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SHOT PELLETS: AN OVERVIEW

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INTRODUCTION

Shot pellets are frequently recovered from migratory waterfowl carcasses in connection with the investigation of alleged violations of hunting regulations.

A substantial body of information has been published on the composition and shot tower method of manufacture for lead shot. There is a dearth of information available in the scientific literature on alternative manufacturing methods for lead shot, and on the production and composition of steel, bismuth and tungsten-polymer shot pellets.

We have attempted to collate existing information on shot pellets from a wide variety of resources. In addition, we have characterized the four main types of shot pellets, lead, steel, bismuth and tungsten-polymer, according to their physical and chemical properties, and target impact features. We also offer presumptive field tests to assist the investigator in making a preliminary determination of type prior to laboratory submission.

Routine forensic laboratory analysis provides the field agent with an approximate size and the basic elemental composition of these pellets. The laboratory examiner should be prepared to provide additional information on the manufacture, physical characteristics and general elemental analysis of shot pellets during courtroom testimony.

MATERIALS AND METHODS

Shot pellets examined in connection with this study were from manufactured shot shells purchased from commercial sources. The lead and steel shells were obtained locally. Bismuth shot shells were purchased by mail order from Old Western Scrounger, Montague, CA and Forensic Ammunition Service, Okemos, MI. Tungsten-polymer shot shells were also bought from Old Western Scrounger.

All pellets were analyzed visually and by optical microscopy, scanning electron microscopy (SEM) with secondary and backscattered (SEM/BSE) imaging, scanning electron microscopy/energy dispersive x-ray spectroscopy (SEM/EDX), and by x-ray fluorescence spectroscopy (XRF). In addition, bismuth shot pellets were analyzed by inductively coupled plasma atomic emission spectroscopy (ICP).

Optical Microscopy

A Reichert Universal Forensic Microscope IV was used to optically examine pellets immediately upon removal from the shot shells. Optical micrographs were obtained using Polaroid Type 54 film.

Scanning Electron Microscopy

SEM examinations were performed using a Camscan Series 4 equipped with a secondary electron detector, a backscattered electron (BSE) detector and a Kevex Analyst 8000 energy dispersive x-ray (EDX) detector. The accelerating voltages for imaging ranged from 20 KV to 25 KV. The accelerating voltage for EDX analysis was 25 KV, with emission current set at 100 microamps. Counts per second averaged approximately 2000 with a live time collection of 100 to 250 seconds. Dead time averaged approximately 25% to 35%. The SEM/EDX was used for qualitative analysis only. Samples for SEM/EDX were examined washed, using Fisher FL70 and water, and unwashed. An acetone rinse was also used on some of the samples to facilitate drying. Unflattened pellets were mounted on ¾" carbon pin mount stubs with double sided STR carbon tape. No conductive coatings were applied. Micrographs were recorded on Polaroid Type 54 film and Kodak 4162 negatives.

X-Ray Fluorescence Spectroscopy

XRF analysis was performed using a Baird (formerly Asoma) EX-6000 x-ray fluorescence spectrometer with the primary rhodium tube set at 35 KV or 40 KV. Emission currents ranged from 60 to 100 microamps. Count rates averaged from approximately 3500 to 7500 counts per second with a live time collection of 100 seconds. Dead time ranged from approximately 14% to 40%. Samples were examined with and without washing and in spherical and artificially flattened shapes. Quantitative analysis by standardless fundamental parameters was experimentally applied to a bismuth shot pellet. The results of this analysis are detailed in the bismuth section of this paper.

Inductively Coupled Plasma Atomic Emission Spectroscopy

ICP analysis of bismuth shot was performed off-site at IMO/Baird Corporation in Bedford, MA. Baird ICP model 2000 (simultaneous) was used to quantitate tin, lead and twenty-five other potential trace components. Model 2070 (sequential) was used for quantitating bismuth and antimony. Both instruments were operated using the following analytical conditions: RF (radio frequency) power 1100 watts, coolant flow 10.5 liters/min., auxillary flow 1.0 liter/min., nebulizer pressure 43 psi, sample flow 2 ml/min. Data was collected on the 2000 for three integrations of five seconds and the integration time on the 2070 was 20 ms/point. Ten ppm standards were used for all elements with the exception of the lead (200 ppm) and bismuth (1000 ppm) standards.

Sample preparation consisted of placing 0.576 gram of unfired bismuth pellets from #6 Bismuth Cartridge Company lot 19212014 in 5 milliliters of room temperature concentrated nitric acid until the sample went into solution. The solution was diluted to 50 ml for all elements except bismuth. For bismuth analysis, 2 ml of the 50 ml solution was diluted to 50 ml.

Target Impact Analysis, Lead and Steel

Target impact analyses, specifically the physical characterization of target impacted lead and steel pellets, are based on the radiographic and physical (necropsy) examinations of more than 200 waterfowl carcasses submitted as evidence to the National Fish & Wildlife (NFW) Forensic Laboratory over a period of approximately three years. The shooting distances, shell powder loads, shot hardnesses, and shell manufacturers were, for the most part, unknown, and therefore represent a random sampling. The carcasses were submitted by wildlife law enforcement agencies from the U.S. and Canada. Pellet sizes recovered from the carcasses ranged from 12 to T and larger.

Target Impact Analysis, Bismuth and Tungsten-Polymer

The physical characterizations of target impacted bismuth and tungsten-polymer shot pellets are based on the examination of experimentally shot waterfowl. Previously frozen carcasses of full plumage adult canadian geese, a mallard duck and a pintail duck which had been confiscated during the 1993 fall hunting season by Klamath National Wildlife Refuge personnel were used in this study. Prior to shooting, all carcasses were examined radiographically. Only carcasses free of pre-existing shot pellets and/or pellet fragments were utilized for testing. Thawed carcasses were suspended by the neck in a 2 feet X 3 feet X 2 feet open backed cardboard box. The wings of the canadian geese were held in an extended position by slits in the sides of the box. The ducks were shot without their wings extended. All of the carcasses were shot with the ventral surface facing the shooter to simulate the relative positions of shooter and bird in a hunting situation.

Individual carcasses were shot from 30 or 40 yards with commercially loaded Bismuth Cartridge Company #6 bismuth (lot #19309036, 2¾ inch shell, Upland Game Load) or Eley #6 tungsten-polymer (lot #2811919236, 2½ inch shell) pellets. A full choke Remington 870 Wingmaster with a 2¾ inch chamber was used to discharge the shot shells.

After shooting the carcasses were examined radiographically and were given abbreviated necropsies. Pellets, pellet fragments and wound tissue were removed and retained for further study.

DISCUSSION

LEAD SHOT

The primary metallic components of commercially manufactured lead shot are lead and antimony. The amount of antimony can vary from 0.5% to 6.5% depending on the size and the desired hardness of the pellet (1,2). A small amount of arsenic (approximately 0.1% to 0.2%) may be added to the alloy to facilitate sphere formation (1,3,4). Tin (approximately 0.1%) may also be an intentional inclusion in the pellet alloy (4). Instrumental analyses of projectile lead have also revealed the presence bismuth, copper, zinc, chromium and silver as trace elements (5,6).

Most commercially manufactured lead shot is made by the traditional tower method or by the newer Bleimeister technique. The larger shot sizes, BB through buckshot, are usually swaged or cold headed from wire.

Traditional drop shot is made in a tall tower (Fig. 1). Remington's tower is approximately 145 feet (7), and the Winchester tower is approximately 200 feet (8). A generic description of the drop tower manufacture process is as follows: Molten lead (ca. 400 decrees C) from ingots or "pigs" of specified alloy content is poured into a perforated pan at the top or near the top of the tower. Metal droplets emerge from the base of the pan and fall unimpeded for most of the tower's height to a water quenching bath at its base. Spherical formation of the shot occurs during the drop. The shot is collected from the water bath, dried in a heated drum, size screened, and conveyed to a series of four to five inclined and gaped glass roundness tables. The tables serve to separate perfectly spherical from malformed shot pellets. Substandard shot is collected and recycled to the melting pot. The final stage usually involves graphite coating and tumble polishing (1,3,8).

The horizontally oriented Bleimeister (translated Lead Master) technique of shot manufacture (Fig. 2) is a radical departure from the vertical shot tower method. According to Waite (1), this technique was "devised by Louis A. Bliemeister (*sic*) of Los Angeles, Calif." and has been available in the United States since 1959. The smaller lead shot pellets (9, 8½, 8, 7½, 6, 5, and 4) marketed by Federal Cartridge Co. are made by this method, shot sizes 2 and larger are swaged (9).

Walter H. Collin, GmbH, which manufactures the Bleimeister machine in West Germany, provides the following description of their lead shot manufacture process: Thermally monitored and controlled molten lead alloy (antimony content approximately 2.7%, arsenic approximately 0.2% and tin approximately 0.1%) is pumped into a heated pot and then fed into a feeder head or mold. The temperature controlled feeder head contains various perforated plates which determine the size of the shot. The shot droplets fall approximately 0.5 inch into a constant temperature heated recycling water bath (pH 7) containing detergent and acetic acid. Spherical formation and ball solidification occur in the water bath. The shot is removed from the water and dried in a heated drum. Preliminary sorting for malformed shot also occurs in the drum. Stair-like glass gaped plates complete the quality control process. As with the drop tower method, second quality pellets are recycled to the melter. The final stage includes graphiting, polishing and screen sorting for size. The Bleimeister technique, as applied by Collin, produces lead shot from approximately 1.3 mm to 3.3 mm (approximately .05 inch to .13 inch) in size (4,10).

Although some of the larger shot sizes have been made in towers, most shot sized BB and above and buckshot are made from diameter specific wires using cold heading or swage processes. Swage shot is cut from a length of wire and tumbled in kerosene and graphite to a nearly spherical shape. Final rounding is performed by barrel tumbling for approximately two hours in graphite (1). A header is used in the cold heading process to cut a piece of wire and then squeeze it between two punches in a die. The punches cause the formation of a nearly spherical shot pellet. Final forming is accomplished by barrel tumbling (3).

Laboratory Analysis of Lead Shot

Unfired, uncoated lead pellets and buckshot from shot shells are shiny and uniformly round. Low power optical microscopy of unfired lead shot revealed frequent contact indentations from adjoining pellets and occasional shallow irregular surface pits (Fig. 3). Optical microscopy of unfired swaged shot occasionally revealed shallow surface scratches which may be remnants of the manufacturing cut lines, and contact indentations.

SEM secondary and BSE imaging of unfired lead pellets revealed a lightly textured surface without significant inclusions (Fig. 7). Probable graphite particles appear as dark spots.

SEM/EDX and XRF of unfired lead shot pellets detected lead and frequently detected antimony but did not detect arsenic or the other possible trace elements (Figs. 11,15). Although the arsenic may be beyond the detection limits of many EDX and XRF units, arsenic may also escape detection because the lead $L\alpha 1$ peak (10.549 keV) obscures the expression of the arsenic $K\alpha 1$ (10.543 keV) peak.

Target Impact of Lead Shot

The effect of lead and steel pellets on experimentally wounded waterfowl was documented through studies associated with the Nilo Lethality Tests (11).

Radiographic examination and necropsy of a wide variety of avian species and low power optical microscopic examination of extracted pellets at the NFW Forensic Laboratory have revealed that target impacted lead pellets may fragment, show deep gouges from contact with bone and other hard tissue, may deform with minimal loss of mass, or may be recovered from a carcass without observable damage (Fig. 19).

Field Testing of Suspected Lead Shot

Lead shot is non-magnetic. When compressed with pliers, non-swaged, uncoated lead pellets will expand smoothly and uniformly without significant edge cracking (Fig. 23, Tables 1,2). The larger swaged pellets will compress but with greater difficulty.

The July 1990 Journal of Wildlife Law Enforcement reported the successful field testing of a Whites Electronics Professional Series Model 4900/D metal detector factory modified by Geoquest, Inc. to differentiate between lead and steel shot in bird carcasses. The unit was tested during the 1988/1989 waterfowl season by the Tennessee Wildlife Resources Agency. This metal detector is reportedly battery operated, compact, functional in field conditions, and capable of differentiating between lead and steel shot without dissection (12).

STEEL SHOT

Steel shot made its official public debut for waterfowl hunting in nine States in the Atlantic Flyway in 1976 (13). According to the Code of Federal Regulations, 50CFR20.21(j), steel shot is the only specifically approved shot which may be used to hunt waterfowl and coots within the United States.

A significant proportion of steel shot sold in the United States is made by Daisy Manufacturing Company, Inc. and remarketed in shells or sold for reloading by Remington, Winchester, Federal and Fiocchi (14).

Daisy uses low carbon steel 1008 wire to make its shot. Steel wire of a selected diameter is protruded through a hole in a header machine plate. A blade cuts the wire to the desired size. Opposing dies catch the falling piece and press it into a ball. The collected balls are ground using cast iron grinding wheels to a specified diameter. The shot is then annealed to a maximum hardness of 79 on the Rockwell 15T scale. The final step is the application an oil coating to prevent rust. There is no polishing. Daisy manufactures steel shot in whole number sizes from #8 to F (TTT) size (14,15).

1008 steel wire is 99% iron. Intentional trace element composition, as set by the American Iron and Steel Institute, includes 0.10% carbon (maximum), 0.3% - 0.5% manganese, 0.04% phosphorous, and 0.05% sulfur (16). Unintentional trace element inclusions (tramp elements) due to the use of scrap steel in the manufacturing process, may include copper, nickel, chromium and molybdenum.

Laboratory Analysis of Steel Shot

Uncoated steel pellets, both fired and unfired, are dull in appearance and uniformly round. Low power optical microscopy may reveal light pitting. Pock-marks and fissures are not unusual surface features of steel pellets (Fig. 4).

SEM imaging of unfired steel pellets revealed surface roughness reminiscent of sculpted carpet pile (Fig. 8). SEM/BSE imaging for elemental separations was unremarkable.

Analysis by SEM/EDX and XRF revealed iron (Figs. 12,16). Manganese is weakly expressed and may go undetected in some preparations. Sulfur, phosphorous and other possible trace elements were not detected. Carbon detection is not included in the specifications of these instruments.

Target Impact of Steel Shot

Radiographic examination and necropsy of steel shot bird carcasses followed by low power optical microscopic examination of the extracted pellets revealed that steel shot will not deform or fragment on impact with soft or hard tissue (Fig. 20).

Field Testing of Suspected Steel Shot

Steel shot is magnetic. Steel shot will not compress with normal hand pressure using pliers (Tables 1,2).

BISMUTH SHOT

Bismuth shot was invented by John Brown of Canada in the late 1980's as a possible nontoxic alterative to steel. The original pellets were hand molded, thirty at a time (17,18). Bismuth shot is now mass produced using the Bleimeister process (19).

Bismuth shot is manufactured in the United States by Scott Shot of Ventura, CA. The shot is loaded and shell assembled by Estate Cartridge Co. for Bismuth Cartridge Co. of Dallas, Texas (20). Challenger Shotshell Co. of Canada has also loaded bismuth pellets (21). The Bismuth Cartridge Company brochure states that their company is the "exclusive North and South American manufacturer and distributor shot shells made of highly desirable bismuth" (22). Bismuth Cartridge Company reported in April of 1994 that shells loaded with sizes 4, 5 (this size may be discontinued), 6, 7½, 8, 9 are available for purchase by the general public and that they expect to have BB and #2 shells for sale by the fall of 1994. Pellets are not currently available for reloading (20). Bismuth shot is marketed in Europe by Eley Hawk as Grand Prix Bismuth Shot and Alphamax Bismuth Shot (23). Bismuth shot is expensive. The full retail price in November, 1993, was $31.95 for a box of 25, 12 gauge 2¾ inch #5 bismuth shells (steel costs approximately $13.00).

Although it is not currently approved for use in nontoxic zones in the U.S., bismuth shot was recently approved for use in Canadian nontoxic zones. In 1993, Canadian migratory birds hunting regulations were amended "to redefine non-toxic shot as shot with less than 1 per cent of lead by weight rather than identifying steel shot as the only acceptable non-toxic shot. This amendment will allow the use of non-toxic alternatives to steel shot, such as bismuth."(24)

Bismuth Cartridge Co. stated in April 1993 that bismuth shot consists of 97% bismuth and 3% tin and that they were still experimenting with the appearance of their product (19). The elemental composition of bismuth shot pellets seems to vary. Analysis by ICP of discharged Challenger loaded Eley #7½ pellet fragments by the Illinois Natural History Survey in November of 1992 revealed the presence of 97.7% bismuth, 0.40% lead, 0.48% tin and 1.40% arsenic (25,26). The same shot was also analyzed by ICP by the Environmental Protection Agency (EPA) in Corvallis, OR in January of 1993. These results reported 98% Bi, 0.35% Pb, 0.11% As, <0.01% Sn, 0.48% Sb and trace amounts of Cu and Fe. The Illinois Natural History Survey also analyzed #5 Bismuth Cartridge Co. bismuth shot (lot number unknown) by ICP in November, 1992. These results revealed 94% Bi, 2.85% Pb and 3.05% Sn (25). See Table 3.

Bismuth is a by-product of the refining of lead, copper and tin ores (27,28) which may account for the presence of lead in the pellet. The sources of the antimony and arsenic are not known but the arsenic may be an intentional inclusion in the bismuth shot alloy to facilitate sphere formation.

Laboratory Analysis of Bismuth Shot

Unfired bismuth shot pellets are shiny. Low power optical microscopy of unfired bismuth pellets revealed a rounded but not perfectly spherical shape. Surface features include a slightly roughened appearance and small blister-like defects (Fig. 5). One of the examined lots of bismuth shot included pellets with deep unilateral serrations.

SEM of unfired bismuth pellets revealed a mottled surface and the presence of rounded blister-like surface defects. Closer examination of bismuth pellets by BSE and object specific EDX revealed veins of bismuth and discrete islands of tin surrounded by fields of bismuth/lead (Fig. 9). The surface eruptions and elemental separations were documented on pellets from three different lot numbers.

Analysis of unfired bismuth pellets by XRF and general surface area analysis by SEM-EDX revealed the presence of bismuth, tin and lead (Figs. 13,17). Arsenic and antimony were not detected. The XRF expression of the lead $L\alpha 1$ (10.549 keV) and $L\beta 1$

(12.611 keV) peaks are strongly overshadowed by the bismuth $L\alpha 1$ (10.836 keV) and $L\beta 1$ (13.021 keV).

We wish to note that standardless quantitative analysis of bismuth shot by XRF is not recommended until further parallel comparative analyses are performed. Our efforts to apply the Baird standardless fundamental parameters program to a flattened bismuth shot pellet showed lead results that were approximately one order of magnitude higher than the quantities obtained using ICP on pellets from the same lot. Similar results were reported by Sanderson of samples analyzed by XRF and ICP at the EPA Laboratory in Corvallis, OR (25).

ICP analysis of unfired #6 Bismuth Cartridge Co. bismuth shot from lot number 19212014 in March of 1994 revealed the following: Bismuth 95.039% (Percent Relative Standard Deviation 1.15), tin 2.8364% (%RSD 1.4), lead 1.5632% (%RSD 0.38), antimony 0.0392% (%RSD 0.518). Twenty-five other elements, including arsenic, copper and iron, were scanned. None of these elements registered concentrations of greater than 0.02%. See Table 3.

Target Impact of Bismuth Shot

Anderson (26) reported the fragmentation of test fired bismuth pellets. He did not know if the fragmentation occurred in the gun barrel or during flight. The popular press (29) has also reported shattering of test fired bismuth pellets.

Radiographic examination of previously frozen duck (one) and geese (four) carcasses after experimental shooting from 30 and 40 yards with #6 Bismuth Cartridge Company shot revealed fragmentation and shattering of pellets upon impact with bone. Bismuth pellets did not appear to fragment in soft tissue (Fig. 21). Low power optical microscopic examination of pellets removed from the carcasses during necropsy revealed sharp edges on fragments, and minor flattening with occasional cracking on otherwise intact pellets.

Field Testing of Suspected Bismuth Shot

Bismuth shot is non-magnetic. Bismuth shot will shatter when hit with a hammer or if sudden force is applied with hand pliers. If gradual force is applied, bismuth shot will expand uniformly and show significant edge cracking (Fig.23, Tables 1,2).

TUNGSTEN-POLYMER SHOT

Tungsten-polymer shot was developed by Royal Ordnance Specialty Metals in the 1980's. Tungsten-polymer shot supplied by ROSM is loaded and sold by Eley Hawk as Eley Black Feather (available in number 6 only) (30,31). In response to the authors' letter requesting technical information on tungsten-polymer shot, Eley Ltd. wrote that "tungsten-polymer shot really has been overtaken by bismuth shot in the non-toxic stakes" (32). The remainder of the letter focused on the qualities of bismuth.

Black Feather shells are very expensive, $56.50 full retail for a box of 25, 12 gauge 2½ inch shells, and very difficult to obtain in the United States.

Tungsten-polymer shot is composed of "powdered tungsten metal combined within a continuous thermoplastic" (33) which is formed into a wire, extruded, swaged and rolled or tumbled. The proportion of metal to polymer has been suggested as 50/50 (30).

Laboratory Analysis of Tungsten-Polymer Shot

Tungsten-polymer shot is shiny and nonspherical. Low power optical microscopy of unfired tungsten-polymer pellets reveals the presence of fissures (Fig. 6) and occasional knobs.

SEM/BSE imaging of unfired tungsten-polymer pellets revealed the presence of discrete metallic flakes of varying brightness yields in a low atomic number matrix (Fig. 10). These flakes range in size from less than one micrometer to approximately 20 micrometers. SEM/EDX of a general surface area of a tungsten-polymer pellet revealed tungsten, iron, chromium, nickel and copper (Fig. 14). High magnification object specific SEM/EDX revealed tungsten flakes and mixed flakes of three or more of the other listed elements.

XRF of unfired tungsten-polymer shot pellets revealed tungsten, iron, nickel, chromium and copper (Fig. 18). Chromium and copper may be weakly expressed. The copper $K\alpha 1$ (8.047 keV) and Kß1 (8.904 keV) peaks may appear as shoulders on the tungsten $L\alpha 1$ (8.396 keV) peak depending on the resolution of the XRF unit.

Target Impact of Tungsten-Polymer Shot

Radiographic examination of previously frozen duck (one) and geese (three) carcasses after experimental shooting from 30 and 40 yards with #6 Eley tungsten shot revealed pellet fragmentation without shattering upon impact with bone. Tungsten pellets did not appear to fragment in soft tissue (Fig. 22). Low power optical microscopy of pellets removed during necropsy revealed sharp edges on granular appearing fragments, granular appearing shavings attached to otherwise relatively intact pellets, minor flattening of pellets, and some loss of mass due to probable shearing. One pellet showed possible gouging.

Field Testing of Suspected Tungsten-Polymer Shot

Tungsten-polymer shot pellets are magnetic. Under simple hand pressure using pliers, tungsten-polymer pellets will expand uniformly and show significant edge cracking (Fig. 23, Tables 1,2).

A BRIEF WORD ABOUT COATINGS

Copper coatings are commonly available on both lead and steel shot pellets. Nickel coatings on lead and steel may also be encountered although with a lesser frequency than copper. Zinc chromate and zinc chloride were added to the list of approved nontoxic anti-corrosion coatings for steel shot by the U.S. Fish & Wildlife Service starting with the 1993-1994 hunting season (34).

Companies which were listed as selling or in anticipation of selling zinc coated steel shot as of August of 1993 are Remington and Reloading Specialties (34). Fiocchi has been selling zinc coated steel for approximately one year (36). Metallic coatings are not currently available on bismuth or tungsten-polymer pellets.

The application of metallic coatings to shot pellets is generally electrolytic (8,9,36). Federal regulations specify that approved coatings have a nominal thickness of 0.0002" and typically constitute less than 1% of the total body weight of the pellet (35).

CONCLUSIONS

The four basic types of shot pellets are distinct and relatively easy to differentiate in the field and in the laboratory. Presumptive field tests distinguish the pellet types based upon magnetism and compression characteristics (see Table 1). Table 2 provides a summary of magnetic, compression and visual characteristics of shot pellets.

Laboratory analysis can confirm or independently identify the basic qualitative elemental composition of submitted pellets with a choice of instrumentation. Information on manufacturing methods and the physical and general chemical characteristics of shot pellets was provided.

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Fig. ①

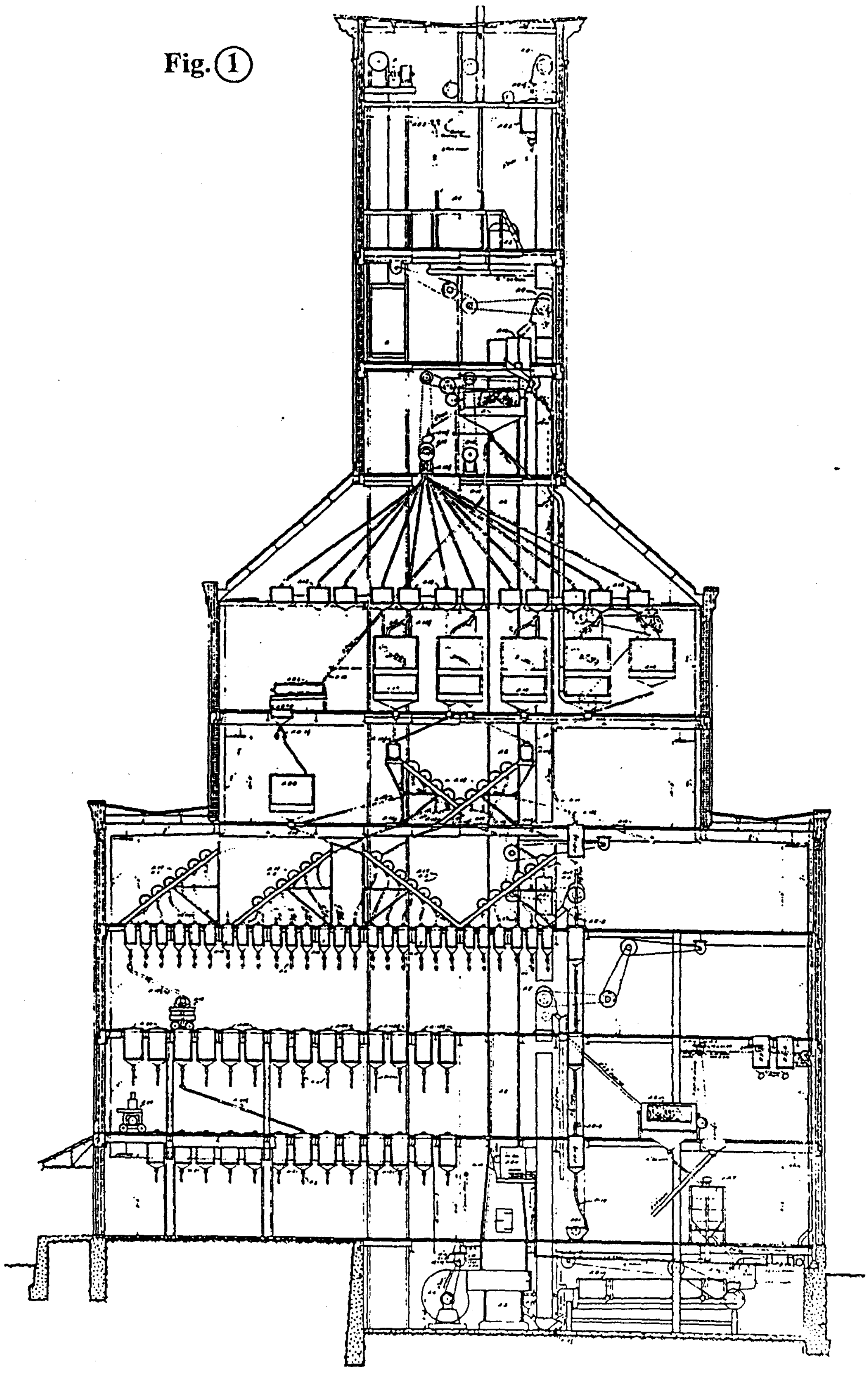
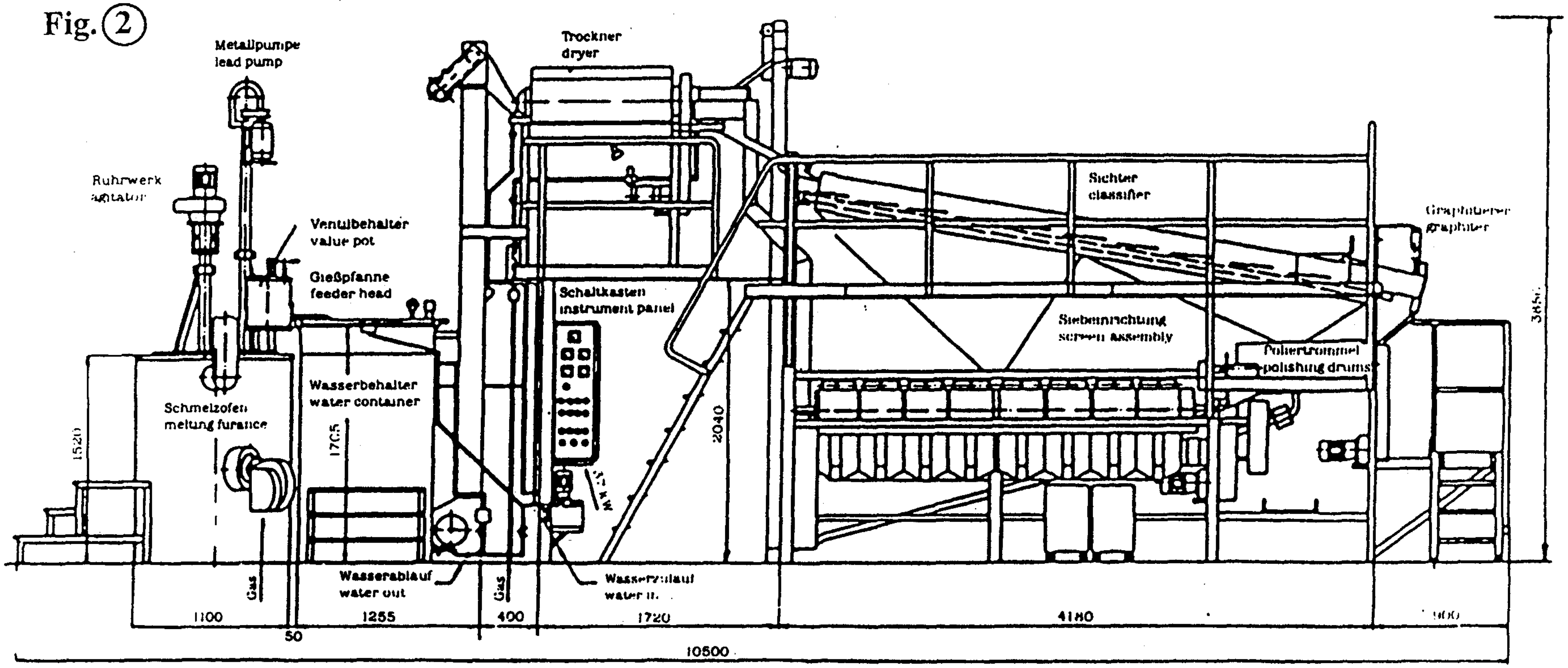


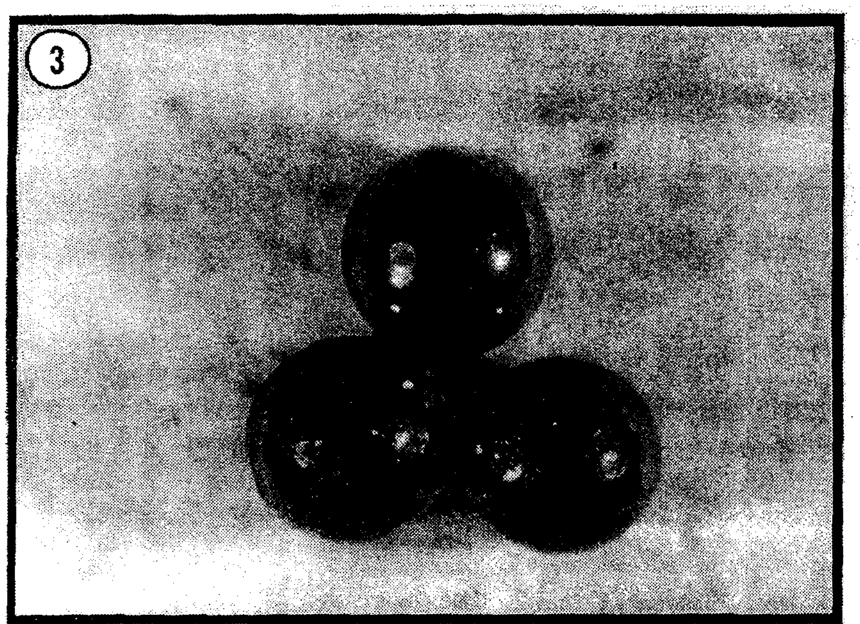
Fig. 1 *Cutaway drawing of the decommissioned 10 story tall Remington shot tower in Connecticut (Courtesy of Remington Arms).*

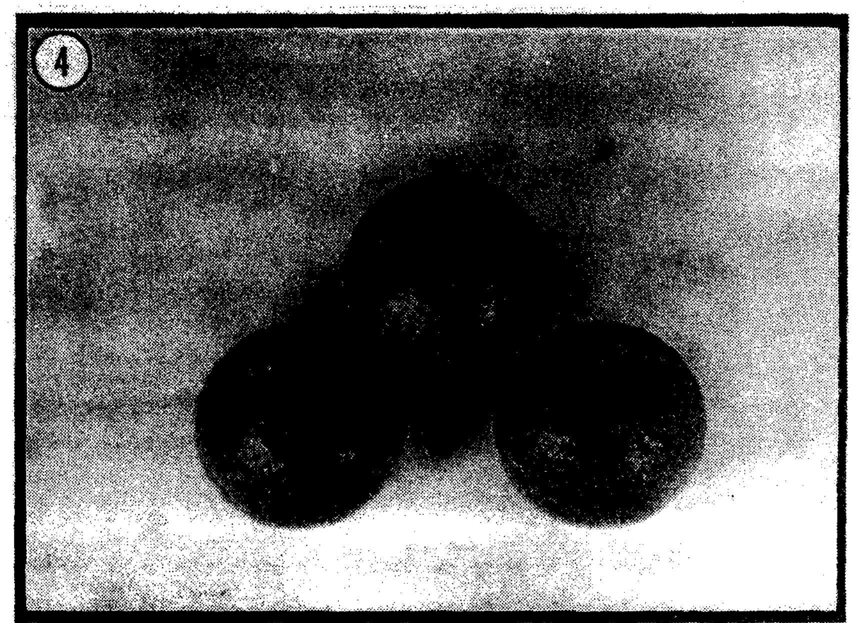
Fig. ②

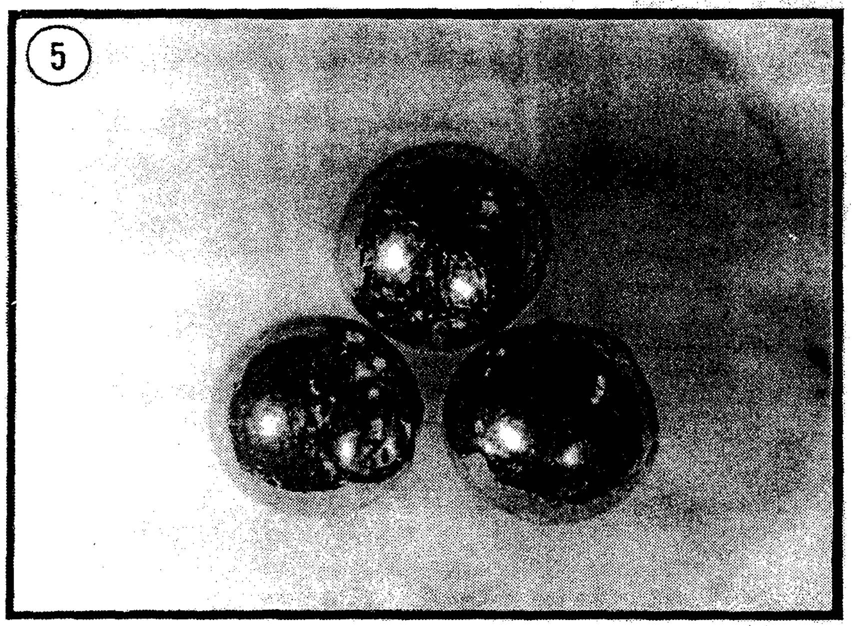


mm measurements

Fig. 2 *Cutaway drawing of the Collin Bleimeister Lead Shot Casting Machine (Courtesy of Walter H. Collin GmbH).*







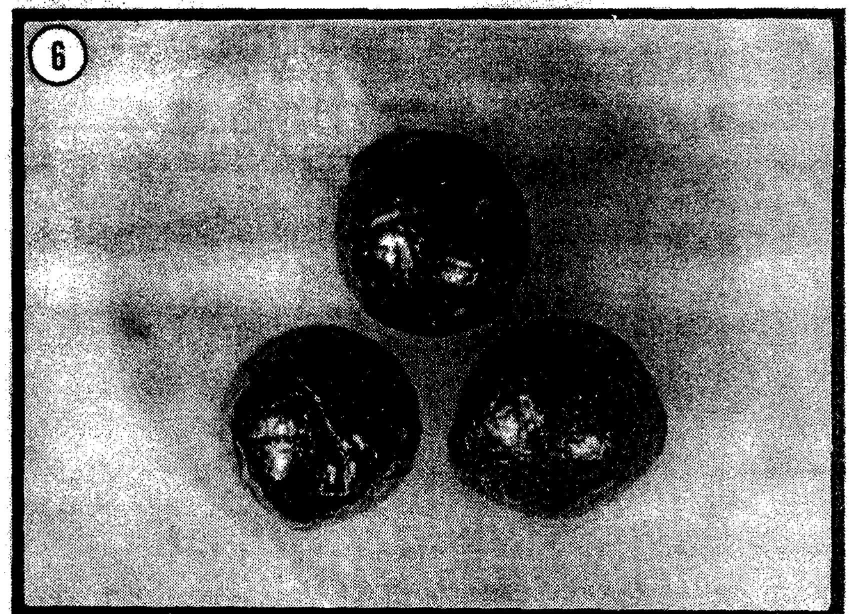
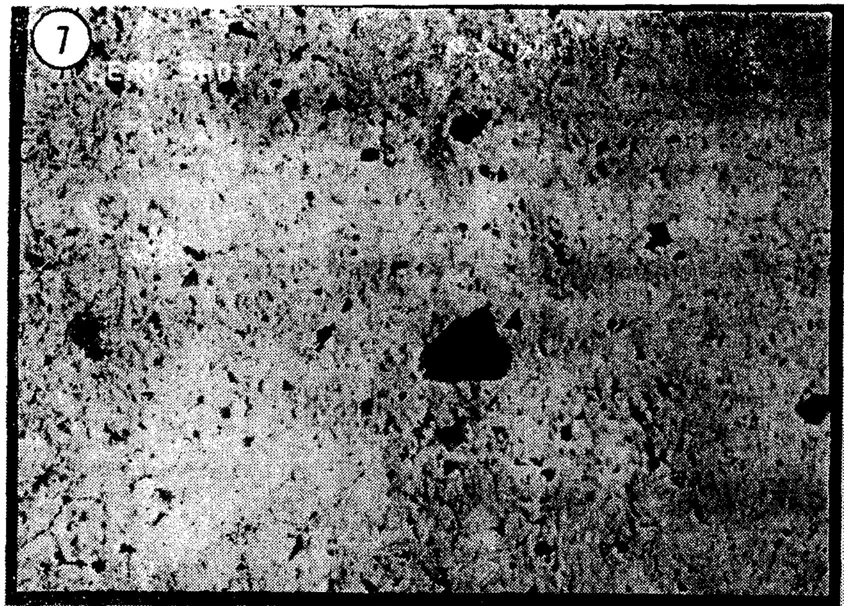
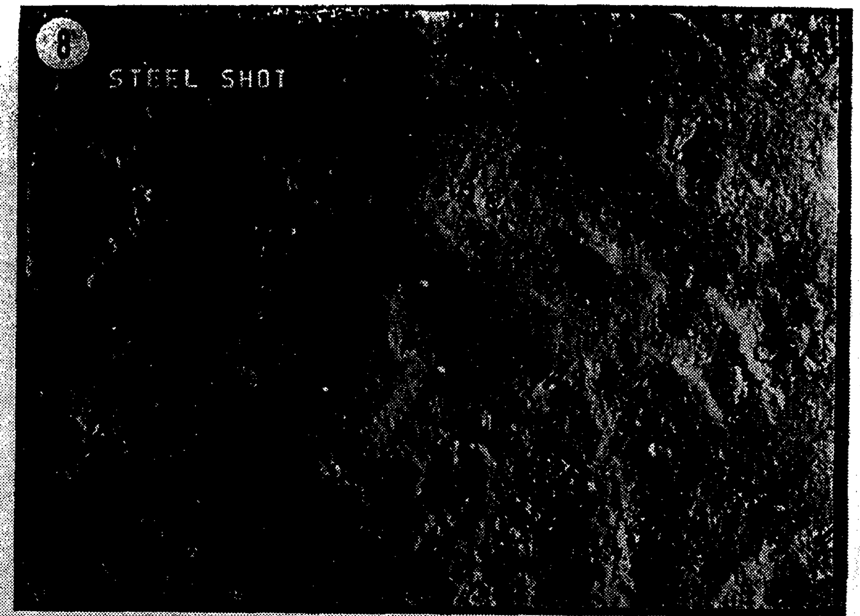
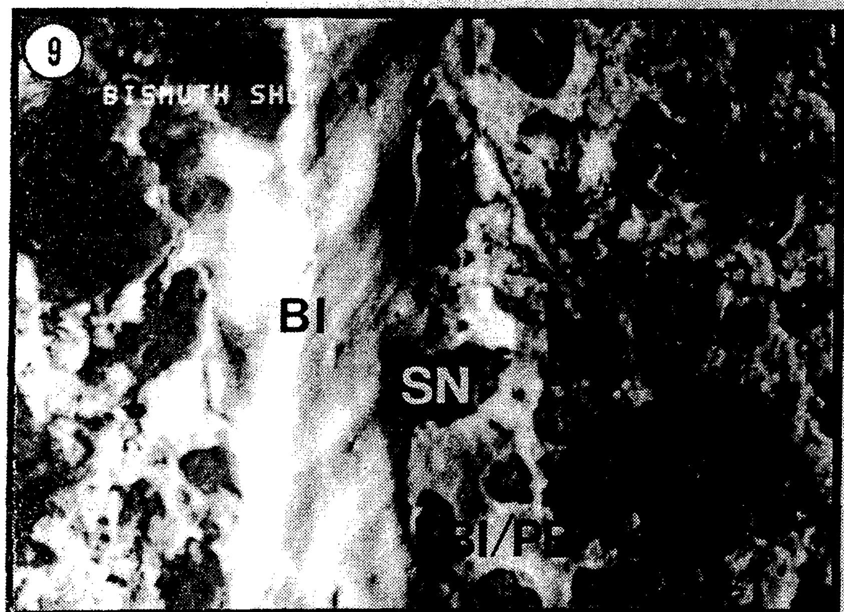


Fig. 3 Optical micrograph of Winchester #6 lead shot. Magnification X10.
Fig. 4 Optical micrograph of Remington #6 steel shot. Magnification X10.
Fig. 5 Optical micrograph of Bismuth Cartridge Co. #6 bismuth shot. Magnification X10.
Fig. 6 Optical micrograph of Eley #6 tungsten-polymer shot. Magnification X10.







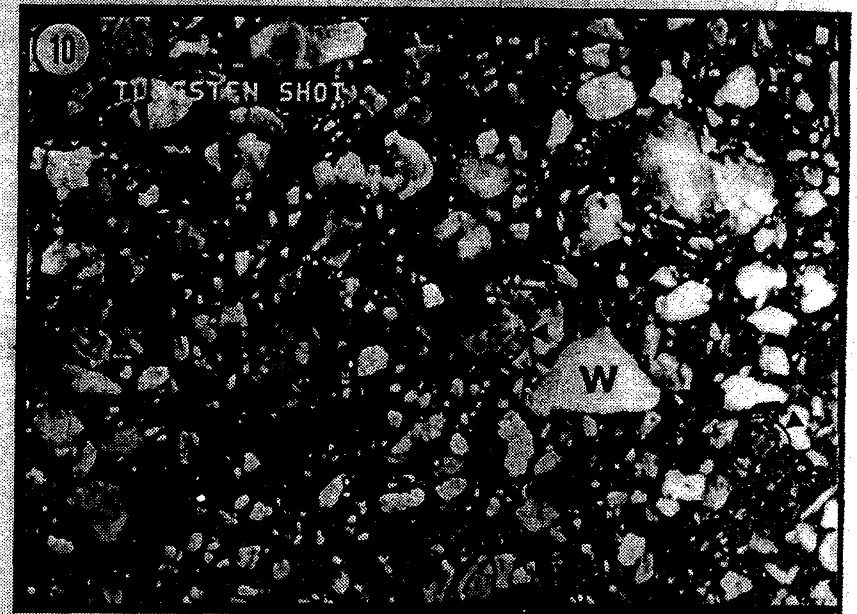


Fig. 7 Backscattered electron micrograph of the surface of a Winchester #6 lead shot pellet. The dark areas are probably graphite fragments. Magnification X500.
Fig. 8 Backscattered electron micrograph of the surface of a Remington #6 steel shot pellet. Magnification X250.
Fig. 9 Backscattered electron image of the surface of a Bismuth Cartridge Co. #6 bismuth shot pellet. Note the vein of bismuth, discrete islands of tin and the fields of bismuth/lead. The dark area is probably graphite. Magnification X2000.
Fig.10 Backscattered electron micrograph of the surface of an Eley #6 tungsten-polymer shot pellet. The large bright triangular flake is composed of tungsten as are several of the other high brightness flakes. The circled flakes contain (left) iron/nickel/copper and (right) iron/nickel/chromium. Magnification X1000.

Fig. 11

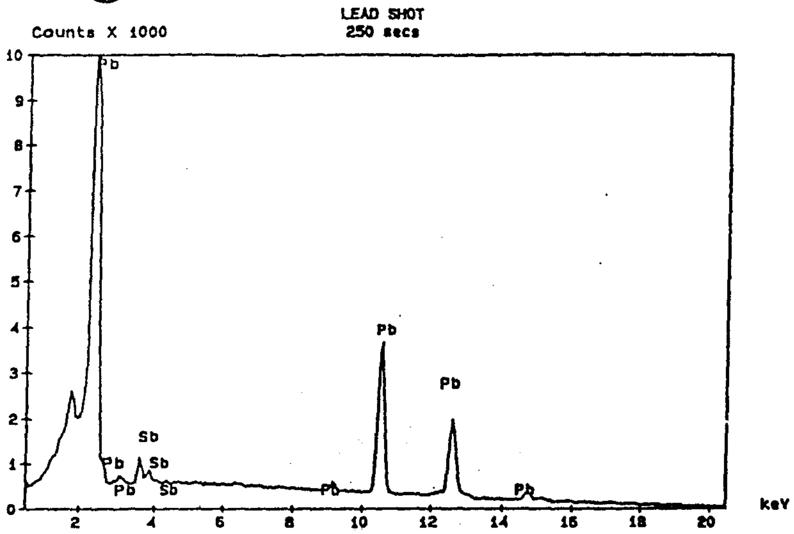


Fig. 12

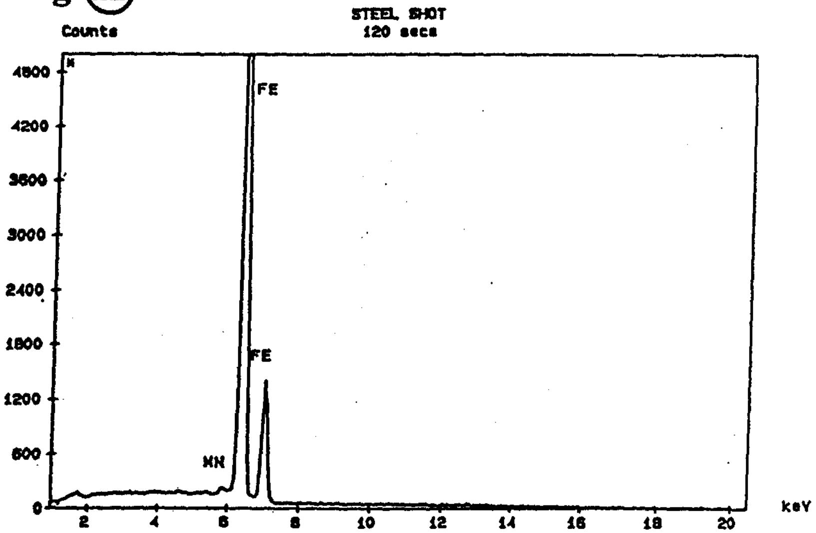


Fig. 13

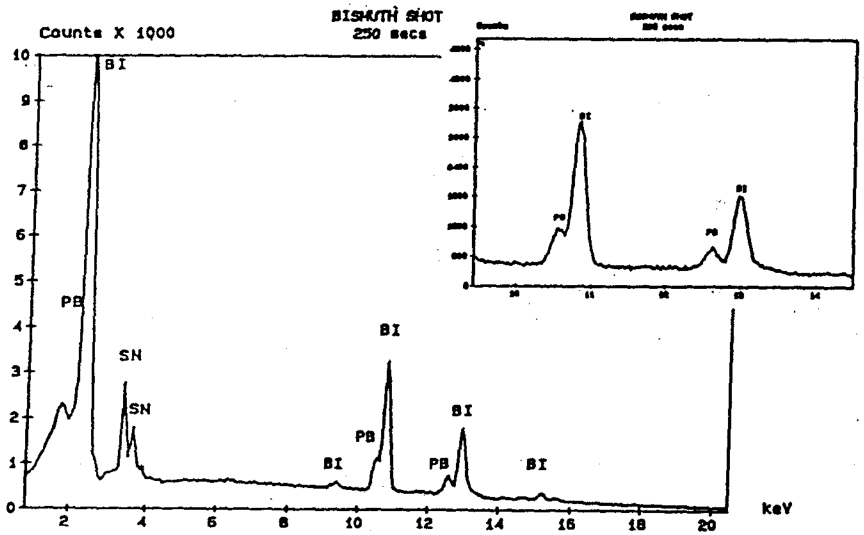


Fig. 14

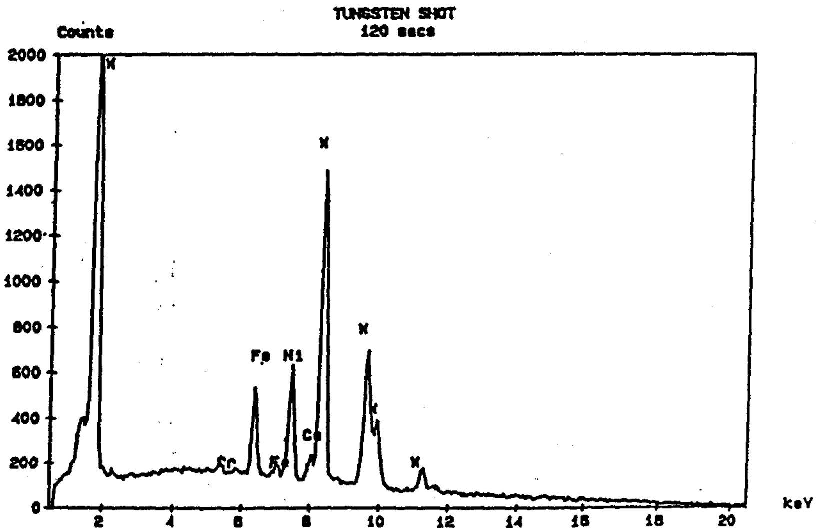


Fig.11 *Energy dispersive x-ray spectrum of a general surface area of a Winchester #6 lead shot pellet.*

Fig.12 *Energy dispersive x-ray spectrum of a general surface area of a Remington #6 steel shot pellet.*

Fig.13 *Energy dispersive x-ray spectrum of a general surface area of Bismuth Cartridge Co. #6 bismuth shot. The insert shows an expanded horizontal scale with better resolution of the lead peaks.*

Fig.14 *Energy dispersive x-ray spectrum of a general surface area of an Eley #6 tungsten-polymer shot pellet.*

Fig. 15

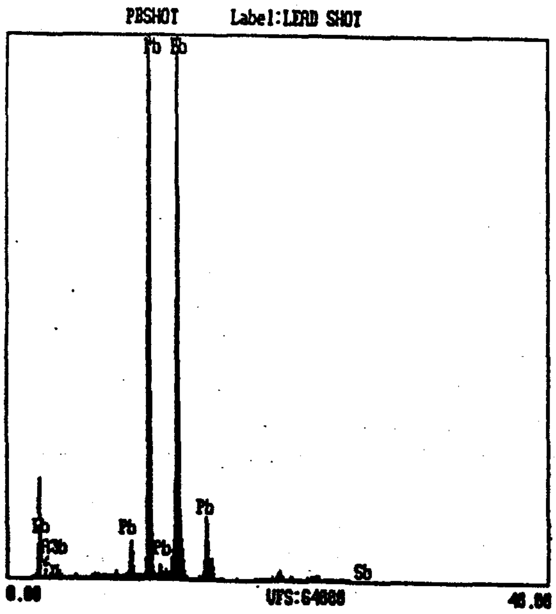


Fig. 16

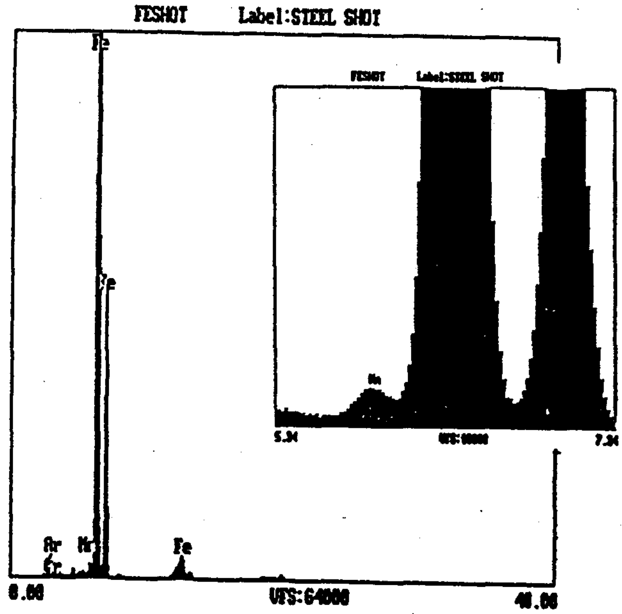


Fig. 17

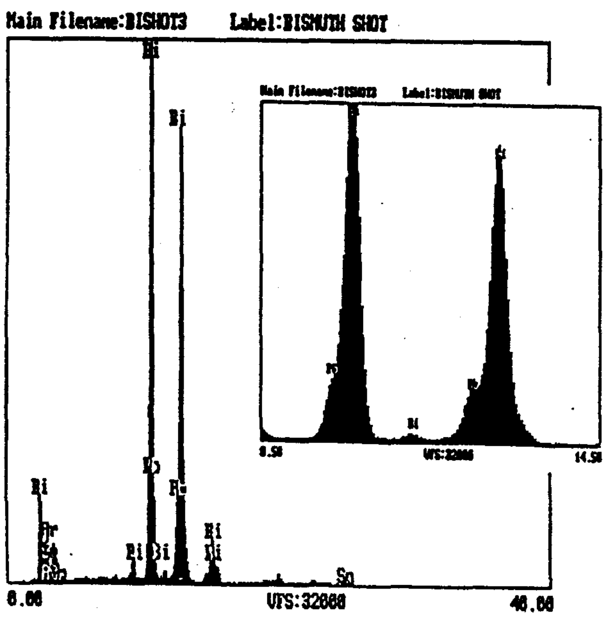


Fig. 18

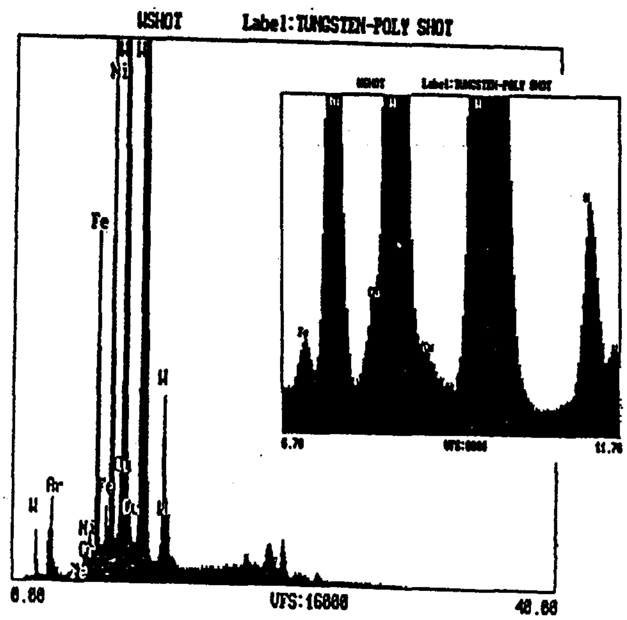
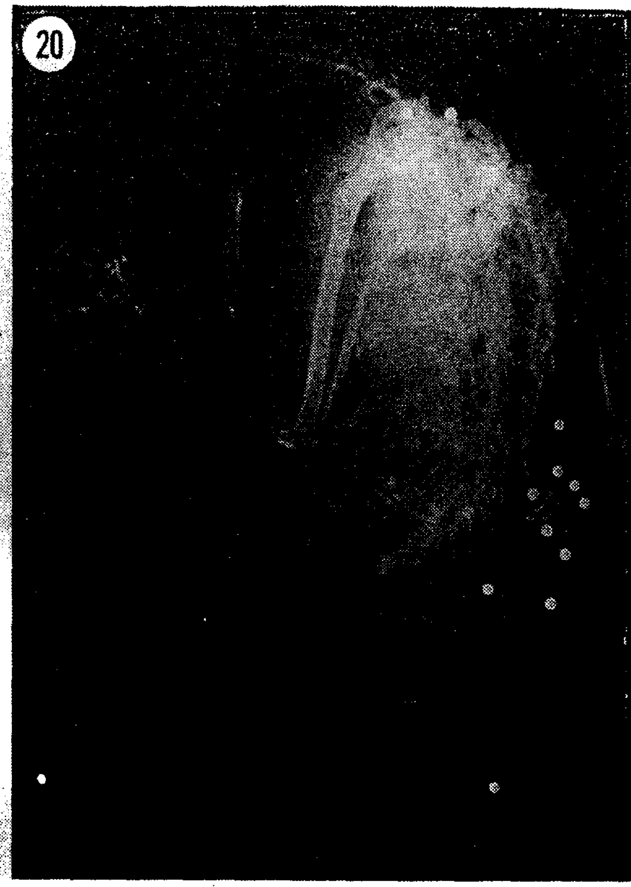


Fig.15 X-ray fluorescence spectrum of Winchester #6 lead shot.

Fig.16 X-ray fluorescence spectrum of Remington #6 steel shot. The insert shows an expanded horizontal scale with better resolution of the manga nese peak.

Fig.17 X-ray fluorescence spectrum of Bismuth Cartridge Co. #6 bismuth shot. The insert shows an expanded horizontal scale with better resolution of the lead peaks.

Fig.18 X-ray fluorescence spectrum of an Eley #6 tungsten-polymer shot pellet. The insert shows an expanded horizontal scale with better resolution of the copper peaks.



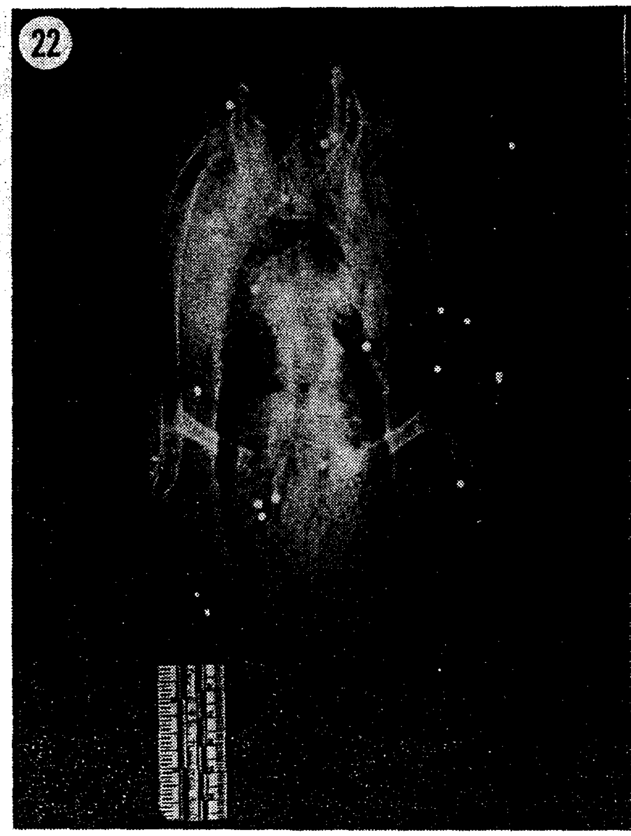


Fig.19 *Radiograph of #6 lead pellets in a hunter shot mallard duck (Anas platyrhynchos) carcass. Shooting distance unknown.*

Fig.20 *Radiograph of #4 steel pellets in a hunter shot canvas back duck (Aythya valisineria) carcass. Shooting distance unknown.*

Fig.21 *Radiograph of Bismuth Cartridge Co. #6 bismuth shot in a canada goose (Branta canadensis) carcass. Shooting distance 30 yards.*

Fig.22 *Radiograph of Eley #6 tungsten-polymer shot in a canada goose (Branta canadensis) carcass. Shooting distance 30 yards.*

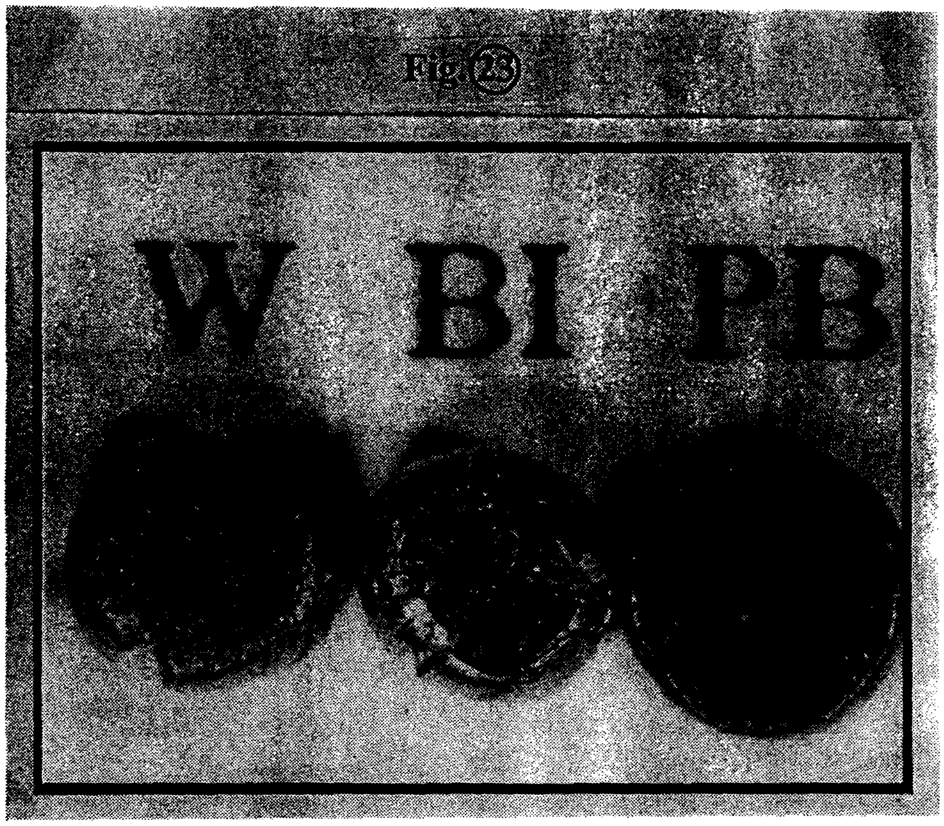


Fig.23 *Optical micrograph showing the results of gentle compression by hand pliers on tungsten-polymer, bismuth and lead shot pellets. Magnification X10.*

Table 1.

FIELD IDENTIFICATION OF SHOT PELLETS

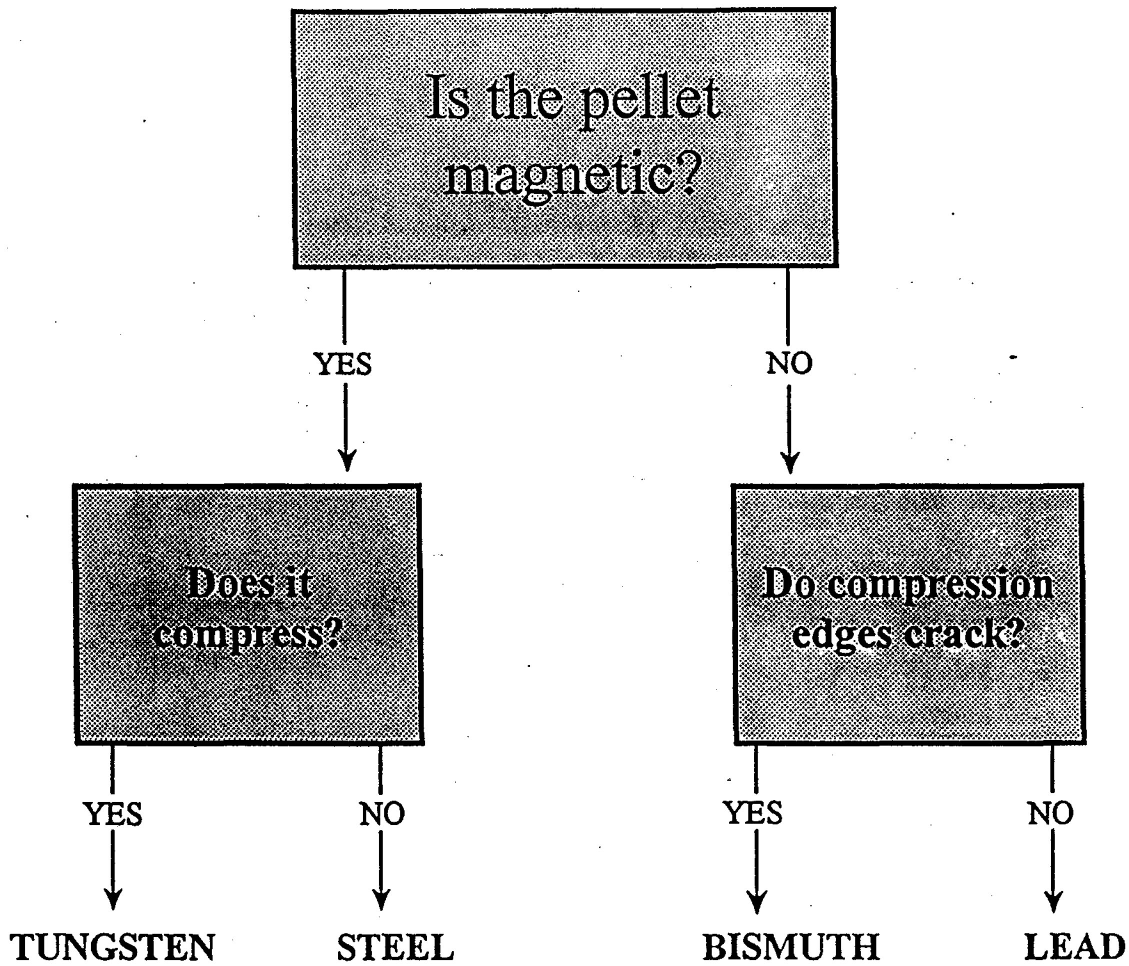


Table2.

Physical Characteristics of Shot Pellets

Pellet	Magnetic	Compression	Compression Cracking	Other
Lead (Pb)	No	Yes	No	Smooth and shiny.
Steel (Fe)	Yes	No	No	Smooth and dull.
Bismuth (Bi)	No	Yes	Yes	Shatters with high velocity force. Rough and shiny.
Tungsten (W)	Yes	Yes	Yes	Rough and shiny.

Table 3. ANALYSIS OF BISMUTH SHOT BY ICP

	BISMUTH	TIN	LEAD	ARSENIC	ANTIMONY
ILLINOIS NATURAL HISTORY SURVEY #7½ 1992 CHALLENGER-ELEY LOT # UNKNOWN	97.7%	0.48%	0.40%	1.40%	---
ENVIRONMENTAL PROTECTION AGENCY #7½ (same) 1993 CHALLENGER-ELEY LOT # UNKNOWN	98%	<0.01%	0.35%	0.11%	0.48%
ILLINOIS NATURAL HISTORY SURVEY #5 1992 BISMUTH CART. CO. LOT # UNKNOWN	94%	3.05%	2.85%	---	---
IMO/BAIRD FOR NFW FORENSIC LAB #6 1994 BISMUTH CART. CO. LOT # 19212014	95%	2.8%	1.5%	<0.01%	0.03%