THE NATIONAL ACADEMIES
REPORT IN BRIEF

Forensic Analysis: Weighing Bullet Lead Evidence

Since the 1960s, the law enforcement community has used evidence derived from Compositional Analysis of Bullet Lead (CABL) in some criminal cases involving gunfire. Different from ballistics techniques that compare striations on the barrel of a gun to those on a recovered bullet, CABL is used when no gun is recovered, or when bullets are too small or mangled to observe striations. CABL compares the elemental composition of bullets recovered from a crime scene to bullets found in a suspect's possession.

CABL has 3 distinct steps: 1) chemical analysis of trace elements in the bullets' lead 2) statistical comparison of the lead compositions, and 3) the legal interpretation of data derived from steps 1 and 2. Witnesses have testified that bullets found to be analytically indistinguishable probably come from the same "box" or "source." However, some of this testimony has been controversial.

It is important that criminal justice and legal professionals, as well as juries, understand both the capabilities and the limitations of this forensic technique. *Forensic Analysis: Weighing Bullet Lead Evidence*, a National Academies report carried out at the request of the Federal Bureau of Investigation (FBI), examines the scientific validity of the chemical and statistical analyses used in CABL, and what can and can not validly be stated in court regarding CABL evidence.

Analytical Technique Is Sound

The report finds that the technique the FBI uses for chemical analysis, called inductively coupled plasma-optical emission spectroscopy (ICP-OES), is accurate and reliable, and that the seven elements currently analyzed [arsenic (As), antimony (Sb), tin (Sn), copper (Cu), bismuth (Bi), silver (Ag) and cadmium (Cd)] are appropriate choices for differentiating one sample from another. Although the report concludes that ICP-OES is currently the best available technology for the job, it also recommends that the FBI evaluate a new variant called "high-performance" ICP-OES, which might allow even better differentiation among samples.

The report recommends, however, that the FBI take several steps to ensure the validity of CABL results:

- **Improve Documentation.** FBI should collect all details of its analytical protocol in a single, authoritative document, and this protocol should be followed rigorously in every case.
- **Publish Details.** To allow others to fully understand the FBI's CABL results and technique, the FBI should publish methodological details in a peer-reviewed journal or other public forum.

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- **Improve Training and Oversight.** FBI should provide regular training and improve proficiency testing for CABL examiners.

Statistical Test Should Change

CABL examiners use statistical tests to determine when the set of concentrations from two samples are close enough to say with high confidence that the bullets cannot be distinguished from each other. The report finds that current FBI methods of statistical analysis, both as written in the FBI's protocol and as actually practiced in FBI laboratories, are not the best available for determining whether crime-scene evidence and a suspect's bullets are analytically indistinguishable.

The FBI's written CABL protocol uses a statistical method called chaining, in which the analyst sequentially compares crime scene bullets to a set of reference bullets, assembling them into groups of compositionally indistinguishable bullets. The report concludes that the chaining procedure can lead to the formation of artificially large sets of matching bullets, because two bullets that are distinguishable from each other but both fall close to a third group can be put in the same "indistinguishable" group.

Although the chaining method is the FBI's documented protocol, interviews with FBI personnel indicated that they no longer use it. Instead, examiners either use a method that declares a match between any two bullets whenever all seven elemental concentrations fall within two standard deviations of each other (the 2-SD procedure), or they use a method that declares a match when the error bars on two measurements overlap (the range overlap method). The FBI claims based on historical data that the 2-SD procedure will result in a false match in about 1 of every 2500 cases. The report provides better methods of estimating false match and false non-match probabilities.

The report makes the following recommendations for improving the FBI's statistical methods of analyzing CABL data:

- **Replace the current statistical tests with either the T^2 statistic or the successive t-test statistics procedure described in Chapter 3 of the report.** These tests would provide a much better quantitative assessment of the chance that two bullets have been mistakenly declared indistinguishable because of random statistical variations, thereby increasing the certainty of CABL evidence in the courtroom. To give a

Box 1. CABL Statements in Court

Although CABL has been admitted in evidence for about 40 years, there are relatively few published cases that rely on the technique. The overwhelming majority of those are state homicide prosecutions, some of which are capital cases. CABL evidence is often used in cases in which numerous other items of evidence are introduced, but courts have sometimes indicated that it played an important role in securing a conviction.

The published cases reveal a wide variety of interpretive conclusions with respect to CABL evidence. In many cases, the experts apparently have not stated the limitations of such evidence. In some cases, experts have testified only that two exhibits are "analytically indistinguishable"; other experts concluded that samples "could have come" or "came" from the same "source" or "batch."

The testimony in a number of cases goes further and refers to a "box" of ammunition (usually 50 loaded cartridges, sometimes 20). Examples from actual testimony include statements that two specimens "could have come from the same box," "could have come from the same box or a box manufactured on the same day," and "must have come from the same box or from another box that would have been made by the same company on the same day."

In recent years, testimony appears to have become more limited. A 2002 FBI publication states the conclusion as follows: "Therefore, they 'likely' originated from the same manufacturer's source (melt) of lead."

Range. A measure of the variability in a set of several measurements, found by subtracting the lowest measurement from the highest in the set.

Standard deviation. A quantitative assessment of uncertainty calculated on the basis of how far each of several measurements falls from the average.

more reliable estimate of uncertainty, the FBI should use a pooled standard deviation over many bullets that have been analyzed with the same ICP-OES technique.

- **Improve Consistency.** The FBI's statistical protocol should be properly documented and followed by *all* examiners and consistently applied in *every* CABL case.

Testimony Should be Carefully Limited

Even if the recommended improvements are made in handling the chemical and statistical analysis, the value of CABL evidence in a criminal case and how it is conveyed to a jury remains a critical issue. Attorneys, judges, juries and even expert witnesses can easily and inadvertently misunderstand and misrepresent the analysis of the evidence and its importance. The report's review of expert testimony from the FBI reveals a wide range of statements made about CABL evidence (see Box 1).

To understand the limits of CABL, it is important to understand variations in the manufacturing process for bullets (see Box 2). These variations sharply limit statements that written laboratory reports and expert testimony about CABL findings can justifiably make regarding the "source" of the bullets. Every step from smelting the lead to buying the ammunition in a store provides opportunities for bullets with different compositions to be mixed and for bullets with the same composition to be shipped separately to different outlets in a region or to different regions. In fact, the FBI's own research shows that a single box of ammunition can contain as many as 14 distinct compositional groups.

The report finds that there is a volume of material in the manufacturing process that is compositionally indistinguishable, referred to in the report as a "compositionally indistinguishable volume of lead" (CIVL). A CIVL yields bullets that are analytically indistinguishable. However, due to variations in manufacturing, the size of the group of bullets from a CIVL might be small—on the order of 12,000 bullets—or large—more than 35 million bullets. The committee also found that nothing guarantees that CIVLs of the same composition could not, by chance, be created more than once at different times and places.

A bin of bullets at a manufacturer. Photo courtesy Sporting Arms and Ammunition Manufacturer's Institute (SAAMI)

Box 2. Bullet Production and Packaging

The bullet manufacturing process can differ substantially from manufacturer to manufacturer, and even between lots made by the same manufacturer. But the following general description of the process illustrates the points most relevant to this analysis.

Molten lead—primarily from recycled car batteries—is cast into blocks of a few hundred pounds called billets. Manufacturers sometimes deliberately add two of the elements CABL measures—antimony and tin—to the molten lead to make it harder; the other five—copper, bismuth, silver, arsenic, and cadmium—are common impurities. Many bullet manufacturers add scrap lead from bullet production into the "melt" at random times, sporadically changing the composition of the original melt.

Billets are extruded into wire with a diameter that matches the bullet caliber, and the wire is cut into bullet-sized chunks (slugs) that are pressed into shape. At large facilities, slugs from many wires, and from many billets, are often collected and mixed together in large hoppers. They can be mixed further as they are washed, polished, and shaped. The bullet is then mated with the cartridge casing and charge (gunpowder) to make a fully-assembled round of ammunition. These are often again mixed together in hoppers before being packaged into individual boxes. Bullets from a single day's production run do not necessarily move together through the network of distributors, and wholesalers to the retail shelf.

Expert witnesses who testify about CABL data should take great care not to overstate the significance of a CABL match, and to make clear the limits on conclusions that CABL results can support. Specifically, the report recommends that reports and witnesses:

- **Avoid over-broad statements.** Witnesses should **not** say that two analytically indistinguishable bullets come from the same: melt, production run, or box, or were made on or about the same day. None of these assertions, the report found, can be justified by the available data.
- **Use the term "CIVL."** Interpretation and testimony of examiners should be limited to the following two statements: 1) Bullets from the same CIVL are more likely to be analytically indistinguishable than bullets from different CIVLs; and, 2) CABL evidence that two bullets are analytically indistinguishable increases the probability that two bullets came from the same CIVL, versus no evidence of a match.
- **Acknowledge Uncertainties.** Expert witnesses should define the range in size of CIVLs that could make up the source of analytically indistinguishable bullets because of variability in the bullet manufacturing processes, and acknowledge the fact that different CIVLs can sometimes coincidentally be analytically indistinguishable.

The report concludes that, in many cases, CABL is a reasonably accurate way of determining whether two bullets came from the same compositionally indistinguishable volume of lead. Thus, in appropriate cases, CABL may provide additional evidence that ties a suspect to a crime, or in some cases evidence that tends to exonerate a suspect. The value and reliability of CABL can be enhanced if the recommendations of this report are implemented.

Committee on Scientific Assessment of Bullet Lead Elemental Composition Comparison: Kenneth O. MacFadden, (Chair) Independent Consultant; **A. Welford Castleman, Jr.,** The Pennsylvania State University; **Peter R. DeForest,** John Jay College of Criminal Justice; **M. Bonner Denton,** University of Arizona; **Charles A. Evans, Jr.,** Consultant; **Michael O. Finkelstein,** Attorney; **Paul C. Giannelli**, Case Western Reserve University, **Robert R. Greenberg,** National Institute of Standards and Technology, **James A. Holcombe,** University of Texas; **Karen Kafadar,** University of Colorado at Denver; **Charles J. McMahon, Jr.,** University of Pennsylvania; **Steven R. Prescott,** Hercules, Inc.; **Clifford Spiegelman,** Texas A&M University; **Raymond S. Voorhees,** United States Postal Inspection Service, **Jennifer Jackiw** (Study Director until September 2003) and **Dorothy Zolandz,** Director, Board on Chemical Sciences and Technology.

This report brief was prepared by the National Research Council based on the committee's report. For more information, contact the Board on Chemical Sciences and Technology at (202) 334-2516. *Forensic Analysis: Weighing Bullet Lead Evidence* is available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242 or 202-334-3313 (in the Washington area); www.nap.edu.