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Spherical Coordinates for Plotting the Positions of Powder Residues

The idea of the "Reconstruction of the Crime" as an aid to its solution was first succintly expressed and practiced by Alphonse Bertillon [*1*] toward the latter part of the nineteenth century. Since that time investigators have aimed at ever more detailed descriptions and reconstructions. The phases of description and reconstruction employ procedures very similar to those employed in the compilation of maps. The mapping quality is the basis for the experiments to be described in this paper.

Since firearms are sometimes employed in crime, exact descriptions of their structure and behavior are sometimes useful in the reconstruction of criminal events. The more frequently pursued studies on firearms have involved bullet and cartridge case markings and powder residues deposited on the suspect's or victim's hands and clothing. It is sometimes possible to approximate the distance from which a gun was discharged by the density of the pattern of powder residues present on clothing, applying methods described by O'Hara and Osterburg [*2*] and attributed to Walker.

Not all of the powder residues however follow the general pathway of the projectile. What then is the configuration of the entire cloud of residues emitted from the gun? Is the configuration of this cloud (a rapidly changing function) in any way peculiar to a given firearm? In general it is believed that the residues travel from the discharging muzzle spreading posteriorly and, according to Kirk [*3*], around the projectile in a cone-shaped cloud. How can this cloud be arrested in its flight to determine the positions of the powder residues? In order to answer these and other questions it would be helpful if the cloud at a given instant could be reconstructed and made to pass in review.

Photographic procedures have yielded important information about the bullet's path, but the paths or trajectories of powder residues are more difficult to photograph, at least by procedures ordinarily available in the police laboratory. It would therefore be useful to prepare a map of the cloud of residues. A map as such depends for exact construction upon a set of coordinates. The cloud of residues from a discharging firearm is a rapidly expanding structure occupying the space around the firearm. It is therefore proposed that a theoretical set of concentric reference spheres be set up around the firearm with the muzzle at the exact center.

A coordinate system for the surface of the earth, a spherical body, is already in existence and seems adequate for the family of spheres assumed to exist around the firearm. This coordinate system consists of meridians of longitude and parallels of latitude; and all

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points on this sphere are represented by pairs of coordinates, that is, longitude east or west of Greenwich and latitude north or south from the equator. As the cloud of powder residues expands from a discharging firearm it passes through the surfaces of the proposed family of concentric spheres. Each particle of powder residue will therefore have a pair of geographic coordinates for each spherical surface traversed. For practical purposes it will be necessary to replace the infinite number of theoretical concentric spheres with finite and less numerous ones of definite radii and made of cloth. The muzzle of the firearm is placed at the exact center of the cloth sphere and aimed at the point determined by the intersection of the equator and the prime meridian, as schematically shown in Fig. 1. For convenience the longitude readings range from 0° through 360° instead of 0° to 180° east or west of Greenwich. The first data available from this experiment will be the position of the bullet hole in the canvas expressed in geographic coordinates as longitude and latitude and in ready measure as angular and linear deviations as desired. The powder residues will impact on the inner surface of the cloth spheres and can be developed for visibility and positioning by the Walker [*2*] test for powder residues.

These experiments can be repeated using successive cloth spheres of increasing radii to produce as much detail as desired. The trajectory of the projectile in successive firings can be reconstructed and the configuration of the expanding cloud of residues can be approximated. The cloth sphere could also collect other information in proper space relationships such as lead shavings from revolvers, primer residues (demonstrable by the method of Harrison and Gilroy [*4*]), and nitrates as reviewed by O'Hara and Osterburg [*5*] and smoke rings demonstrable by infrared photography as described by Turner [*6*]. Presumably the lower quality firearms, that is, those which are old and worn and of cheap construction, will be more likely to exhibit a distinctive assemblage of data brought about

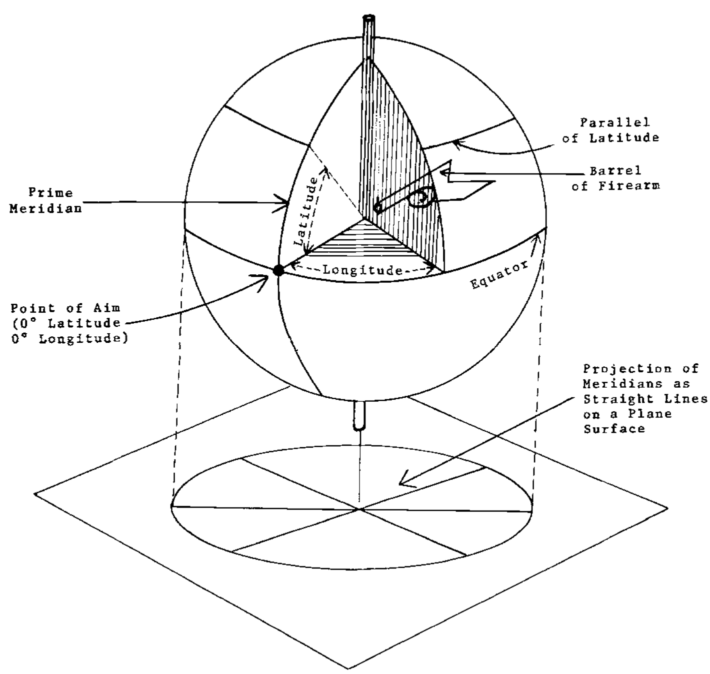

FIG. 1—*Position of Firearm relative to the proposed coordinate system and its projection on a plane surface.*

by poor rifling, leaking chambers, fragmentation of projectiles, poor alignment of cylinder, etc.

To present the curved surface of a sphere or any portion thereof on the plane surface of a map or drawing involves serious mathematical difficulties. In fact it is impossible to do so with perfect accuracy. The term "projection" applied to the representation on a plane of points corresponding to positions on a sphere is not always used in a strictly mathematical sense, but denotes any representation on a plane of the parallels and meridians of geographical coordinates.

Conversely, the construction of the physical cloth models of the theoretical reference spheres suggested here is the first problem encountered in these experiments. That this is a very real problem can be visualized by recalling the removal of the peel from an orange. If the peel is removed in rather large sections, the sections cannot be pressed onto a plane surface such as a table without tearing. However, if cuts in the peel of the orange are made along its meridians from north pole to south pole (see Figure 1) as it were, the sections of peel or "gores" as they are called in map parlance, can be flattened on a plane surface with a minimum of distortion. This is the basis of an interrupted projection devised by Goode in 1923 as described by Greenhood [7]. In fact by cutting the gores only a few degrees of longitude in width, a series can be obtained which will correspond to any minimum of distortion desired. The shapes of the gores and their relationship to a sphere are shown in Fig. 2.

The problem of constructing a physical sphere is just the reverse of the procedure detailed above, that is, a sphere is to be constructed out of a series of plane surfaces, or gores of cloth.

An approximation of a sphere can thus be achieved by cutting gores along meridians of longitude and sewing them together. This is one method employed in the manufacture of geographical globes. Raisz [8] recommends cutting 24 gores for large globes and 12 for smaller ones with small discs for the polar regions. In this study it was decided that ten gores, each subtended by 36° of longitude, cut from cotton cloth and sewn together in spherical form would serve as a suitable approximation of a sphere for experimental purposes. In this way the gores could serve as a sphere (Fig. 1) in assembly and as a projection (Figs. 3 and 4) when separated and laid out flat.

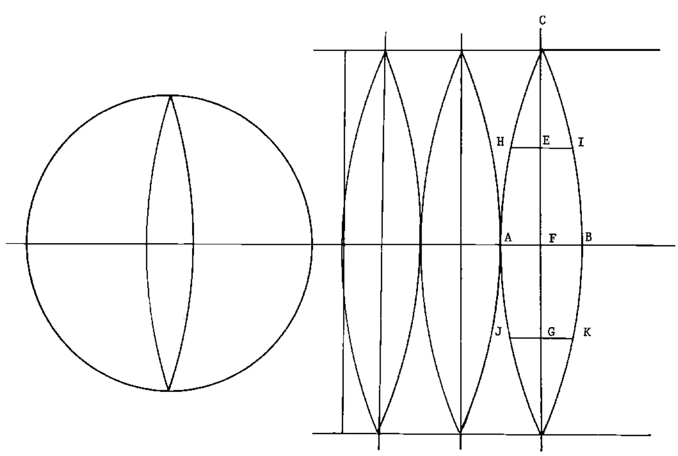

FIG. 2—*Surface areas between Meridians projected to a flat surface as gores and gore dimensions given in Table 1.*

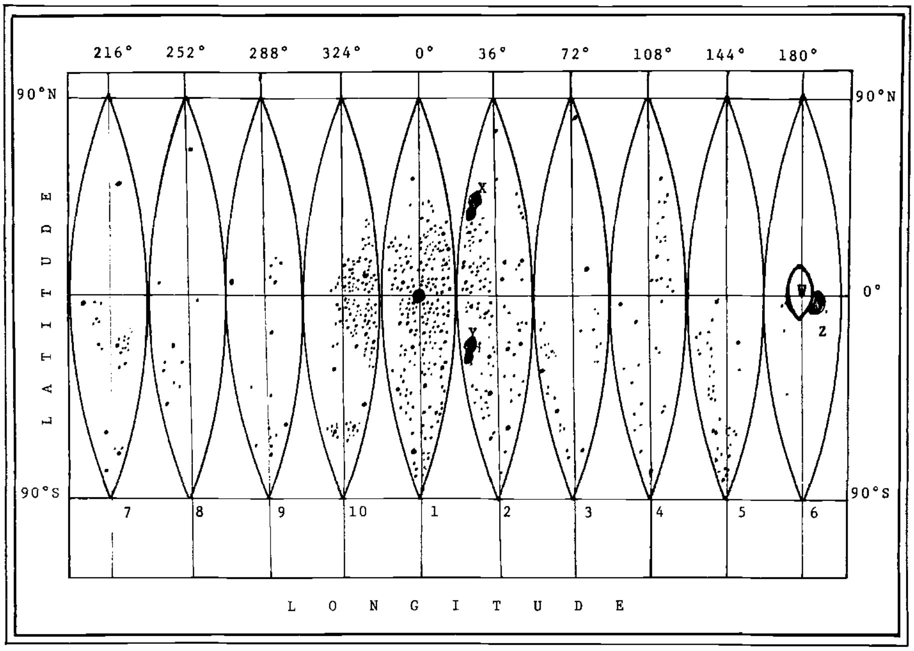

FIG. 3—*Projection on a flat surface of the gores from a sphere 12 in. in diameter with the positions of powder residues plotted. Gores are numbered at the bottom for convenience of assembly after test firing.*

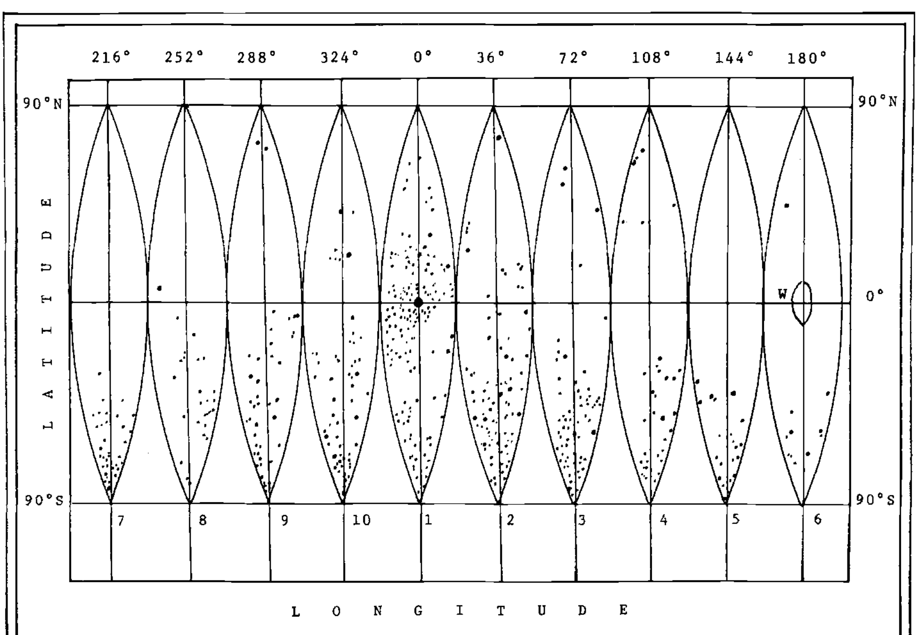

FIG. 4—*Projection onto a flat surface of the gores from a sphere 36 in. in diameter with the positions of powder residues plotted.*

The discharge of firearms takes place in a gravitational field. The axis of the proposed reference sphere is a vertical one and therefore parallel to the vector representing the force and direction of gravity. The pathway of discharged powder residues is the resultant of the forces of explosion and gravity modified by the surrounding atmosphere. If these residues land on the floor, their pattern thereon is one type of projection. The proposed reference sphere with meridians of longitude running from pole to pole has the unique advantage of projecting on a perpendicular plane surface below as a series of straight lines intersecting at a central point the projection of the axis of the pole (see Fig. 1). Furthermore, these straight lines are an expression of the azimuth or direction in degrees from the poles of the sphere. How this convenience can be employed will be more apparent when the experiments themselves are described.

The objectives of this study are:

1. To use geographic coordinates as a reference frame for reconstructing the entire cloud of residues emitted from a discharging firearm.
2. To represent these coordinates on a cloth sphere and to collect all of the residues which are emitted in any and all directions in the space surrounding the firearm.
3. To develop and make visible the nitrites on the coordinate system, and to examine the pattern both on a spherical surface and when projected.
4. To explore further uses of such a mapping procedure.

Procedure

A single gore can be constructed given the dimensions shown in Fig. 2. These dimensions can be calculated by relationships from analytic geometry, and these values for a series of spheres have been assembled in Table 1. These dimensions were plotted on heavy white cardboard by the use of two intersecting perpendicular lines as bases. A smooth curve was drawn through these points by the use of a flexible spline held to the desired points by weights. The cardboard was then cut along the penciled curve and used as a pattern for the cutting of ten identical gores from bleached domestic, a lightweight but closely woven cloth. A one-half inch excess margin was allowed along the margin (meridian) of each gore to provide an external tab for handling and suspension. The ten cloth gores were then machine stitched together, seams outward, along the penciled lines (meridians) to form a

TABLE 1—*Dimensions and Construction data for a series of spheres at 6 in. increments. (All dimensions are in inches.)*

Diameter	Radius	Great Circle Circum-ference	Gore Length Dimension, *CD*	½ Gore Length Dimensions, *EF* and *FG*	Gore Width Dimension, *AB*	Gore Width Dimensions, *HI* and *JK*
6	3	18.84	9.42	4.71	1.88	1.61
12	6	37.68	18.84	9.42	3.77	3.26
18	9	56.55	28.27	14.13	5.66	4.89
24	12	75.40	37.69	18.85	7.54	6.52
30	15	94.25	47.12	23.56	9.43	8.16
36	18	113.10	56.55	28.27	11.31	9.79
42	21	131.95	65.97	32.99	13.20	11.42
48	24	150.80	75.40	37.70	15.08	13.06
54	27	169.65	84.82	42.41	16.97	14.69
60	30	188.50	94.25	47.12	18.85	16.32
66	33	207.35	103.67	51.84	20.74	17.95
72	36	226.20	113.10	56.55	22.62	19.58

spherical cloth bag. The bag was suspended as a sphere by strings in a cubical wooden frame. A hole was cut in gore number six, shown in Figs. 3 and 4, for the admission of a wooden boom on which the firearm to be tested was rigidly mounted. A calibrated wooden dowel rod was inserted through the poles of the sphere and used to fix the gun muzzle at the sphere's exact center. The gun, a .32 caliber, 6 shot revolver loaded with Remington (.32–20) ammunition, was scrupulously aimed and fixed at a point established by the intersection of the sphere's equator and the prime or zero meridian as in Fig. 1. The dowel rod was then removed and the area behind the point of aim was backed with several layers of wood to accept the projectile. Just before test firing, the inner surface of the cloth was sprayed with a slow-drying cement for the purpose of securing the powder residues at the points of impact. The sphere was then closed snugly around the boom and the firearm discharged by means of a wire pull on the trigger. While the adhesive was drying and freezing the powder residues in place, preparations were made for chemical treatment of the gores for demonstration of nitrites following Walker's [*2*] procedure. After the residues were developed, the geographical coordinates of the nitrite spots and areas were determined and plotted at a smaller scale on a previously prepared projection as appears in Figs. 3 and 4.

The opening marked *W* in gore number 6 on both these figures admitted the boom to which the firearm was fixed.

Results and Discussion

This procedure was followed in two test firings into cloth spheres of 12 and 36 in. diameters, respectively, and the positions of all nitrite particles and smudged areas were determined from geographic coordinates and replotted at a smaller scale in Figs. 3 and 4.

Although only two spheres of 12 and 36 in. diameters, respectively, were studied, the testing at additional dimensions is well within the realm of experimental possibility; and in each instance, the entire cloud of nitrite residues emanating from the firearm could be shown in terms of the exact position of each particle and area. It should thus be possible to obtain an exact description in terms of coordinates of the entire cloud of residues at varying distances from the firearm.

From an inspection of Fig. 3, it is seen that nitrite residues form smudged areas at x and y on gore number 2 and at z on gore number 6. The presence of two nitrite smudges at x and y suggest that there was a leakage of residues in two jets resulting in depositions at 23°12′ east longitude, 41°6′ north latitude which is the x area and 23°12′ east longitude, 22°45′ south latitude which is the y area. These positions lie to the right of the gun muzzle and suggest an origin either from the muzzle or from the cylinder-barrel interface. The positions of these areas suggest, but do not prove, that gases emanate from the cylinder-barrel interface. Resolution of this problem might be possible through the use of a smaller cloth sphere. Such a test would add further to the stock of data being accumulated and would further enrich the description of this particular firearm.

Presumably powder residues forming the smudged area at z in gore number 6 of Fig. 3 originated from gases escaping from or near the lower left rear of the cylinder. This area was in direct contact during the firing with the rear surface of the cylinder of the revolver. Whether the smudged areas x, y, and z, have any specific significance can only be determined by further experiments with this and other types of firearms.

It was mentioned earlier that the meridians of the sphere appear in a polar projection as intersecting straight lines with the pole at the vertex. This projection appears in perspective as the bottom plane of Fig. 1. This same projection appears in flat view in Figs. 5 and 6 on which are plotted the longitudinal positions of the nitrite particles shown in

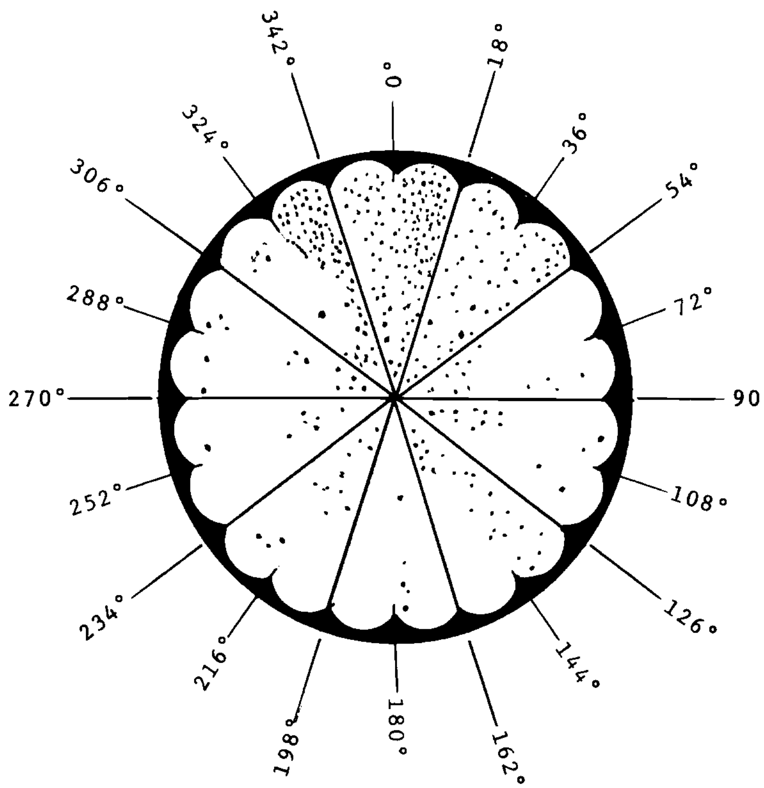

FIG. 5—*Projection of the polar aspect of the 12 in. canvas sphere with meridians of longitude appearing as straight lines and with the position of powder residues plotted according to their geographical coordinates.*

Figs. 3 and 4. Figures 5 and 6 are essentially frequency diagrams from which it can be seen that the point of aim was 0° longitude, 0° latitude. Such a diagram prepared and printed to scale on a clear acetate sheet could be oriented over a plot of the crime scene, in a test for "goodness of fit" with the positions of the powder residues on the floor or on curtains, clothing, or objects in the room. This kind of follow up presupposes that possible powder residues and other particles, lead shavings, etc., have been recovered from the crime scene by the adhesive tape procedures described by Frei-Sulzer as reported in Thorwald [9].

By use of the same coordinate system, the "map" could be further enriched by inclusion of the positioning of nitrate particles, primer residues, smoke rings, and lead shavings (or even fragments of the firearm itself since cheap firearms often fling metal fragments from the cylinder, barrel, or frame). These items, because their azimuths would be indicated by longitude values from the sphere, could be further correlated with the results of the crime scene search. The map could be a guide to what to look for and where in terms of azimuth, thus substituting guided activity for random searching.

It would be possible to conduct test firings over a flat adhesive plane with subsequent development for nitrites and plotting of positions in terms of rectangular coordinates. In fact, this could be done in a later test firing assuming the discharge as one into a canvas sphere of infinite radius. However there is something especially desirable about considering the position of the residues at points everywhere equidistant from the point of

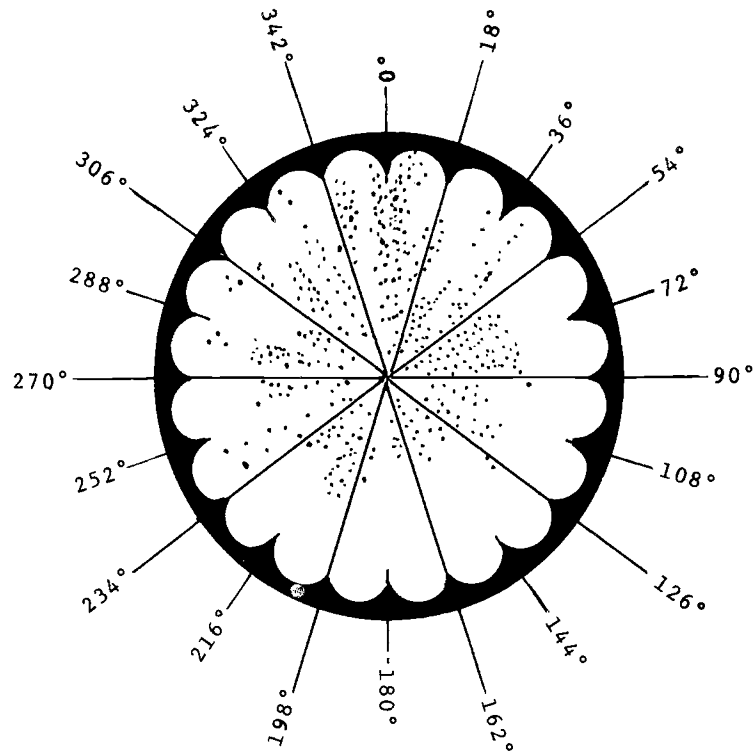

FIG. 6—*Projection of the polar aspect of a 36 in. canvas sphere and the associated powder residues.*

origin which is the muzzle of the gun. This consideration can be met only by the inner surface of a physical sphere, a macrocosm the boundaries of which are everywhere equidistant from the point of origin.

The closed sphere has the further advantage of collecting all or at least most of the residues and fixing them at points definable by two coordinates (longitude and latitude).

The use of the cloth sphere suggests further experiments such as the introduction of objects, curtains, or plane surfaces with the idea of discovering the effects of these bodies upon the pattern of residues.

Because the mechanical problem of suspending the cloth sphere fully expanded in a cuboidal frame was a troublesome one, the following experiments were conducted. As mentioned earlier the canvas gores were cut with a half-inch margin or "tab." When the gores were machine stitched along the meridians, the outer margins of abutting tabs were also stitched to form a narrow channel above the seam between adjacent gores. Slender, cylindrical dowel rods were threaded through these channels to converge toward the poles. Pressure applied at the poles bent each rod into a "great circle" which stretched the gores of canvas into a very good approximation of a perfect sphere. Such mass production methods also suggest the use of a greater number of gores for a better spherical approximation and more meridians for greater ease in determining coordinates. The possibility of treating the cloth with the necessary reagents for development of nitrites *in situ* without sensitized paper would be a further time and labor saving strategem, although this aspect has not at the present time been explored by this author. Perhaps the greatest convenience would be photography of the entire projection including both the nitrites and the meridians and parallels, thus adding the process of photogrammetry to the other techniques employed. Photographs could be printed at any desired scale as negatives or positives, and subsequently filed or cut out and pasted onto plastic spheres forming a model of the tests conducted.

Conclusion

By the use of Table 1 containing data on gore dimensions and the diagram shown in Fig. 2 for drafting, it is mechanically possible to construct a series of cloth spheres. The construction of such spheres can provide definite answers to the following questions:

1. What are the positions of the nitrite particles in the entire cloud of powder residues spreading from a discharging firearm? The positions at muzzle distances of 6 and 18 in. can be read as geographic coordinates from Figs. 3 and 4.
2. Does the density of nitrites striking a concave spherical surface decrease as the radius increases? Inspection of Figs. 5 and 6 shows that it does.
3. Does discharge of a firearm into a canvas sphere reveal any specific peculiarity? Inspection of Fig. 3 in the areas of x, y, and z on gores 2 and 6 suggests uniqueness but does not in these tests constitute proof.
4. Can the positions of nitrite particles with geographic coordinates be shown on a polar projection, and, if so, what is their significance? The positions of nitrite particles in polar or azimuthal projections are shown in Figs. 5 and 6 and constitute frequency diagrams. The azimuth or direction of the path of greatest density shows the direction in which the firearm was discharged.
5. Does the firearm shave lead, and, if so, to what distances and in what directions are the shavings thrown? The tested firearm produced no lead shavings. The question can be answered with confidence in the negative since the design of the canvas sphere with a tacky concave surface is such as to make recovery and positioning certain.

Summary

Geographic coordinates have been applied to cloth spheres as a reference frame for collecting and positioning powder residues (nitrites) emanating from a discharging firearm. A procedure for constructing cloth spheres of varying dimensions has been described, and two such spheres of 12 and 36 in. diameters, respectively, have been used to present data in test firings.

The use of this technique in preparing a detailed description of a discharging firearm has been described. Further experiments and mathematical treatment of the gathered data have been proposed.

References

[1] Rhodes, H. T. F., *Alphonse Bertillon, Father of Scientific Detection*, Abelard Schuman Ltd., New York, 1956, p. 125.
[2] O'Hara, C. E. and Osterburg, J. W., *Criminalistics*, The Macmillan Company, New York, 1949, p. 384.
[3] Kirk, Paul, *Crime Investigation*, Interscience Publishers, Inc., New York, 1953, p. 353.
[4] Harrison, N. C. and Gilroy, R., "Firearms Discharge Residues," *Journal of Forensic Sciences*, Vol. 4, 1959, pp. 184–197.
[5] O'Hara, C. E. and Osterburg, J. W., *Criminalistics*, The Macmillan Company, New York, 1949, p. 386.
[6] Turner, R. F., *Forensic Science and Laboratory Technics*, Charles C Thomas, Springfield, Ill., 1949, pp. 105–106.
[7] Greenhood, D., *Down to Earth: Mapping for Everybody*, Holiday House, New York, 1944, pp. 106, 153.
[8] Raisz, E., *General Cartography*, McGraw-Hill Book Co., New York, 1948, p. 267.
[9] Thorwald, Jurgen, *Crime and Science*, Harcourt, Brace, and World, New York, 1966, p. 384.