Forensic Testimony:
"Matches", An Over-Inference of Data?
A *Giglio* Obligation?

Frederic Whitehurst[1]

Exec. Dir., Forensic Justice Project, 3233 "P" St. N.W., Washington, D.C. 20007, USA

ABSTRACT

The expert witness who over-infers his data through the misuse of adjectives of comparison opens himself up to cross-examination that can and will discredit his work product. This paper uses the example of forensic analysis of black powder explosive to demonstrate that one can not categorically "match" one Black Powder sample to another or very often one complex chemical system to another and that even if this were possible, such "matches" may have limited probative value. The paper also explores the legal obligation of the expert to reveal to the prosecutor, court and trier-of-fact the limitations of the probative value of the evidence where those limitations might be considered to be exculpatory information.

Keywords: Black Powder, forensic analysis, *Giglio*, sulfur, potassium nitrate, charcoal

The Problem

While reviewing case opinions in criminal matters involving forensic examinations, one is often presented with various adjectives of comparison such as "matches", "consistent with", and "identical to". The expert witness who uses such terms may find counsel elated at seeing these adjectives in forensic reports if legal theories are supported, or disturbed if not. However, one way or the other, there is a wealth of information behind these adjectives of comparison, which may go unexplored. If the basis for use of such terms of comparison is brought up during trial, counsel may find himself either defending new ground during trial or scoring important points in discrediting proffered expert testimony. One should be drawn to question whether these words are an indication that data has been over-inferred by the expert offering them. One is also drawn to ask, whether the information behind these words should have been presented as possible exculpatory information to unsuspecting prosecutors before trial (following *Giglio*[2]). Comparison adjectives left dangling alone to describe the results of comparisons may not properly educate the trier-of-fact to the true significance of the data. And more importantly, the true significance of the data may not be known by the forensic scientist. For example, Jonakait[3] tells us, "The conclusions of forensic science are often based on skimpy, nonexistent, or shoddy research. Forensic scientists do not give juries a thorough presentation of information about scientific technique."

This paper will address the adjective "matches" as an example pointing out the very wide door of opportunity it opens for future probing during examination. The adjectives, if not properly supported by empirical data, can offer counsel the opportunity to point out to the trier-of-fact what may be a flawed opinion, possibly even a "forensic scam" being perpetrated upon the court through the hiding of exculpatory information. This paper will also explore the legal or *Giglio* obligation of the prosecution's forensic scientists to reveal the empirical data (or lack thereof) and their total understanding of that data to full view.

The world of man-made products is composed of complex materials constructed with many components, each with its own manufacturing signature. When the forensic expert testifies that two complex materials "match", coun-

Table 1. Guaranteed Composition in Weight Percent.

Component	Industrial	Refined
KCl (potassium chloride)	99.5	99.9
Na (sodium)	0.18 max	0.0150 max
Br (bromine)	0.09 max	0.0600 max
SO_4 (sulfate)	0.001 max	0.0010 max
Ca (calcium)	0.0075	
Ca + Mg (calcium+magnesium)	0.0180	0.0030 max
Pb (lead)	0.0003	0.0003 max
Fe (iron)	0.0005	0.0005 max
Cu, Ni (copper, nickel)	0.0001	0.0005 max
Cu, Mo, V, Ti (copper, molybdenum, vanadium, titanium)	0.00004	0.00001 max

sel is encouraged to ask of what the materials are composed, which of the components match, how the expert has determined this, what components were not and/or cannot be detected with the analyst's tools, and the implications of not being able to determine if these components matched or not. As an initial example we will look at a very simple and very old man-made material, Black Powder, an explosive.

Black Powder

Though the origins of Black Powder are debated, it was the major explosive used in warfare, firearms and industries such as mining until the late 1800's. The black grains of material, which are composed of potassium or sodium nitrate, sulfur and charcoal, have been produced by a number of methods in different countries for hundreds of years. At first glance Black Powder appears to be a simple material of three components. However a closer, "hard look" reveals a fascinatingly complex material of many, many possible subcomponents and physical characteristics. The expert witness who opines that two Black Powders "match" then can be asked to explain what about the materials is it that matches, and what is the significance of that match. Let us explore the world of information behind the word "match" when it is applied to two Black Powder samples.

We may ask first who manufactures the components of Black Powder. This knowledge allows us to check proffered expert opinions against actual manufacturers' understanding of their own products. We can easily determine the manufacturers of a material and ask a number of questions. How is potassium nitrate manufactured? How is sulfur manufactured? How is charcoal manufactured? What are the raw products that go into the manufacture of these materials, and what chemical and physical signatures do they carry with them to the final Black Powder mixture? What possible minor impurities are found in these components that might change the types of Black Powder in minor but important ways? Who manufactures Black Powder itself? How much of the material is manufactured? What are the physical characteristics of Black Powder? What grades of Black Powder are manufactured? The expert who is prepared under oath to render the *bare* opinion that Black Powder specimens "match" should surely have considered these questions at length and have ready answers, data and the scientific literature to support his opinion.

Potassium Nitrate

A quick trip to the chemistry library to look into the *Encyclopedia of Chemical Technology*[4a] tells us "Potassium nitrate, which was essential in the manufacture of black gunpowder, was produced centuries ago by the Chinese.... The process involved leaching soil in which nitrogen from urine had combined with mineral potassium. By the time of the Napoleonic wars, potassium nitrate was a strategic chemical and was still obtained in the same manner, primarily from India." One can certainly imagine that if potassium nitrate were still manufactured in this manner it would carry a lot of impurities out of the soil with it. However we are not to be treated to such a simple answer.

We find from the same reference[4b] that "Most of the potassium nitrate, KNO_3, produced commercially in the United States is based on the reaction of potassium chloride and nitric acid." So here we have two other materials the origins and purity of which we must consider. Table 1 lists the composition of potassium chloride: [4c]

One can see that with all of these materials in the potassium chloride used in the manufacture of potassium nitrate, their occurrence in the potassium nitrate, derived in part from the potassium chloride, is possible. Indeed, reference to the certificate of analysis on a bottle of a Fisher™ Certified Reagent grade potassium nitrate from lot number 745536, found in the laboratory in which the author works, notes the following impurities:

Component	Guaranteed Composition (wt %)
Fe (iron)	.0001%
Heavy metals (as lead)	.0001%
SO_4 (sulfate)	.001%
Na (sodium)	.005%
Insoluble matter	.001%
Cl (chlorine total)	.002%
PO_4 (phosphate)	.0001%
Ca + Mg (calcium + magnesium)	.002%

As small as the percentages are, they are still measurable and have obviously been measured in the assay of this reagent grade material. Counsel should note that Black Powder is made from technical or industrial grade potassium nitrate, which may very well have higher levels of impurities than the more refined reagent grade potassium nitrate. Counsel also should not have to accept the opinion that the materials are not present in sufficient quantity to measure and are therefore not important to establishing a match. That kind of statement should be backed up with empirical data, data that indicates that minor components do not change *significantly* between batches or grades of Black Powder. What does "significantly" mean? That is another question for the expert to answer.

Sulfur

In the *Encyclopedia of Chemical Technology*[5a] we read, "Sulfur has been known since antiquity... One contemporary use was developed in 500 BC, when the Chinese used sulfur as an ingredient of gunpowder." And further we read,[5b] "Sulfur occurs in a number of different allotropic modifications, that is, in various molecular aggregations which differ in solubility, specific gravity, crystalline form, etc. Like many other substances, sulfur also exhibits dynamic allotropy, i.e. the various allotropes exist together in equilibrium in definite proportions, depending on the temperature and pressure...The particular allotropes that may be present in a given sample of sulfur depend to a large extent upon its previous thermal history, the amount and type of foreign substance present, and the length of time that has passed for equilibrium to be attained."

These are statements full of the wonderful potential for exploration. One must ask what type of sulfur did the manufacturer use in his product. Whereas the commercial manufacturer of Black Powder may be limited to the use of a particular type of sulfur in the United States (that typically being a low acidity sulfur commonly referred to as sulfur flour), what limits can one place upon the foreign and homemade Black Powder manufacturers? There is also mention of impurities. What impurities exist in sulfur? An expert in a particular type of material might reasonably be expected to have considered this question in the past just as he might have been expected to consider the impurities in potassium nitrate. After all, if an expert is going to say that the chemical composition of two materials such as Black Powder match, then he can reasonably be expected to have some understanding of what those chemical compositions are. And then we can ask what allotropes are present in the sulfur that is in the Black Powder. Interestingly the *Encyclopedia*[5c] notes the many grades of sulfur as follows: amorphous sulfur, bright sulfur, brimstone, broken rock sulfur, colloidal sulfur, crude sulfur, dark sulfur, dusting sulfur, elemental sulfur, flour sulfur, flowable sulfur, flowers of sulfur, Frasch sulfur, insoluble sulfur, lac sulfur, liquid sulfur, molten sulfur, native sulfur, precipitated sulfur, prilled sulfur, recovered sulfur, refined sulfur, roll sulfur, rubbermaker's sulfur, run-of-mine sulfur, screened commercial sulfur, slated sulfur, specialty sulfurs and wettable sulfur. Now who would imagine that sulfur could come in so many grades? Dare we ask if the different grades might have different impurity signatures? Any expert who professes to know that two Black Powder samples "match" without describing those characteristics that match might be inclined to have asked and to have answered that question. Or possibly the "match" did not include consideration of trace impurities.

Charcoal

The most impressive complex component of Black Powder is charcoal. It is this component that contains the greatest wealth of opportunity for examination, both legal and scientific. The *Handbook of Charcoal Making*[6a] defines charcoal as "The residue of solid non-agglomerating organic matter, of vegetable or animal origin, that results from carbonization by heat in the absence of air at a temperature above 300 °C."

The definitions also include those of charcoal's components as follows: [6b]

1) Content of Volatiles: If charcoal is heated to 900 °C under confined conditions, it will lose weight because hydrocarbons and nitrogen are driven out. This weight loss is extremely important to industrial charcoal consumers when defining the utilization properties.
2) Ash content: The ash is composed of the natural minerals contained in almost any organic matter and contaminations. The quantity is related to the composition of the raw material mix, e.g. wood branches with a high proportion of bark will give high ash containing charcoal. Charcoal ashes are distinguished by their solubility in water and by chemical analysis.
3) Sulphur and phosphorus content: The low sum of these substances normally found in charcoals makes them especially attractive for use in blast iron furnaces and for metallurgical purposes.
4) Pyrolysis Oil: The oil varies very much with the type of raw material. It contains more than one hundred different substances, which once made it a valuable feedstock for the chemical industry.

With these definitions we realize that charcoal could be considered the most complex component of Black Powder.

An important field of research in Black Powder charcoals has been conducted by military laboratories in attempts to better define the power of this explosive.[7] Black powder is used as an initiating charge, providing rapid and efficient ignition, and as a propellant for some military projectiles. If the Black Powder is not well characterized and does not perform consistently, then high explosive rounds may fall on friendly lines or may not hit intended targets. The work of Ronald Sassé et al. for the U.S. Department of Defense is particularly instructive in characterizing Black Powder. In Sassé's papers[8–10] we see a treasure of information that can be explored by counsel. Charcoal used in Black Powder originates from different vegetable sources. These sources invariably originate from different areas and therefore nutrient environments. Each batch of charcoal is consequently very likely different. Even the manufacturer who uses the same type of tree for his charcoal utilizes trees that originate from different sources. These sources imprint their own nutrient and growth signature on the charcoal product and, if batches of charcoal are blended, such blends may create their own signatures.

Expert testimony that is offered that Black Powder samples "match" should raise questions concerning the chemical and physical characterization of the charcoals found in the Black Powder. Remembering that charcoal particles will have different contents of organic and inorganic chemicals as well as different shapes and structures, counsel can ask for the data that totally defines these characteristics. If they have not been defined then a dangling "match" must be better defined.

Black Powder, The Product

Black powder utilized in the United States originates from a number of sources. The largest of those sources is Goex, Inc. [11] The GOEX Black Powder plant in Moosic, Pennsylvania, started producing Black Powder in 1912. Kosanke[12] advises that there are also sources of Chinese, German, Russian, Brazilian, Scottish and homemade Black Powders in the United States at this time as well as Black Powder that originates from military surplus. A simple review of the GOEX sales brochure notes that Black Powder comes as superfine black sporting powder, military powder, fireworks powder, blasting powder and commercial powder. Each of those headings has subclasses. Under superfine black sporting powder one finds cannon, Fg, FFg, FFFg, FFFFg, and cartridge powders. Under military Black Powder one finds type Mil-P-223P powder further subdivided into class 1 through class 8 propellant composition, type JAN-P-663A subdivided into type I fuse and type II fuse powders, and type JAN-P-362 powders. Under fireworks powder one finds 1Fa through 7Fa, meal D, fine meal and extra fine meal. Under Blaster Powder one finds 1FBB, through 4FBB powder. Under commercial fuse powder one finds powders with speeds of 85, 108, 111, 116, 124, 126, 132, 140 and 165 seconds/yard.

As the reader can see, these powders, though all composed of potassium or sodium nitrate, sulfur, and charcoal may have different characteristics. For instance, no two Black Powder granules, which have the appearance of blackened coarse grains of sand, are exactly alike in size and shape. Sassé and Rose can therefore tell us that there is a size distribution of these powder particles in any one product type.[13] According to information the author received from a representative of GOEX, because of this size distribution, particles of one size may be found in more than one type of Black Powder. For example, particles of a particular size that are found in FFg may also be found in FFFg powder. Therefore while noting that particles from two different sources of different types of Black Powder match in size, the expert must also honestly put forth the information that other sources of different types of Black Powder are not excluded as possible sources. It would also be helpful to let counsel and the trier-of-fact know just how many other sources of a particular type of Black Powder there were. This may be impossible as the Black Powder particles fracture in the can.[14] Another problem with Black Powder size comparison may very well be in comparing uninitiated Black Powder with Black Powder particles found in residue from exploded improvised explosives devices. If powder can fracture in the can, one can be certain that it will fracture when subjected to explosive forces.

Though quantities of Black Powder that exist in the United States are not known accurately, one can get an estimate from looking at Black Powder usage as well as the published scientific literature on Black Powder. Jon Uithol, of the National Muzzle Loading Rifle Association[14] advises that there are three to seven million muzzle loading state hunting licenses issued per year in the U.S. These firearms utilize Black Powder or substitutes such as Pyrodex™[15] and Clean Shot™.[16] Black powder is sold in units as small as one pound. This would indicate that millions of pounds of Black Powder presently exist in this country as purchased product. Rose notes about Black Powder "the civilian consumption alone must be more than a thousand metric tons annually".[17]

A Range of Choices

The Federal Judicial Center's *Reference Manual on Scientific Evidence*[18] asks the question "Have alternative explanations been ruled out?" explaining, "Alternative explanations and confounding factors should be examined and ruled out to avoid reaching an erroneous conclusion. However, it is never possible to rule out every alternative explanation." Another source[19] describes Judge Weinstein in *Agent Orange*[20] recognizing that unless research seeking to establish causation for one agent also takes into account other factors that may explain the plaintiff's injuries, the finding may improperly overestimate causation. Because the evidence presented failed to take into account factors other than Agent Orange dioxin that could have caused the veteran's illnesses, it was not scientifically valid, and Judge Weinstein properly excluded the evidence as legally unreliable." This is very much on point here. Complex materials and their components are manufactured in many forms with many uses, and with upper and lower limits of acceptance of physical and chemical characteristics. Those limits translate into products having different chemical and physical characteristics even though produced on the same production lines for identical purposes. When those limits are very tight, differences are difficult if not impossible to detect with modern analytical tools. The result of this is that alternative explanations cannot always be ruled out no matter how thorough the analysis is. In the case of Black Powder, the manufacturers' upper and lower limits must be carefully controlled so that the powder initiates only upon command and not spontaneously, resulting in unplanned damage and/or death. The range of differences in Black Powder do exist, however, and preclude absolute matches.[21] The analyst is compelled to determine the limits of ranges and if possible to determine if suspect materials fit within those ranges and therefore could have originated from the same sources. Ultimately, however, the scientist reaches the point at which available technology cannot assist in the further characterization of materials. At that point the legal system must determine if the scientist should be compelled to report that failure and its in light of what alternative explanations for the data cannot be ruled out. Apparently Judge Weinstein would suggest that alternative explanations that cannot be ruled out should be presented as evidence.

Giglio v. United States

One would assume that a prosecutor would want to know the weaknesses of opinions presented by forensic experts if for no other reason than to avoid problematic revelations during testimony on cross examination. But does the forensic scientist have a duty to present his total understanding of data or just that part that gives strength to the prosecutor's theory of guilt?

One approach to the reporting of limitations of scientific protocols is that established under *Giglio*. It is strange that a forensic scientist would even have to consider the law in dealing with the completeness of his reports. One would hope that there would be no taint of bias and that the scientific opinions would be rendered objectively. However as noted in the British case *Regina v. Judith Theresa Ward*,[22] "the disclosure of scientific evidence was woefully deficient. Three senior RARDE scientists took the law into their own hands and concealed from the prosecution, the defense and the court, matters that might have changed the course of the trial." Forensic scientists do at times take the law into their own hands and become partisan. Therefore guidance in the reporting of the significance of forensic evidence might be necessary.

We are taught in "The Prosecutor's Duty of Disclose: From *Brady* to *Agurs* and Beyond"[23] that *Giglio* and progeny establish that "Generally a prosecutor 'should know' of a piece of evidence if it is in his possession or in the possession of any agency involved in the prosecution." Other agencies can include other prosecutors in the office,[24] law enforcement officers,[25] and any other investigative agencies involved in criminal prosecution.[26] This would naturally include government forensic laboratories. And in footnote 130 of this article, quoting *U.S. v. McCord*,[27] "The prosecution involves all agencies of the federal government involved in any way in the prosecution of criminal litigation." *Giglio* and progeny establish that failure to present exculpatory information is not excused as a result of the prosecutor having no personal knowledge of such information while members of the agency assisting in the prosecution do have such knowledge. What does this say for forensic scientists who present their findings as "matches" without describing the underlying meaning of the adjective? Do these scientists have an obligation to present the underlying meaning of the data that establishes the match? If the matches are not absolute should the level of uncertainty be exposed to the prosecutor? If the level of uncertainty is unknown should that also be reported to the prosecutor? If forensic scientists are not willing to report the significance of their data objectively, then how can the prosecutor decide if *Brady* material and *Giglio* obligations exist as a result of scientific investigations?

What obligation does the prosecutor have to provide possibly exculpatory forensic information? *Agurs*[28a] teaches that:

> Although there is, of course, no duty to provide defense counsel with unlimited discovery of everything known by the prosecutor, if the subject matter of such a request is material, or indeed if a substantial basis for claiming materiality exists, it is reasonable to require the prosecutor to respond either by furnishing the information or by submitting the problem to the trial judge. When the prosecutor receives a specific and relevant request, the failure to make any response is seldom, if ever, excusable.

But how does defense make specific requests about complex scientific information that may be exculpatory in nature, or may prove or be favorable to establishing innocence. The "matching" of complex forensic samples is generally not a skill that is employed outside the government's own laboratories. How can defense counsel even know to ask about the morphological structure of the charcoal in Black Powder samples, or the volatile organic compounds, or the pyrolysis oils, or the impurity content of potassium nitrate, or the size distribution characteristics of particular types of Black Powder? Generally, neither prosecution nor defense counsel have appropriate backgrounds to delve into or understand this type of information.

Agurs[28b] identified this situation in describing the prosecution's failure to disclose allegedly favorable evidence that the defense had not specifically requested. This failure could be inexcusable under *Giglio,* and yet the prosecutor, defense and court never pick up on the failure when forensic evidence is concealed. One can imagine testimony that established that two Black Powder samples "matched" and yet the "match" was only in qualitative content of potassium nitrate, sulfur and charcoal. A trier-of-fact could wrongly infer from this testimony that both Black Powder samples had unique characteristics that set them apart from all the other hundreds of thousands, possibly millions, of pounds of Black Powder in existence in the United States. Without explaining the meaning and limitations of "match" and without the prosecutor or defense counsel being able to see through the problem, the trier-of-fact might not be able to place the proper weight on evidence and injustice might result.

What evidence would be considered exculpatory? It would not take a great leap of faith to believe that if Black Powder were found at a crime scene and at a defendant's residence that the defendant would argue that there are thousands of tons of Black Powder available and in the hands of the American public and that the Black Powder found at the crime scene did not originate from the defendant's Black Powder. The expert who opined simply that the two Black Powder samples "matched" could very well mislead the trier-of-fact into believing that the two samples of Black Powder originated from the same source. That expert would be concealing evidence that very well could be considered to be exculpatory. One can also imagine the trier-of-fact who has been led by the expert to believe that two Black Powder samples "match" most likely originated from the same source. Under these circumstances, any information that revealed the limited weight of that evidence could be considered favorable to the defense. Such evidence, if unsuccessfully concealed, might even lead jurors to question the credibility of the proffered expert. Imagine the trier-of-fact who has been led to believe through the "dangling adjective of comparison" that two samples originated from the same source. Imagine now the effect on that same trier-of-fact when she learns that there are thousands if not millions of possible sources of the same material, that the analyst can not, in reality, determine if the two materials are chemically and physically identical, and that the analyst did not present that information in his report or in his testimony.

Solutions

Counsel should look behind the adjectives of comparison, demanding to know what they mean. Forensic scientists should report their full understanding of the meaning of the comparison adjectives, remembering that the oath is to "Tell the truth, the whole truth, and nothing but the truth." A list of possibly useful exploratory questions is presented as a guide, using Black Powder as an example:

1) Of what is Black Powder composed?
2) What analytical techniques were used to determine the composition of these pieces of evidence?
3) What information about the components did each of these analytical techniques and instruments present?
4) Are each of the materials used in the manufacture of Black Powder pure? How is purity defined or determined?
5) If not, then did the instruments measure these impurities?
6) If the instruments did not measure the impurities, how can one be sure that the Black Powders "match"?
7) What does "match" mean?
8) If you did not or cannot measure impurities such as pyrolysis oils and minerals in Black Powder particles, then how can you say that the particles match without revealing in what specific ways they do match?
9) Are all Black Powder particles the same size and shape?
10) If they are not the same size, then what is the size distribution of the particles that you analyzed and how did you measure the distribution?
11) Was the Black Powder used in an improvised explosives device that exploded?
12) Wouldn't such an explosion break apart powder particles?
13) If you say that it would not, please present your empirical data and results of your scientific analyses to show that an explosion would not fracture larger Black Powder particles into smaller particles?
14) Did you conduct a scanning electron microscope comparison analysis of the morphology, size and shape of the charcoal in the Black Powder particles that you had as evidence?
15) Did you determine whether the Black Powder particles that you had were manufactured with charcoal from different types of trees?
16) If you did not, why didn't you before you simply said that the two powder samples matched?
17) Do you know what types of trees are used for the charcoal used in the manufacture of Black Powder particles? If you do, then would you name them?
18) Did you look for these different types of wood charcoal? How do you recognize the different charcoals?
19) Did you measure the density and hardness characteristics of the Black Powder particles, which you say "match?" If not, why not? If so, can you provide the data and explain how you conducted that measurement?
20) If you believe that the Black Powder particles "match" and yet you have not measured all the characteristics of the particles, can you explain what is the basis for your saying that the particles match?
21) Can you explain why even though you were not able and/or did not measure some very important characteristics of the Black Powder particles, you still wrote a laboratory report that said the Black Powder particles matched and did not further explain the significance of the "match?"

Summary

Adjectives of comparison such as "match", "consistent with" and "identical to" can be misleading to triers-of-fact and can be used to prove almost anything. The expert witness who opines that two materials match opens the door very possibly to cross-examination that could be easily used to discredit the witness. Cross-examination can delve into the physical characteristics and chemical components of the matching materials, the instrumental data from analyses of the materials and into the basic scientific foundation for the opinion rendered.

We are left with a question as to whether *Giglio* obligations of the prosecutor require that the prosecutor's experts reveal the basis for their use of comparison adjectives in their reports to the prosecutor. These revelations would seem to be necessary in order that the prosecutor be able to decide if information held by members of his team was favorable to the defense. Such information would normally be found in scientific reports from other disciplines and should not be left out of forensic reports.

References and Notes

1) Executive Director, Forensic Justice Project, Washington, D.C.; Former Supervisory Special Agent, Federal Bureau of Investigation, assigned to FBI laboratory, Washington, D.C., 1986–998; B.S., Chemistry, 1974, East Carolina University; Ph.D., Chemistry, 1980, Duke University; J.D., 1996, Georgetown University School of Law.

2) "Giglio v. United States", Vol. 405 U.S., 1970, p 150.

3) Randolph N. Jonakait, "Stories, Forensic Science, and Improved Verdicts", *Cardozo L. Rev.* Vol. 13, 1991, pp 343, 349.

4) W.B. Dancy, "Potassium Compounds", *Encyclopedia of Chemical Technology*, Vol. 18, John Wiley & Sons. 1982; [a] p 920; [b] p 939; [c] p 930.

5) D. W. Bixby, H.L. Fike, J.E. Shelton and T.K. Wiewiorowski, "Sulfur", *Encyclopedia of Chemical Technology*, Vol. 22, John Wiley & Sons, 1982; [a] p 78; [b] p 79; [c] p 97.

6) Walter Emrich, *Handbook of Charcoal Making*, D. Reidel Publishing Co., 1985; [a] p 13; [b] pp 14, 17.

7) R. Sassé, H. Homes, D. Hansen, W. Aungst, O. Doali, and R. Bowman, "Evaluation of Black Powder Produced by the Indiana Army Ammunition Plant", Vol. 11 *Proc. Int. Pyro. Semin.* Technical Report, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1986, p 489.

8) S. Wise, R.A. Sassé, and H.E. Homes, *Organic Substitutes for Charcoal in 'Black Powder' Type Pyrotechnic Formulations*, Technical Report, Ballistic Research Lab, Army Armament Research and Development Center, Aberdeen Proving Ground, MD, 1984.

9) R. A. Sassé, *Characterization of Maple Charcoal Used to Make Black Powder*, Ballistic Research Lab, Army Armament Research Development Center, Aberdeen Proving Ground, MD, 1983.

10) R. A. Sassé, "Characterization of Charcoal Used to Make Black Powder", *Proc. Int. Pyrotechnic Sem*., Vol. 9, 1984, p 471.

11) GOEX, Inc., P.O. Box 659, Doyline, LA, 71023-0659, USA; (318) 382-9300.

12) Kenneth Kosanke, Editor of *Journal of Pyrotechnics*, 1775 Blair Road, Whitewater, CO, 81527 USA, (970) 245-0692.

13) R. Sassé and J.E. Rose, "Comparison of Spherical and Ellipsoidal Form Functions for Evaluating Black Powder", *Proc. Int. Pyrotechnic Sem.*, Vol. 13, 1988, p 679.

14) John Uithol, Executive Vice President, National Muzzle Loading Rifle Association, Friendship, IN, USA; (812) 667-5131, advised the author in a private communication that some Black Powder rifle enthusiasts wish greater reproducibility of results in shooting. They therefore sieve purchased Black Powder to achieve a more uniform particle size distribution. The sieving is required not only because of the size distribution, which originates with the

purchased product, but also because of fracture in the can over time with jarring and dropping.

15) Hodgdon Powder Co. Inc., P.O. Box 2932, Shawnee Mission, KS, 66201, USA; (913) 362-9455.

16) Clean Shot Technology, Inc., P.O. Box 100, Whitewater, CO, 81527, USA; (970) 262-0100.

17) J.E. Rose, “Black Powder – A Modern Commentary – 1979”, *Proc. Symp. Explos. Pyrotech.* Vol. 10, 1979, p 6a-1.

18) Federal Judicial Center, *Reference Manual on Scientific Evidence*, West Publishing Co., 1993, p 163.

19) “Confronting the New Challenges of Scientific Evidence”, *Harv. L. Rev.*, Vol. 108, 1995, pp 1481–1539.

20) “In re Agent Orange”, Vol. 611 F. Supp. p 1223 (E.D.N.Y. 1985), aff’d, Vol. 818 F.2d p 187 (2d Cir. 1987), cert. denied, Vol. 487 U.S. p 1234, 1988.

21) L. Freedman and R. Sassé, “The Thermodynamics of Real and Unreal Black Powder”, *Proc. Int. Pyrotechnic. Sem.*, Vol. 9, 1984, pp 177–178. [Describes the manifestations of the variability of Black Powders. Interestingly the authors note that “Good analyses of Black Powder are rare; analyses of the charcoals used are even rarer.”]

22) “Regina v. Judith Theresa Ward” was heard in the Royal Courts of Justice in the Court of Appeal, Criminal Division on June 4, 1992 before Lord Justices Glidewell, Nolan and Steyn. The case is notorious for its exposure of inappropriate forensic practices by government scientists.

23) “The Prosecutor’s Duty of Disclose: From Brady to Agurs and Beyond”, *J. Crim. L. & Criminology*, Vol. 69, 1978, p 197.

24) “Giglio v. United States”, Vol. 405 U.S., 1972, p 150.

25) “Barbee v. Warden, Maryland Penitentiary”, Vol. 331 F.2d (4th Cir. 1964) p 842.

26) “United States v. Eley”, Vol. 335 F. Supp. (N.D.Ga. 1972) p 353.

27) “United States v. McCord”, Vol. 509 F.2d (D.C. Cir. 1974) p 334.

28) “United States v. Agurs”, Vol. 427 U.S., 1976; [a] p 97; [b] p 106.