	1.39
Fired once	fingers-palm	66.4	2.05	3.09
Fired once	fingers-back	66.4	1.65	2.48
Fired three times	web-back	69.3	1.40	2.02
Fired three times	web-palm	70.4	4.14	5.88
Fired three times	fingers-palm	77.0	3.37	4.37
Fired three times	fingers-back	53.2	4.39	8.25
Machinist	web-back	73.9	0.244	0.330
Machinist	web-palm	126	...	...
Machinist	fingers-palm	113	0.170	0.151
Machinist	fingers-back	60.0	0.324	0.540
Garage mechanic	web-back	562	3.03	0.539
Garage mechanic	web-palm	420	1.53	0.364
Garage mechanic	fingers-palm	406	1.56	0.385
Garage mechanic	fingers-back	570	3.14	0.550
Nonsmoker	web-back	84.6	0.343	0.470
Nonsmoker	web-palm	204	0.600	0.294
Nonsmoker	fingers-palm	91.7	0.102	0.111
Nonsmoker	fingers-back	83.3	0.633	0.760
Cigarette smoker	web-back	49.0	...	...
Cigarette smoker	web-palm	41.7	0.258	0.619
Cigarette smoker	fingers-palm	40.0	0.102	0.255
Cigarette smoker	fingers-back	51.8	0.380	0.734

[a]Obtained by dividing the numbers in Column 4 by the numbers in Column 3.

The radioantimony background generated in the tape itself by the irradiation procedure was determined in a separate experiment. The radiosodium and other radioactivities generated in the tape constituted a background in the autoradiography against which the pattern of firearms discharge residue and other debris had to be measured. The background was found not to be sufficiently intense to constitute a significant problem.

Recognition of a Bullet Hole

Krishnan [*2-4*] has demonstrated the power of the autoradiography technique, when applied directly to residue on a target surface, to demonstrate the presence of firearms discharge residue around the edges of a bullet hole (and indeed distributed for some distance around the hole in the case of short firing distances). The present work examined whether recognition of a bullet hole was possible by using the lifting procedure (thus avoiding irradiation of a potentially valuable specimen), particularly under the common circumstance where a target fabric material is saturated with blood.

A specimen was prepared by firing a .38-caliber bullet through a fabric target to which blood was subsequently applied. The lifting procedure was then followed, and both the target and the lifts were subjected to autoradiography. The result for the target itself is shown in Fig. 1*a*, while in Fig. 1*b* is shown the autoradiograph obtained from the lift. In Fig. 2*a* is seen the gamma-ray spectrum obtained from the irradiated target, and in Fig. 2*b*, that obtained from the lift.

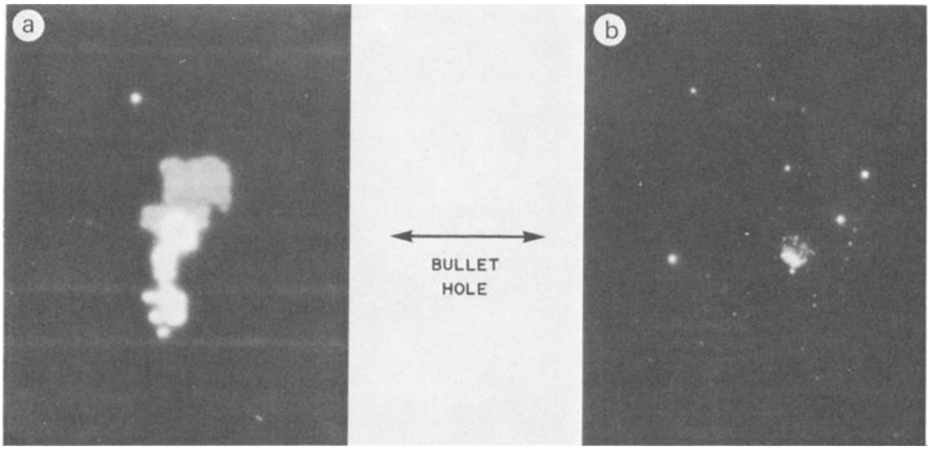

FIG. 1—*Autoradiographs* (a) *from blood-stained cloth target directly and* (b) *from lift taken from same target before irradiation.*

In the autoradiograph from the bloodstained fabric the bullet hole is clearly recognizable, and the antimony radioactivity is clearly distinguished in the corresponding gamma-ray spectrum from the sodium activity generated in the blood. However, in both cases the results are much cleaner from the lift obtained from this specimen. The efficiency of the tape in lifting firearms discharge residue from this sample was something of a surprise; the blood was applied to the fabric after deposition of the residue and thus was expected to overlay it and interfere with the lifting process.

Following this success, an experiment was mounted to determine whether an entrance bullet hole could be distinguished from an exit bullet hole with this same technique. Some beef muscle tissue (in the form of boned roast) was wrapped in fabric and a bullet of .38 Special caliber was fired through the assembly from a standard Colt revolver. Figure 3*a* shows the autoradiograph of the lift taken from the upstream side of the entrance bullet hole, and Fig. 3*b*, that from the upstream side of the exit bullet hole. Figures 4*a* and *b* show the corresponding spectra. Although the firearms discharge residue is visible around the exit hole (Fig. 3*b*), together with debris from the meat itself, the deposit is much weaker than was observed around the entrance bullet hole (Fig. 3*a*) and distinction between the two is possible. Curiously, a much more intense deposit of residue was lifted from around a bullet hole in a cloth target placed 4 in. (102 mm) downstream from the meat plus cloth assembly. It is possible that the residue is diminished from around the exit bullet hole because of the proximity of the tissue to the fabric in that position, but the exact mechanism of this influence is not clear.

Firearms Discharge Residues on Floor Surfaces

The pattern of residue fallout on a floor surface in the vicinity of a firearms discharge has been previously studied [24]. The present work applied the lift procedure to the measurement of such fallout patterns. A linoleum floor surface was set immediately beneath and in front of the point of discharge from a Colt service revolver of .38 Special ammunition. Points on the floor surface arranged in a rectangular grid were sampled by lifting the firearms discharge residue from within a 1-in.^{2} (6-cm^2) area centered on the point in question. The density of residue was estimated from autoradiographs of each of the lifts by the number of deposit spots and their estimated intensity. The corresponding

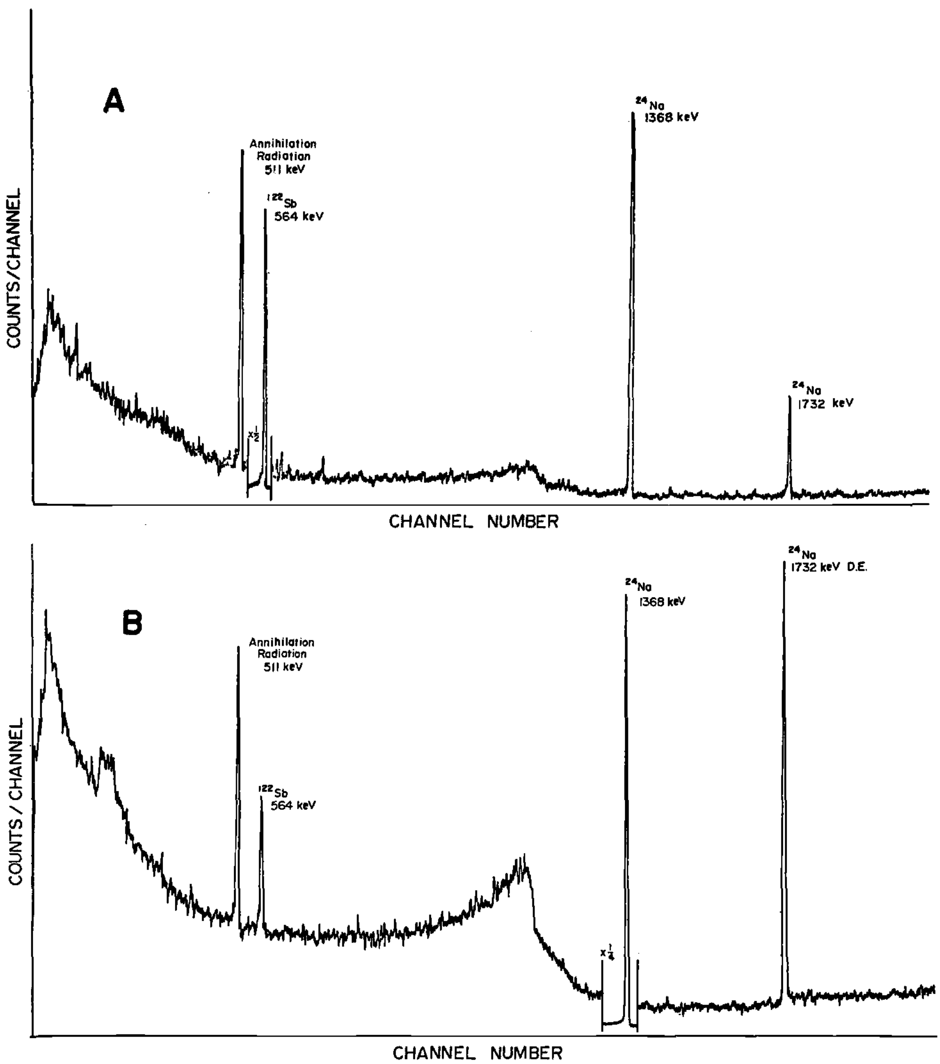

FIG. 2—*Gamma-ray spectra* (a) *from neutron-irradiated bloodstained cloth target directly and* (b) *from lift taken from same target before irradiation.*

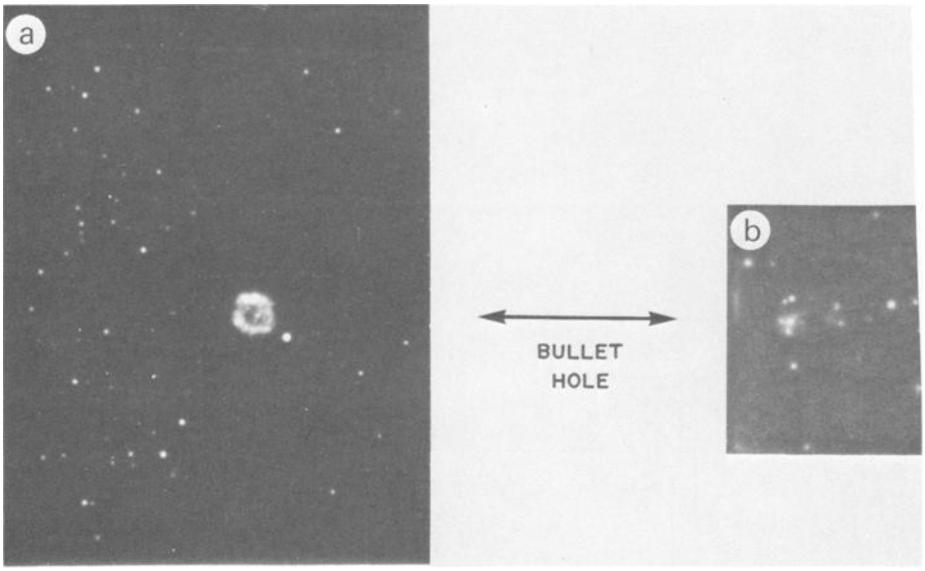

FIG. 3—*Autoradiographs from lifts taken* (a) *from the entrance bullet hole in the cloth wrapping of a muscle tissue target and* (b) *from the exit bullet hole in the same cloth wrapping.*

numerical information was then plotted on a grid corresponding to the one for the floor lifts, and rough contours of equal deposit density were drawn by interpolation.

The results are shown in Fig. 5 with the position of the weapon (which was known in this preliminary qualitative test). The most intense fallout of residue (probably ejected from the barrel) is found about 3 f (0.9 m) ahead of the weapon, and a series of firings involving the same and different types and calibers of weapon and ammunition would be needed to determine the extent to which the intensity and distances may be characteristic.

The second most intense areas of residue fallout are found adjacent to and on both sides of the weapon. This pattern probably arose from residue ejected from between the barrel forcing cone and the cartridge chamber; thus, it may be characteristic of revolver firings and may also serve to locate the firing position.

Additional parameters to be defined are the influence of air currents (the present patterns being apparently displaced a little to the left of the firing line), the efficiency of lifting of residue from carpet and other surfaces, and the optimum technique for residue measurement in such tests (gamma-ray spectroscopy or X-ray fluorescence analysis being other possibilities). The potential of the present technique does, however, appear to justify additional development.

Hand Lifts

The lifting and autoradiography procedure was applied to the right hand (the hand in which the weapon was held) of a police constable after one firing and after three firings from a Colt service revolver of .38 Special ammunition. Figure 6 shows the autoradiographs after one firing, and Column 3 of Table 1 shows the total amount of antimony measured by neutron activation analysis in each of the lifts. Figure 6 shows that the autoradiograph of lifts obtained from the parts of the hand in contact with the gun show

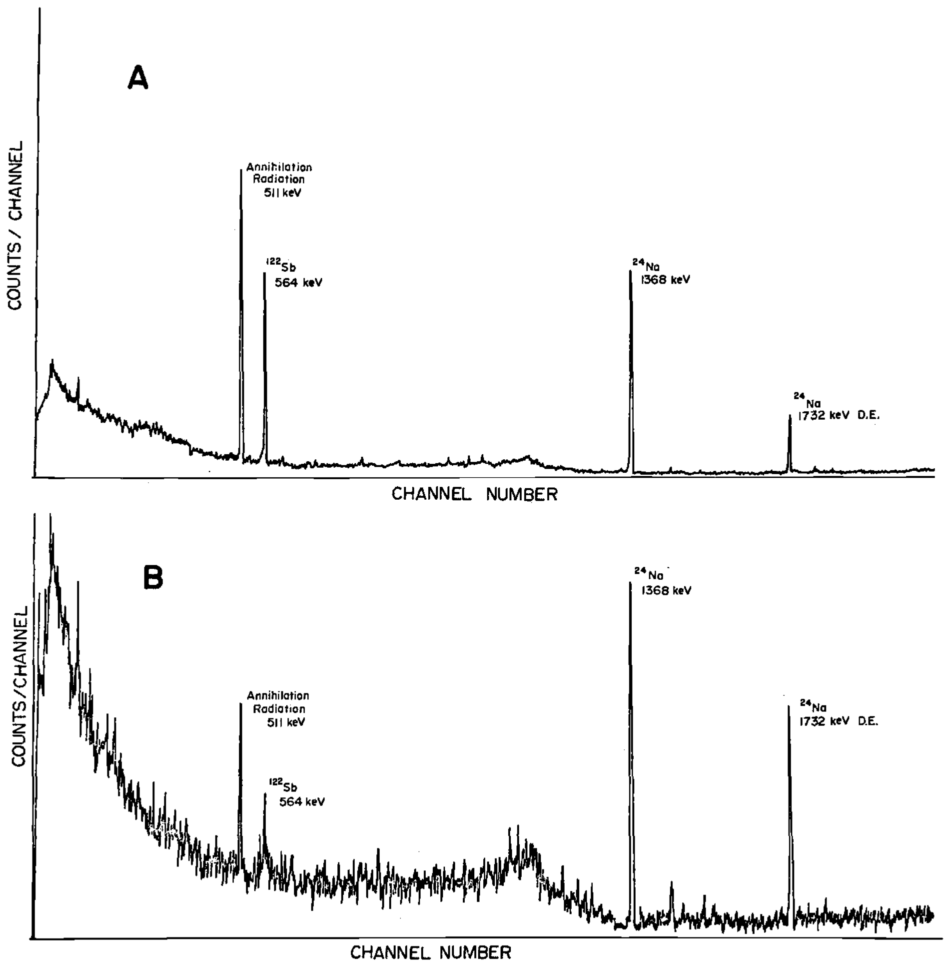

FIG. 4—*Gamma-ray spectra* (a) *from a neutron-irradiated lift from the entrance bullet hole in the cloth wrapping of a muscle tissue target and* (b) *from a neutron-irradiated lift from the exit bullet hole in the same cloth wrapping.*

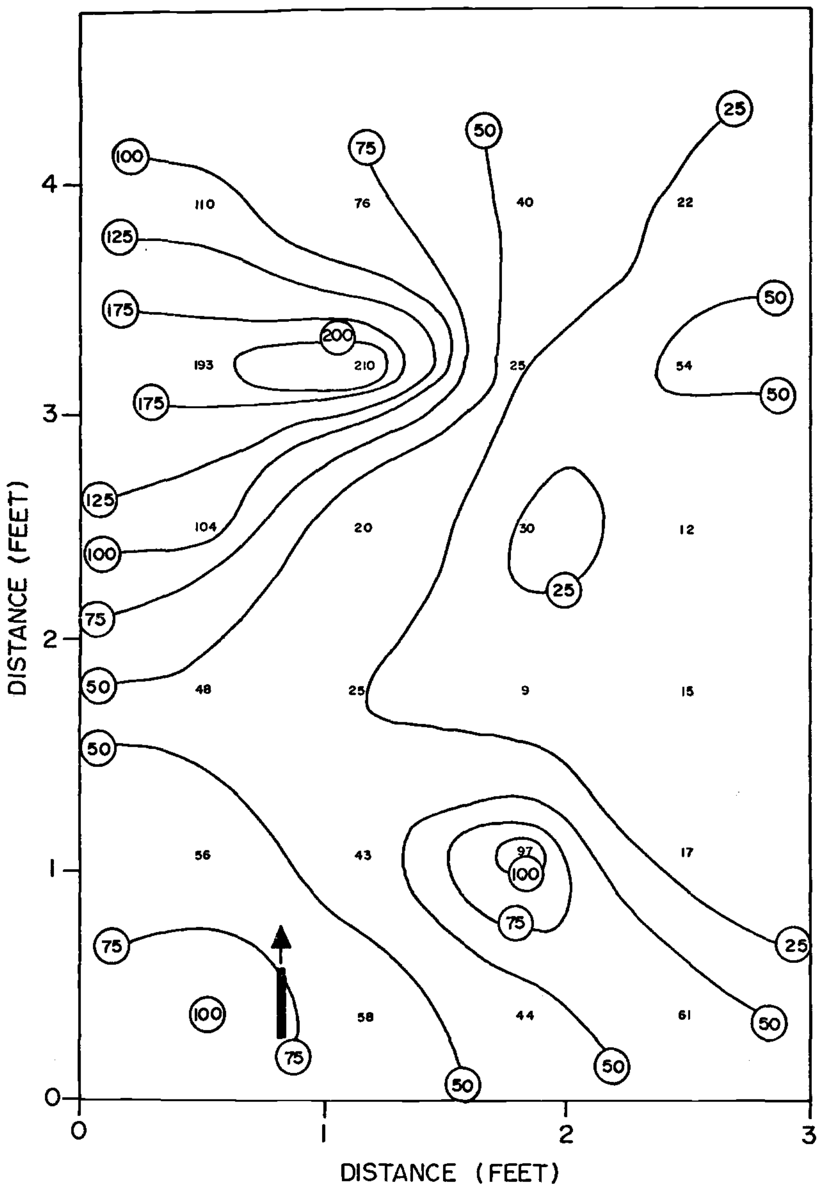

FIG. 5—*Distribution of firearms discharge residue lifted from the floor below and in front of the point of firing of a revolver* (bar and arrow).

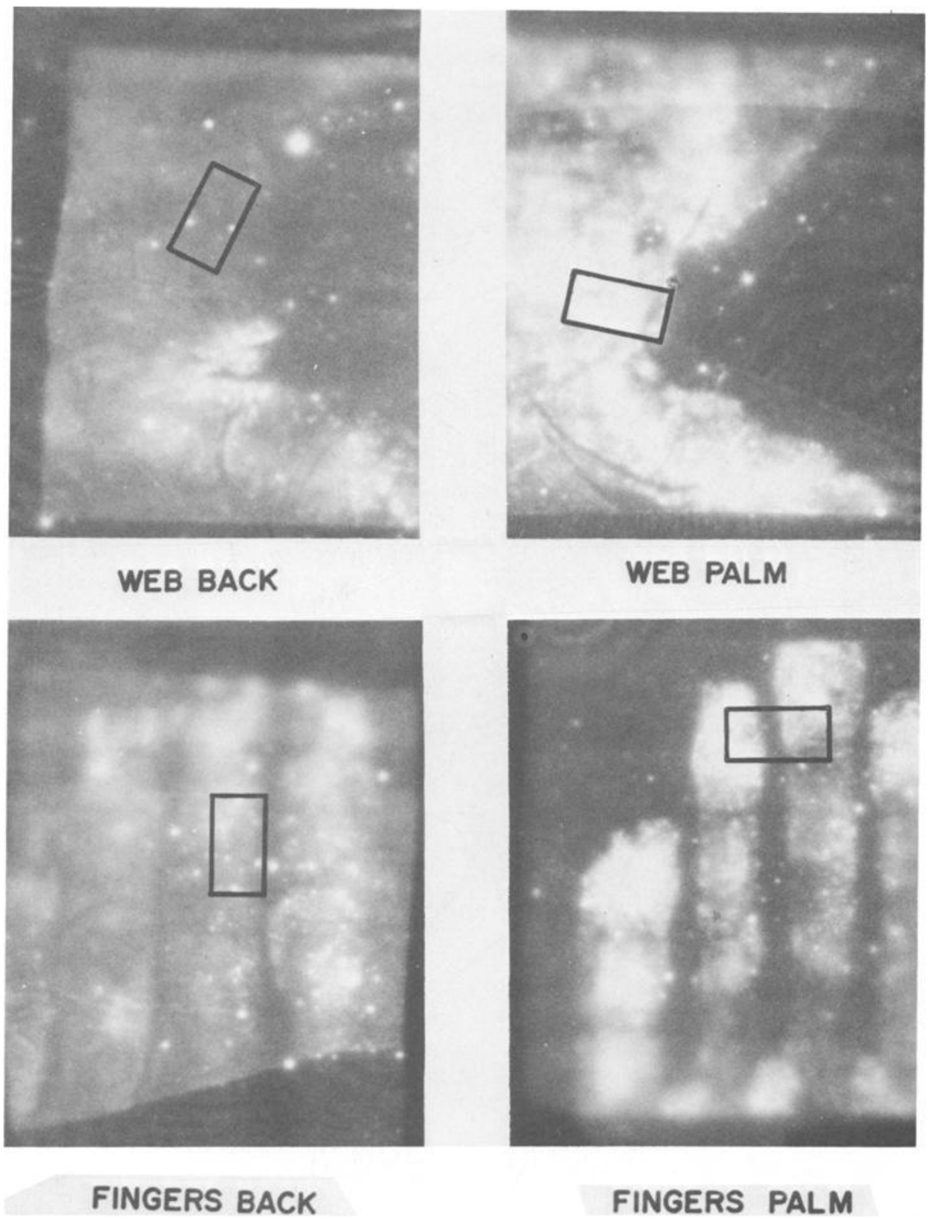

FIG. 6—*Autoradiographs of lifts taken from a hand after one firing. Rectangles indicate typicc regions cut out for subsequent tests (see text).*

evidence of firearms discharge residue, evidently wiped from the gun surface, while the back of the web and fingers gave lifts with a number of deposit spots, suggestive of fallout from residue ejected from between the cartridge chamber and the barrel forcing cone.

The analytical results in Table 1 indicate very little difference in residue lifting after one firing and after three firings in those regions where residue on the gun can be expected to wipe off. More residue was found after three firings on the web back than after one firing, consistent with residue in this location resulting from fallout rather than from being wiped off.

To determine whether the autoradiography patterns in Fig. 6 were sufficiently distinct to permit recognition of a firing hand, the right hands of a machinist and a garage mechanic were also sampled (Figs. 7 and 8, respectively) in the expectation that both would show patterns of material intensely activated by neutron irradiation. In addition, the right hands of two university research personnel, one a nonsmoker and one a smoker, were subjected to the lift procedure. In these two cases the lift patterns were similar to, if less intense than, those shown in Figs. 7 and 8. The neutron activation analysis results for total antimony in the lifts of deposits for these four subjects are also shown in Table 1, Column 3.

It became clear at this point that neither the autoradiography pattern itself (which does not discriminate clearly among the various radioactive species induced in the irradiated lift) nor the results for total antimony content of the lifted residue were sufficiently characteristic to offer a reliable discrimination of firing hands from others. There remains the possibility that the pattern of certain deposited elements, such as antimony, might be characteristic, if this could be determined separately from the distribution of all other material in the lift. One possible way to determine such a pattern might be a point by point activation analysis of the lift area.

As a first approach, it was decided to compare the antimony content in selected regions of a lift to the total for the entire lift with neutron activation analysis. A typical gamma-ray spectrum from a neutron-irradiated lift (taken in this case from a firing hand) is shown in Fig. 9*a*; the spectrum from a control hand is shown in Fig. 9*b*.

The areas sampled were those where the most intense residue pattern was found after a revolver was fired (Fig. 6). Areas 1 by 2 cm were cut from the lifts identified in Table 1 from locations indicated in Fig. 6 by the rectangles drawn on each autoradiograph. These samples were then separately subjected to neutron activation analysis. The results in terms of amount of antimony found are reported in Column 4 of Table 1. The ratio of the amount of antimony found in the given small area to that found in the lift as a whole, expressed as a percentage, is shown in Column 5 of Table 1.

The analytical data in Column 3 are estimated to have a precision of ± 10%. The precision of the data in Column 4 is such that the estimated precision of the percentages given in Column 5 is only ± 25%. Even with these uncertainties, it is clear from Column 5 in Table 1 that the selected areas of the lifts taken from hands of weapon firers contained a substantially greater percentage of the total lift antimony than was the case with other subjects. On an average, after one firing a little more than 3% of the antimony was found within the selected areas, while after two firings a little more than 5% was found within these same areas.

Thus, it is concluded that the antimony deposition patterns from a firing hand may indeed be sufficiently different from the patterns found on hands that have not fired to offer a positive identification, possibly with a simple comparison as described above; alternatively, a certain identification may only be possible after more complete determination of the pattern by analysis of (for example) 1-cm^2 areas cut from the entire lift. Further work is needed to settle this question.

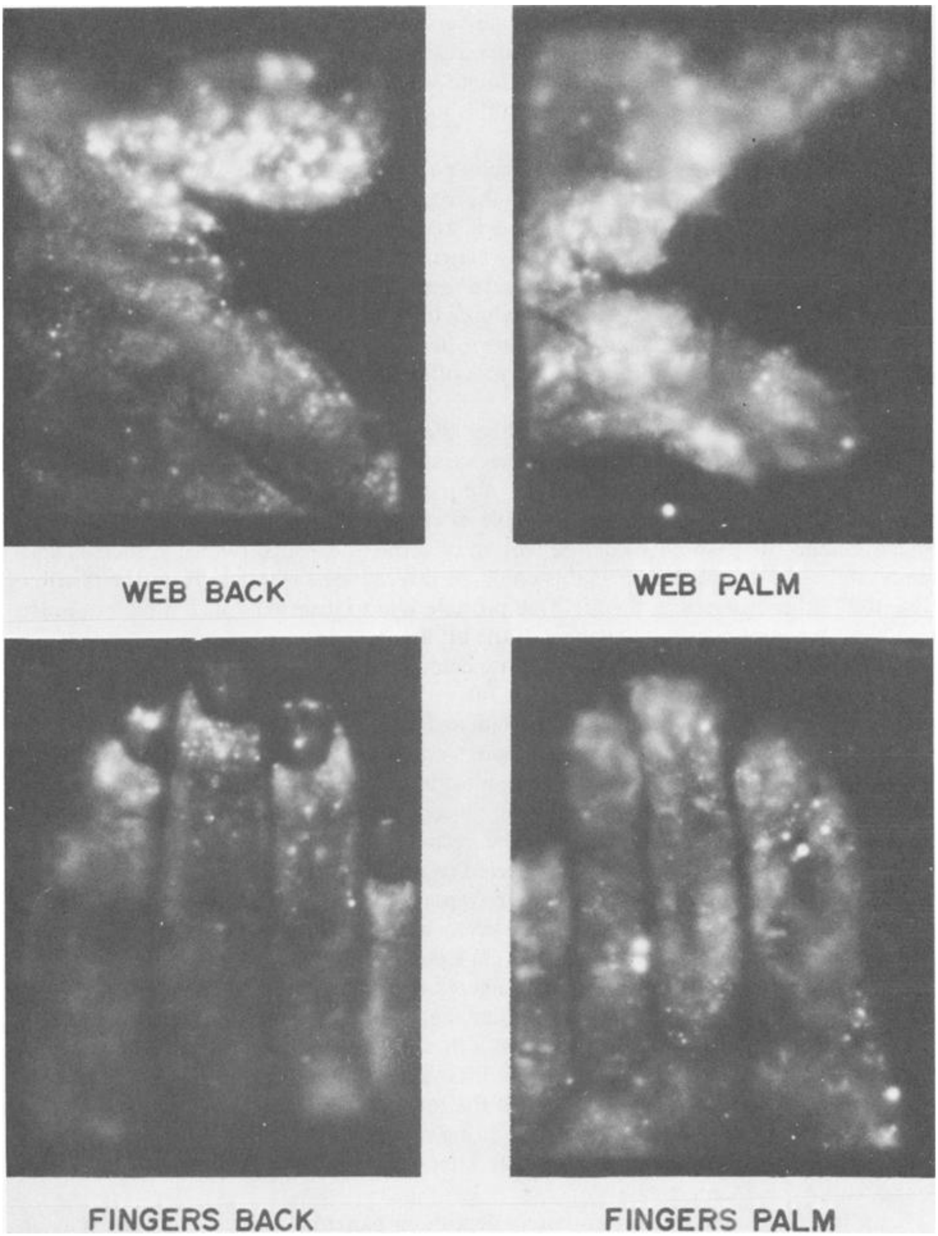

FIG. 7—*Autoradiographs of lifts taken from the unwashed right hand of a machinist.*

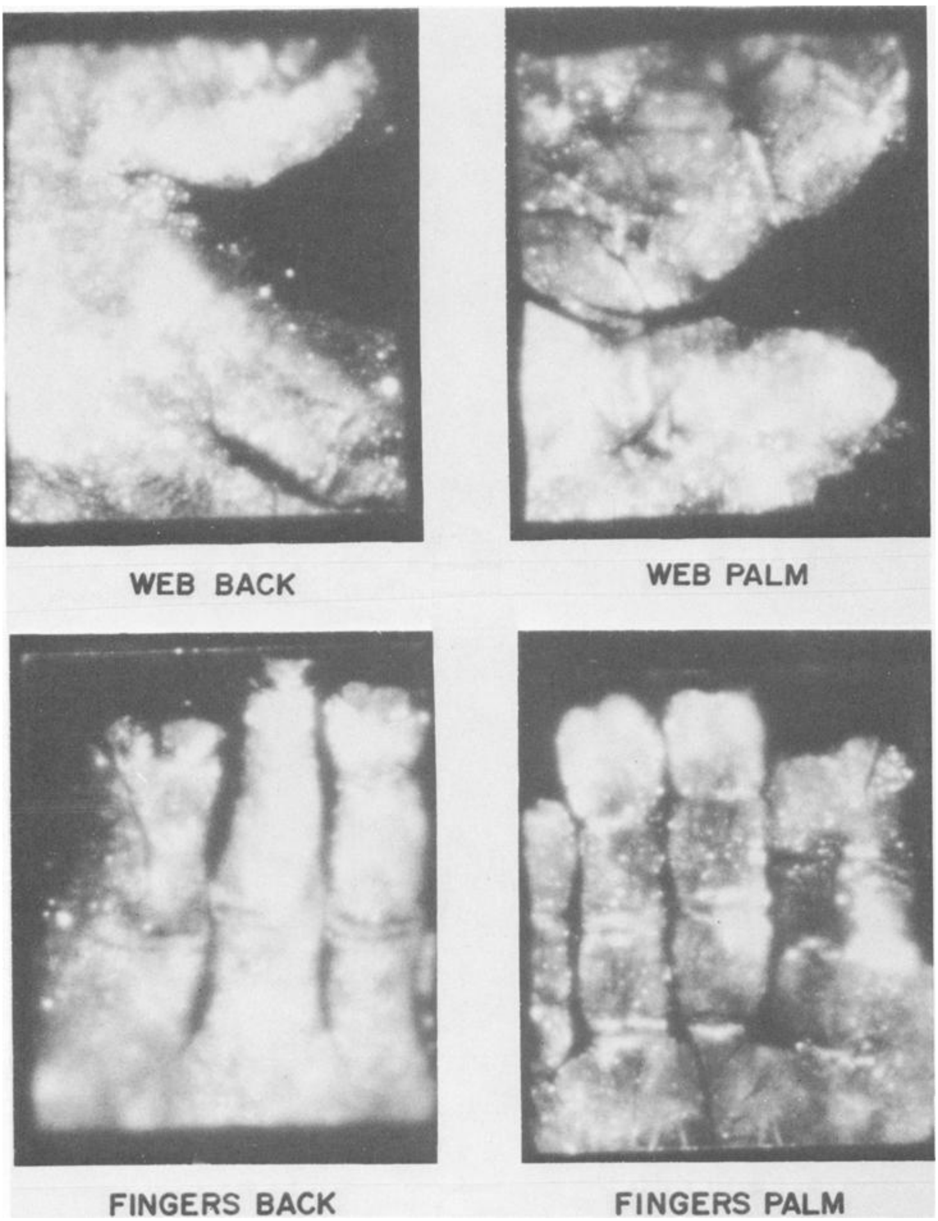

FIG. 8—*Autoradiographs of lifts taken from the unwashed right hand of a garage mechanic.*

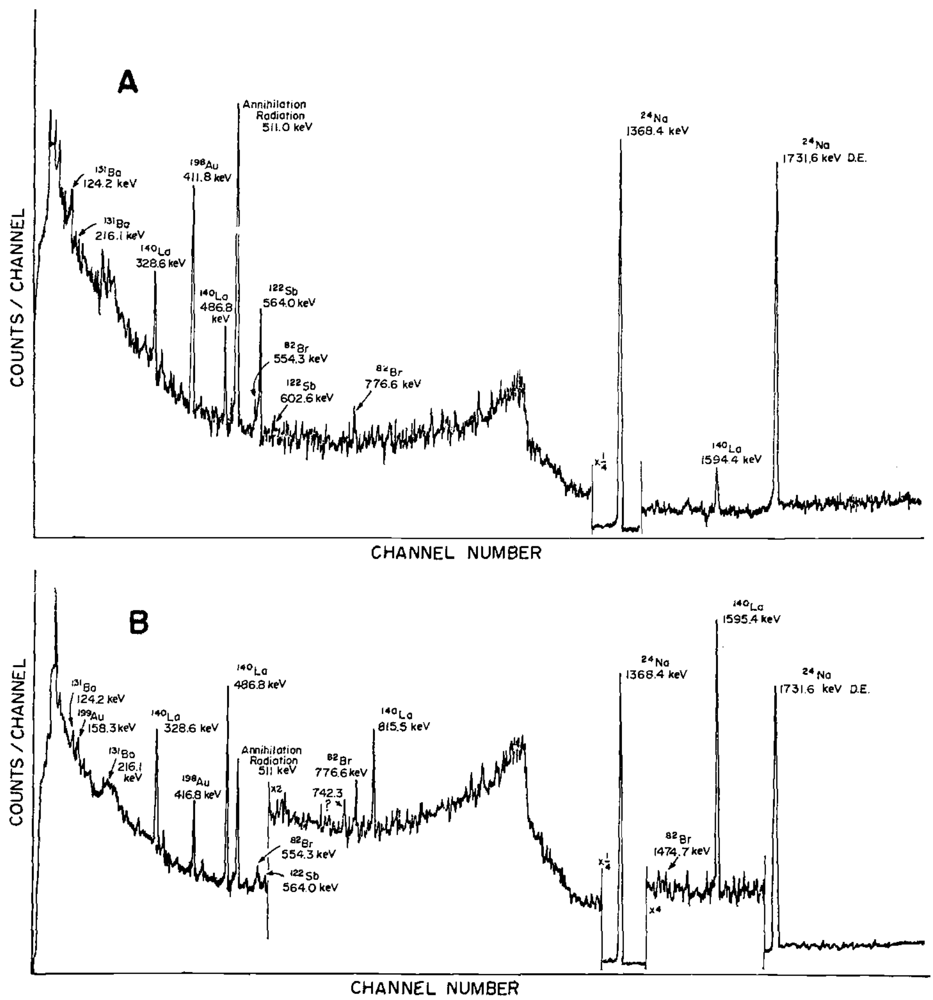

FIG. 9—*Gamma-ray spectra from neutron irradiated lifts* (a) *from a firing hand after three firings of a .38-caliber Colt service revolver and* (b) *from a hand that had not fired.*

Conclusions

Fingerprint lifting tape appears to offer a convenient and reasonably quantitative technique for lifting firearms discharge residues from targets, floor, and skin surfaces. Autoradiography combined with neutron activation analysis may be employed in conjunction with the lifting technique to identify bullet holes, to measure firearms discharge patterns, and perhaps to recognize firing hands. A program of further study involving a range of weapons and firing circumstances is indicated to determine the range of applicability of the technique.

Summary

Fingerprint lifting tape has been applied to the lifting of firearms discharge residue from various surfaces. Lifting efficiencies from coarse fabric ranged from 30 to 70%. Use of the technique has been demonstrated in identifying a bullet hole and in measuring residue patterns on floor and firing hand surfaces. In hand lifts it has been shown that autoradiography alone does not uniquely distinguish the hand of someone who has fired a revolver from the hand of someone who has not. Neutron activation analysis of lifts from selected hand areas may, however, provide such a distinction.

Acknowledgments

The authors gratefully acknowledge advice and cooperation from Inspector P. Gazey and the firearms section of the RCMP Vancouver Crime Laboratory, and also support from the Royal Canadian Mounted Police. Their gratitutde is due to P. Miller and the operating crew of the University of Washington reactor, Seattle, Washington, and to the operating crew of the reactor at the Nuclear Research Center, Washington State University, Pullman, Washington, for scheduling the irradiations.

References

[1] Ruch, R. R., Guinn, V. P., and Pinker, R. H., *Nuclear Science and Engineering*, Vol. 20, 1964, pp. 381-385.
[2] Krishnan, S. S., *Journal of Forensic Sciences*, Vol. 12, No. 1, 1967, pp. 112-122.
[3] Krishnan, S. S. and Nichol, R. C., *Journal of Forensic Sciences*, Vol. 13, No. 4, 1968, pp. 519-527.
[4] Krishnan, S. S. in *Law Enforcement Science and Technology*, Vol. 2, S. I. Cohn, Ed., Illinois Institute of Technology, Chicago, 1969.
[5] Schlesinger, H. L., Lukens, H. R., Guinn, V. P., Hacklemann, R. P., and Korts, R. F., "Report G. A.-9827," Gulf General Atomic Inc., San Diego, 1970.
[6] Krishnan, S. S., Gillespie, K. A., and Anderson, E. J., *Journal of Forensic Sciences*, Vol. 16, No. 2, 1971, pp. 144-151.
[7] Albu-Yaron, A. and Amiel, S., *Journal of Radioanalytical Chemistry*, Vol. 11, 1972, pp. 123-132.
[8] Gislason, J. and Pate, B. D., *Journal of Radioanalytical Chemistry*, Vol. 15, 1973, pp. 103-113.
[9] Rudzitis, E., Kopina, M., and Wahlgren, M., *Journal of Forensic Sciences*, Vol. 18, No. 2, 1973, pp. 93-100.
[10] McFarland, R. and McLain, M., *Journal of Forensic Sciences*, Vol. 18, No. 3, 1973, pp. 226-231.
[11] Hoffman, C. M., *Journal of the Association of Official Analytical Chemists*, Vol. 56, No. 3, 1973, pp. 1388-1390.
[12] Cone, R., *Proceedings of the Spring, 1973 Meeting*, Southern Association of Forensic Scientists, Atlanta, Ga., 1973.
[13] Renshaw, G., Pounds, C., and Pearson, E., *Atomic Absorption Newsletter*, Vol. 12, No. 2, 1973, pp. 55-56.

[*14*] LaFleur, P. D., Gills, T., and Becker, D., *Proceedings of the Winter 1973 Meeting,* American Nuclear Society, San Francisco, 1973.
[*15*] Cornelis, R. and Timperman, J., *Medical Science and the Law,* Vol. 14, No. 2, 1974, pp. 98-116.
[*16*] Pillay, K. K. S., Jester, W. A., and Fox, H. A., III, *Journal of Forensic Sciences,* Vol. 19, No. 1, 1974, pp. 768-783.
[*17*] Stone, I. C., Jr. and Petty, C. S., *Journal of Forensic Sciences,* Vol. 19, No. 4, 1974, pp. 784-788.
[*18*] Krishnan, S. S., *Journal of Forensic Sciences,* Vol. 19, No. 4, 1974, pp. 789-797.
[*19*] Renshaw, G., "C.R.E. Report 103," Home Office Central Research Establishment, Aldermaston, England, 1974.
[*20*] Goleb, J. A. and Midkiff, C. R., Jr., *Applied Spectroscopy,* Vol. 28, No. 4, 1974, pp. 382-383.
[*21*] Kinard, W. D. and Lundy, D. R., *Proceedings,* American Chemical Society National Meeting, Atlantic City, N.J., Sept. 1974.
[*22*] Goleb, J. A. and Midkiff, C. R., Jr., *Applied Spectroscopy,* Vol. 29, No. 1, 1975, pp. 44-48.
[*23*] Goleb, J. A. and Midkiff, C. R., Jr., *Journal of Forensic Sciences,* Vol. 20, No. 4, 1975, pp. 701-707.
[*24*] Smith, C., *Journal of Forensic Sciences,* Vol. 18, No. 2, 1973, pp. 101-109.

Chemistry Department
Simon Fraser University
Burnaby, British Columbia, V5A 1S6, Canada