STABLE ISOTOPES AND COURTS

James R. Ehleringer[*] and Scott M. Matheson, Jr.[**]

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INTRODUCTION

Forensic investigation and courtroom fact-finding seek to determine how seemingly identical evidence specimens are related or where certain evidence came from. For example, does the bullet removed from the victim match the ammunition belonging to the suspect? Do both of these recovered bombs share a common source? Where were these drugs grown or produced? Where was this counterfeit money made? Where was this unidentified body located prior to death?

To be more specific: Were the explosives seized separately from terrorist shoe bombers Richard Reid in 2001 and Saajid Badat in 2003 of common origin? Was natural or synthetic testosterone detected in the urine samples collected from world-class cyclist Floyd Landis during the 2006 Tour de France? What laboratory location may have produced the anthrax that was mailed in 2001 to various targets in the tense aftermath of the September 11 attacks?

Stable isotope ratio analysis was used in each of these investigations. In the shoe bomber case, Mr. Badat pleaded guilty before his trial began.[1] In the cycling case, the Court of Arbitration for Sport relied on stable isotope evidence to conclude that Mr. Landis should be banned from cycling for two years.[2] In the anthrax case, the suspected perpetrator committed suicide before the case was presented to a court.[3] The anthrax case will be used as an example in this Article.

Measuring the abundances of naturally occurring chemical stable isotopes can help answer forensic evidence questions. Quantitative measurements of stable isotopes have been used extensively in the fields of biology, chemistry, ecology, geology, and oceanography for decades. The extension of stable isotope analysis into forensic investigation and identification is more recent. Its presentation in the courtroom is inevitable. Judges and lawyers need to understand the utility and limitations of this technical measurement and potentially significant tool.

What do judges and lawyers need to know about stable isotope data? Is stable isotope evidence relevant? Reliable? Admissible? What should the proponent of stable isotope evidence be required to prove? What challenges to it should be made? How strong are factual claims based on this evidence? How can jurors evaluate it with fairness and understanding?

Rule 702 of the Federal Rules of Evidence and the landmark U.S. Supreme Court case of *Daubert v. Merrell Dow Pharmaceuticals, Inc.*,[4] assign judges the

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[1] *See* WOLFRAM MEIER-AUGENSTEIN, STABLE ISOTOPE FORENSICS: AN INTRODUCTION TO THE FORENSIC APPLICATION OF STABLE ISOTOPE ANALYSIS 169 (2010); Lizette Alvarez, *Briton, in Shift, Pleads Guilty in Bomb Plot*, N.Y. TIMES, Mar. 1, 2005, at A8.

[2] *See* Landis v. U.S. Anti-Doping Agency, CAS 2007/A/1394 (2008) (Ct. Arb. Sport), *available at* http://jurisprudence.tas-cas.org/sites/CaseLaw/Shared%20Documents/1394.pdf; Dale Robertson, *Landis Loses His Latest Doping Suspension Appeal*, HOUSTON CHRON., July 1, 2008, at 7.

[3] *See* Scott Shane, *F.B.I. Shuts Book on Anthrax Case Fatal to 5 in 2001*, N.Y. Times, Feb. 20, 2010, at A1.

[4] 509 U.S. 579 (1993).

duty to evaluate the reliability and validity of scientific evidence and expert testimony. To do so, judges and lawyers must become knowledgeable about scientific methods in general and about specific theories and techniques applicable to particular cases.

The purpose of this Article is to assist courts and counsel to understand measurements of stable isotopes and the admissibility issues this evidence presents.[5] It attempts to:

- explain stable isotope abundance measurement and its many potential forensic applications;
- identify the range of evidentiary claims that reasonably can be made about stable isotope evidence, both to show the powerful potential of this methodology but also its limitations;
- suggest the threshold presentation that proponents of stable isotope evidence should make and what judges should expect;
- offer questions that opponents of this evidence should raise and that judges should consider;
- analyze the reliability issues based on *Daubert* and other factors;
- describe the qualifications that should be required of an expert witness on stable isotope evidence; and
- propose the manner in which stable isotope evidence can be presented to the trier of fact so that it can be fairly understood.

After presenting background on stable isotope analysis and expert evidence admissibility standards, we apply admissibility requirements to this methodology. We consider the use of stable isotope analysis in the investigation of the anthrax attacks of 2001 to illustrate a specific application.[6] We urge courts to apply the rigorous reliability scrutiny to stable isotope analysis that already has been applied to DNA profiling evidence. Accordingly, this Article includes discussion comparing and contrasting stable isotope analysis with DNA identification evidence.

Our goal is to help judges, lawyers, and juries to evaluate stable isotope evidence in a manner that meets the high standards of scientific integrity and due process that our society should demand in resolving critical issues in the courts.

The recent National Academy of Sciences report on forensic science, *Strengthening Forensic Science in the United States: A Path Forward* ("NAS Report"),[7] underscores the importance of achieving this goal. Among its significant conclusions, the report states: "The bottom line is simple: In a number of forensic

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[5] "[I]f scientific insights are going to play a supportive role in the legal process, they must be expressed in a language that legal actors can understand." ROBIN FELDMAN, THE ROLE OF SCIENCE IN LAW 175 (2009).

[6] Professor Ehleringer participated with other scientists in applying stable isotope analysis in the Amerithrax case, the name given to the investigation of the 2001 anthrax attacks.

[7] NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD (2009) [hereinafter NAS REPORT].

science disciplines, forensic science professionals have yet to establish either the validity of their approach or the accuracy of their conclusions, and the courts have been utterly ineffective in addressing this problem."[8]

We seek a better bottom line for forensic use of stable isotope analysis. With solid research, strict adherence to protocols and standards, accurate reporting of results and within-specimen variance, and effective courtroom presentation, stable isotope analysis can contribute to the search for truth in our justice system.

I. BACKGROUND ON STABLE ISOTOPES AND FORENSIC APPLICATIONS

The scientific literature on stable isotope analysis is extensive. The following provides basic background information.

What is an isotope? Atoms of the same element having different numbers of neutrons are called isotopes. A unique characteristic of each chemical element is the number of protons in its nucleus. That number corresponds to the element's place on the Periodic Table of Elements. As examples, a hydrogen atom has one proton, a carbon atom has six protons, and an oxygen atom has eight protons. Atoms of the same element typically, though not always, have the same number of neutrons in their nuclei as they have protons. Some atoms of the same element have greater or fewer neutrons than the most common form of the element.[9]

Virtually all elements on the Periodic Table of Elements have multiple isotopes. We denote different isotopes by listing the number of protons and neutrons as a superscript to the left of the element's symbol. For example, most hydrogen atoms have one proton and no neutrons (= ^{1}H), but a few have one proton and one neutron (= ^{2}H); even fewer have one proton and two neutrons (= ^{3}H). As a second example, most carbon atoms have six protons and six neutrons (= ^{12}C), but other naturally occurring isotopes of carbon can have seven (= ^{13}C) or eight neutrons (= ^{14}C).

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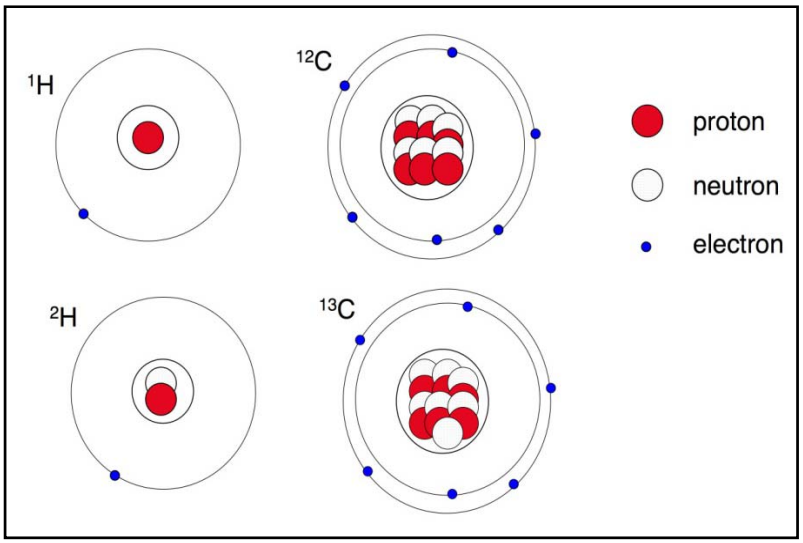
[8] *Id.* at 53.

[9] "[T]he nuclei of atoms are made up of various combinations of protons and neutrons, and . . . within atoms of a given element, the ratio of neutrons to protons may vary from isotope to isotope . . . ." Allen v. United States, 588 F. Supp. 247, 270 (D. Utah 1984), *rev'd on other grounds*, 816 F.2d 1417 (10th Cir. 1987), *cert. denied*, 484 U.S. 1004 (1988).



Light and heavy isotopes of hydrogen (left) and carbon (right) illustrate the presence of an additional neutron in the heavy isotope of the element.

Isotopes come in two forms: stable and radioactive. Isotopes that persist in their same elemental form are stable isotopes. That is, over time, these atoms will not change and will not decay into another element. Most elements on Earth are stable isotopes. In contrast, trace amounts of elements on Earth are radioactive. Radioactive isotopes are not stable and will decay over time from one element to another as parts of the nucleus leave the atom in a sequence of radioactive decay. The lifetime of radioactive elements may be as short as a few nanoseconds for laboratory-produced radioactive isotopes or as long as many billions of years (e.g., Rubidium-87 (^{87}Rb)). In between is the familiar example of ^{14}C dating, a powerful tool for dating materials that are in the age ranges of 300-50,000 years[10] or of 1-40 years.[11] Naturally occurring stable isotopes are the focus of this paper.

For an element, how are the abundances of stable isotopes expressed? As an introduction, the isotope abundances of an element can be expressed as percentages. Consider carbon: 98.89% of carbon is ^{12}C, while 1.11% is ^{13}C, and ^{14}C amounts to less than one ten-billionth of 1%. Lead is a more complicated

[10] *See* M. J. C. WALKER, QUATERNARY DATING METHODS 17–56 (2005); Minze Stuiver & Bernd Becker, *High-Precision Decadal Calibration of the Radiocarbon Time Scale, AD 1950-6000 BC*, 35 RADIOCARBON 35 (1993).

[11] *See* T. Nakamura et al., *Application of AMS ^{14}C Measurements to Criminal Investigations*, 272 J. RADIOANALYTICAL & NUCLEAR CHEMISTRY 327 (2007); Kirsty L. Spalding et al., *Age Written in Teeth by Nuclear Tests*, 437 NATURE 333 (2005); U. Zoppi et al., *Forensic Applications of ^{14}C Bomb-Pulse Dating*, 223 NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RES. 770 (2004).

example, with 52.4% of lead as ^{208}Pb, 22.1% as ^{207}Pb, 24.1% as ^{206}Pb, and 1.4% as ^{204}Pb.

Expressing abundance as a percentage provides only a "low-resolution" approximation of abundance. Instead, the preferred means of expressed natural abundances of stable isotopes is the ratio of the rare-to-common isotope forms (e.g., $^{2}H/^{1}H$, $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{18}O/^{16}O$, $^{87}Sr/^{86}Sr$, $^{204}Pb/^{208}Pb$). For the heavy elements in the Periodic Table of Elements (e.g., Sr and Pb), it is sufficient to describe abundance as the ratio of the rare-to-common isotope forms. However, for commonly analyzed light isotopes (e.g., H, C, N, O, Cl, S), the ratio of the rare-to-common isotope forms is not sufficient because the rare forms are rare enough that the ratio is usually less than 0.01. In response, the scientific community has adopted the "delta notation" (δ) to describe the isotope ratios of light elements. Here, the ratio of the heavy-to-light stable isotopes of a sample (R_{sample}) is compared to the equivalent ratio of an internationally recognized standard ($R_{standard}$) as

$$\delta(‰) = (R_{sample} - R_{standard})/ R_{standard}) \bullet 1000‰$$

where ‰ (per mil) is interpreted as the difference, in parts per thousand, between the sample and the international reference standard. Per mil is per thousand, which is the same as ten times percent (parts per hundred).

The δ value of an international reference standard is defined as 0‰. For hydrogen, we express the delta notation hydrogen isotope ratio as $\delta^{2}H$, for carbon as $\delta^{13}C$, and so forth. Note that the delta notation isotope ratio value may have a positive or negative value, depending on how much of the rare isotope is in the sample versus the standard. International standards are available through the National Institute of Standards and Technology (NIST), which is part of the U.S. Department of Commerce, and through the International Atomic Energy Agency (IAEA) in Vienna, Austria.

Laboratories create working reference materials (also known as working standards) for daily analytical uses through comparisons of working reference materials with international standards. Because the international standards are precious materials and available only in limited quantities, it is an accepted practice to rely on calibrated laboratory-based or association-based working reference materials. Laboratories exchange their working reference materials with other laboratories to verify that the materials have a correct value relative to the international standards. Round-robin exchange tests among laboratories (also known as ring tests) are also a common practice to ensure that analyses conducted in one laboratory will produce the same results when performed in a different laboratory.

How are stable isotope ratios measured? High-precision measurements are required because the differences in stable isotope ratio values among samples can be small. Light elements in the Periodic Table of Elements, such as H, C, N, O, Cl,

and S, are measured on an isotope ratio mass spectrometer (IRMS).[12] There are other established and emerging techniques for measuring isotopic variability in nature. For H and O isotopes in water[13] or C isotopes in carbon dioxide,[14] stable isotope ratios can also be measured with laser spectroscopy.

For some applications, isotopic variability can be measured by nuclear magnetic resonance (NMR) techniques, often referred to as *site-specific natural isotope fractionation* (SNIF-NMR). Strictly speaking, SNIF-NMR does not measure isotope ratios but does measure natural isotopic variability within molecules in liquids, and it is most commonly applied to the detection of adulteration in foods.[15] Traditional structural or organic mass spectrometer (MS) approaches will not provide the accuracy required for a high-precision isotope ratio measurement.

For both IRMS and laser-spectroscopy measurement methods, the sample is converted into a gas, and the different isotopes in the gases are measured in separate detectors. With IRMS, other instruments are often coupled in front of the IRMS to convert the sample from its original form into the gas, which is measured in a continuous analytical process. Quality-control samples with a known isotopic composition are analyzed before and after the sample is analyzed to ensure the long-term accuracy of an observation.[16] For heavy elements in the Periodic Table of Elements, such as Sr and Pb, the samples are measured on a thermal ionization

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[12] *See* MEIER-AUGENSTEIN, *supra* note 1, at 65–142; Herbert Budzikiewicz & Ronald D. Grigsby, *Mass Spectrometry and Isotopes: A Century of Research and Discussion*, 25 MASS SPECTROMETRY REV. 146 (2006); Zeland Muccio & Glen P. Jackson, *Isotope Ratio Mass Spectrometry*, 134 ANALYST 213 (2009).

[13] *See* Willi A. Brand et al., Letter to the Editor, *Cavity Ring-Down Spectroscopy Versus High-Temperature Conversion Isotope Ratio Mass Spectrometry; A Case Study on* δ^2H *and* $\delta^{18}O$ *of Pure Water Samples and Alcohol/Water Mixtures*, 23 RAPID COMM. MASS SPECTROMETRY 1879 (2009).

[14] *See* Ed. H. Wahl et al., *Applications of Cavity Ring-Down Spectroscopy to High Precision Isotope Ratio Measurement of* $^{13}C/^{12}C$ *in Carbon Dioxide*, 42 ISOTOPES ENVTL. & HEALTH STUD. 21 (2006).

[15] *See* Elsa Caytan et al., *Accurate Quantitative* ^{13}C *NMR Spectroscopy: Repeatability over Time of Site-Specific* ^{13}C *Isotope Ratio Determination*, 79 ANALYTICAL CHEMISTRY 8266 (2007); Gilles G. Martin et al., *Detection of Added Beet Sugar in Concentrated and Single Strength Fruit Juices by Deuterium Nuclear Magnetic Resonance (SNIF-NMR Method): Collaborative Study*, 79 J. ASS'N ANALYTICAL CHEMISTS INT'L 917 (Jul.-Aug. 1996); Gilles G. Martin et al., *Interpretation of Combined* ^2H *SNIF/NMR and* ^{13}C *SIRA/MS Analyses of Fruit Juices to Detect Added Sugar*, 79 J. ASS'N ANALYTICAL CHEMISTS INT'L 62 (Jan.-Feb. 1996) [hereinafter Martin et al., *Interpretation of Combined*]; Freddy Thomas & Eric Jamin, ^2H *NMR and* ^{13}C*-IRMS Analyses of Acetic Acid from Vinegar,* ^{18}O*-IRMS Analysis of Water in Vinegar: International Collaborative Study Report*, 649 ANALYTICA CHIMICA ACTA 98 (2009).

[16] *See* James R. Ehleringer et al., *Spatial Considerations of Stable Isotope Analyses in Environmental Forensics*, *in* ISSUES IN ENVTL. SCI. AND TECH., NO. 26 – ENVIRONMENTAL FORENSICS 36, 39–40 (R.E. Hester & R.M. Harrison eds., 2008). [hereinafter Ehleringer et al., *Spatial Considerations*].

mass spectrometer (TIMS) or a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS).[17]

Stable isotope analyses can be applied to samples that consist of the entire organism or mixture (bulk level), specific compounds within an organism or within a mixture (compound-specific level), and specific locations within a complex molecule (position-specific or intramolecular level), reflecting increasing levels of chemical specificity. Samples are most commonly measured at the bulk level; that is, the isotope ratio is determined without chemical separation in a usually complex chemical mixture. Compound-specific isotope analysis is required in some contexts. For instance, it is used to establish whether an athlete's testosterone is naturally produced by the body or is instead a supplemental hormone taken to stimulate athletic performance. Finally, intramolecular isotope ratios, often determined by SNIF-NMR, report on isotopic structure within molecules.

What is an "isotope fingerprint"? "Isotope fingerprint" is a commonly used term in the isotope field to describe combinations of stable isotope ratio observations from a particular specimen. It is an imperfect metaphor because the isotopic characteristics of elements in a sample are not marks or impressions left at a crime scene, and they are analyzed very differently than fingerprints.[18] Nonetheless, the term is used to describe the stable isotope ratios of the chemical elements in a sample taken from a particular specimen, and they can be compared to the observations from one or more other specimens.

Why are stable isotope ratios useful in forensic identification? The various forensic identification techniques in criminal investigation and prosecution share the goal "of matching a sample associated with the defendant (or victim) to a sample found at the crime scene."[19] Comparable applications are made in civil and administrative proceedings as well. Forensic identification is based on differentiation. One challenge that can arise is the ability to distinguish between specimens that are chemically identical. That is, going beyond traditional chemical identification approaches, is it possible to distinguish between two or more specimens that are known to contain the same compound (e.g., the same explosive compound or the same sugar)? Stable isotope ratio analysis may help by providing an additional piece of information about the specific compounds.

If two chemically identical specimens share a common origin or relationship, then we would expect these compounds to have similar stable isotope ratios for

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[17] *See* Andrew J. Walder, *Advanced Isotope Ratio Mass Spectrometry II: Isotope Ratio Measurement by Multiple Collector Inductively Coupled Plasma Mass Spectrometry*, *in* I.T. PLATZNER, MODERN ISOTOPE RATIO MASS SPECTROMETRY (1997); J. Thomas Brenna et al., *High-Precision Continuous-Flow Isotope Ratio Mass Spectrometry*, 16 MASS SPECTROMETRY REVIEWS 227 (1997).

[18] *See* Alexandra J. Roberts, *Everything New Is Old Again: Brain Fingerprinting and Evidentiary Analogy*, 9 YALE J.L. & TECH. 234, 242–56 (2007) (arguing that analogizing novel evidence to more-established forms can hinder understanding of the former).

[19] *See* Margaret A. Berger, *Expert Testimony in Criminal Proceedings: Questions* Daubert *Does Not Answer*, 33 SETON HALL L. REV. 1125, 1125 (2003).

each of the elements in the compound. The source of a sample may be based on production considerations or on geographical location.[20] If a substance of unknown origin appears to be isotopically the same as a substance of known origin, it is at least possible and perhaps probable that the unknown substance and the known substance have the same origin.[21] If the unknown substance and the known substance are different isotopically, then they likely have different origins—geographical origin and/or production method—unless one of the two specimens was treated in such a way as to cause its isotope ratio to change.

Isotope measurement is therefore used to determine whether a sample or specimen is excluded from or consistent with a known source and perhaps even to reach a conclusion that it is a highly probable match with a known source. Stable isotope analysis can be used to reinforce or corroborate other supporting information. It can be used to distinguish among or eliminate other specimens as possibly related to the specimen of interest.

The relative amounts of heavy and light stable isotopes for a given element vary in nature based on physical and biological processes.[22] This naturally occurring variation allows for forensic identification.[23] The ratios may vary based on origin, including geographic location,[24] thereby allowing analysis of whether a sample containing a particular chemical came from a particular location. Ratios also can vary as a result of adulteration, in which chemically similar compounds are substituted for one another, such as substituting a cheaper compound for a more expensive compound.[25] For any given unknown substance, there may be

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[20] *See* John I. Thornton & Joseph L. Peterson, *The General Assumptions and Rationale of Forensic Identification, II. Scientific Issues – Introduction*, *in* 4 MODERN SCIENTIFIC EVIDENCE—THE LAW AND SCIENCE OF EXPERT TESTIMONY 57, 69–70 (David L. Faigman et al. eds., 2009–10).

[21] *See* Thornton & Peterson, *supra* note 20, at 66 ("[I]ndividualization . . . can be achieved only in a probabilistic sense, of reducing uncertainty to the smallest possible amount."); Michael J. Saks & Jonathan J. Koehler, *The Individualization Fallacy in Forensic Science Evidence*, 61 VAND. L. REV. 199, 208–14 (2008) (concluding evidence does not support unique individualization).

[22] *See* ZACHARY SHARP, PRINCIPLES OF STABLE ISOTOPE GEOCHEMISTRY 7 (2006); Gabriel J. Bowen et al., *Isoscapes to Address Large-Scale Earth Science Challenges*, 90 EOS 109 (2009); Wolfram Meier-Augenstein & Ray H. Liu, *Forensic Applications of Isotope Ratio Mass Spectrometry*, *in* ADVANCES IN FORENSIC APPLICATIONS OF MASS SPECTROMETRY 149, 151-52 (Jehuda Yinon ed., 2004).

[23] *See* James R. Ehleringer et al., *Forensic Science Applications of Stable Isotope Ratios*, *in* FORENSIC ANALYSIS ON THE CUTTING EDGE: NEW METHODS FOR TRACE EVIDENCE ANALYSIS 399, 401–05 (Robert D. Blackledge ed., 2007) [hereinafter Ehleringer et al., *Applications*]; Meier-Augenstein & Liu, *supra* note 22, at 150–53; *see generally* MEIER-AUGENSTEIN, *supra* note 1.

[24] *See* Jason B. West et al., *Stable Isotopes as One of Nature's Ecological Recorders*, 21 TRENDS IN ECOLOGY & EVOLUTION 408 (2006).

[25] *See* R. Fügel et al., *Quality and Authenticity Control of Fruit Purées, Fruit Preparations and Jams—A Review*, 16 TRENDS IN FOOD SCI. & TECH. 433 (2005); Jonathan W. White, *Internal Standard Stable Carbon Isotope Ratio Method for Determination of C4*

more than one chemical element to choose from for stable isotope analysis, enabling a higher level of confidence with regard to the conclusion.

What are the forensic applications of stable isotope analysis? The ability of stable isotope analysis to match or distinguish evidence specimens points to three key applications. The first is to determine whether two specimens have the same isotopic composition and therefore may have a common origin. This application describes the classic forensic identification task of comparing an unknown sample or questioned item from a crime scene to a known sample or exemplar taken from a subject or victim. The first step is to compare the items and determine whether they appear to match. If they do, the second step is to determine the probability that the items came from the same source.[26] The reference and test materials that are analyzed are often called *associative evidence*.[27]

The second application is to ascertain the expected stable isotope ratios for specimens from a given location (e.g., the origin or authenticity of a food product) or a production method (e.g., an explosive compound). Then the stable isotope ratio of a sample of unknown origin can be compared to the collection of known observations from the given location, such as data contained in a database of authentic observations.

The third application is to determine a probable geographic source location of an unknown specimen.[28] These *source attribution* applications enable forensic assignment of evidentiary material to a geographic region of origin by comparing the isotopic composition of the sample to geospatial mapping of predicted stable isotope ratios.[29] Maps have been developed for the predicted isotopic composition of water throughout the world and serve as a principal basis for geographic identification of a wide range of stable isotope values in plants, animals, and microbes based on water as a substrate.[30]

What are some examples of stable isotope ratio analysis applications to topics of forensic interest? Some of the many possible examples include:

- distinguishing between real and adulterated food products through carbon isotope analyses;[31]

Plant Sugars in Honey: Collaborative Study, and Evaluation of Improved Protein Preparation Procedure, 75 J. ASS'N ANALYTICAL CHEMISTS INT'L 543 (1992); Jonathan W. White et al., *Stable Carbon Isotope Ratio Analysis of Honey: Validation of Internal Standard Procedure for Worldwide Application*, 81 J. ASS'N ANALYTICAL CHEMISTS INT'L 610 (1998).

[26] *See* Saks & Koehler, *supra* note 21, at 199.

[27] *See* Thornton & Peterson, *supra* note 20, at 62.

[28] *See* Ehleringer et al., *Applications*, *supra* note 23, at 404–05; Ehleringer et al., *Spatial Considerations*, *supra* note 16, at 37, 42–50.

[29] *See* Ehleringer et al., *Spatial Considerations*, *supra* note 16, at 40–50.

[30] *See id.* at 40–43.

[31] *See* MEIER-AUGENSTEIN, *supra* note 1, at 37–42; Ehleringer et al., *Applications*, *supra* note 23, at 406–08; Meier-Augenstein & Liu, *supra* note 22, at 163–65.

- distinguishing between natural and manufactured fertilizers associated with the production of natural foods;[32]
- distinguishing between vegetable products grown with natural versus manufactured fertilizers;[33]
- distinguishing between fruit juices that are natural versus juices that are adulterated by sugar substitutes like high fructose corn syrup;[34]
- distinguishing between real versus manufactured flavorings, such as vanillin;[35]
- determining the region or manufacturer of illicit drug samples;[36]
- determining the source of precursor materials for the manufacture of methamphetamine;[37]
- matching the isotopic composition of an organism with its food and water diet, given the influence of variations in the isotopic composition of water at various geographic locations around the world;[38]
- ascertaining the geographic origins or movements and dietary patterns of individuals based on the hydrogen, oxygen, carbon, and nitrogen isotope analyses of human hair, bones, fingernails, and/or teeth;[39]

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[32] *See* Alison S. Bateman & Simon D. Kelly, *Fertilizer Nitrogen Isotope Signatures*, 43 ISOTOPES ENVTL. & HEALTH STUD. 237 (2007).

[33] *See* Karyne M. Rogers, *Nitrogen Isotopes as a Screening Tool to Determine the Growing Regimen of Some Organic and Nonorganic Supermarket Produce from New Zealand*, 56 J. AGRIC. & FOOD CHEMISTRY 4078 (2008).

[34] *See* Michael Antolovich et al., *Detection of Adulteration in Australian Orange Juices by Stable Carbon Isotope Ratio Analysis (SCIRA)*, 49 J. AGRIC. & FOOD CHEMISTRY 2623 (2001).

[35] *See* Fabienne F. Bensaid et al., *Authentication of Natural Vanilla Flavorings: Isotopic Characterization Using Degradation of Vanillin into Guaiacol*, 50 J. AGRIC. & FOOD CHEMISTRY 6271 (2002).

[36] *See* John Casale et al., *Stable Isotope Analyses of Heroin Seized from the Merchant Vessel Pong Su*, 51 J. FORENSIC SCI. 603 (2006); Ehleringer et al., *Applications*, *supra* note 23, at 408–11; Ehleringer et al., *Spatial Considerations*, *supra* note 16, at 49–50; Meier-Augenstein & Liu, *supra* note 22, at 168–70.

[37] *See* Michael Collins et al., *$\delta^{13}C$, $\delta^{15}N$ and $\delta^{2}H$ Isotope Ratio Mass Spectrometry of Ephedrine and Pseudoephedrine: Application to Methylamphetamine Profiling*, 23 RAPID COMM. MASS SPECTROMETRY 2003 (2009).

[38] *See* Ehleringer et al., *Applications*, *supra* note 23, at 411–13; Helen W. Kreuzer-Martin et al., *Microbe Forensics: Oxygen and Hydrogen Stable Isotope Ratios in Bacillus Subtilis Cells and Spores*, 100 PNAS J. 815 (2003) [hereinafter Kreuzer-Martin et al., *Microbe Forensics*].

[39] *See* James R. Ehleringer et al., *A Framework for the Incorporation of Isotopes and Isoscapes in Geospatial Forensic Investigations*, *in* ISOSCAPES: UNDERSTANDING MOVEMENT, PATTERN, AND PROCESS ON EARTH THROUGH ISOTOPE MAPPING 357, 369–82 (Jason B. West et al. eds., 2009) [hereinafter Ehleringer et al., *Isoscapes*]; Ehleringer et al., *Applications*, *supra* note 23, at 413–14; Ehleringer et al., *Spatial Considerations*, *supra* note 16, at 44–47.

- analyzing the isotopic composition of lead bullets and primers to ascertain which ammunition and/or firearm caused a particular gunshot entry;[40]
- predicting the geographic origin and movement of humans based on the stable isotope composition of their scalp hair;[41]
- tracing the origin of counterfeit currency based on isotopic differences arising from the cotton used to produce the security paper;[42] and
- identifying the starting materials or manufacturing processes by comparing the differentiated isotopic characteristics of organic peroxides in improvised explosives used by terrorists.[43]

How precise and accurate can stable isotope ratio analysis be in identifying the source of an evidence sample? The resolving power of stable isotope ratio analysis can vary depending on many factors, including (a) the precision of the analytical measurement, (b) the heterogeneity within a sample or among a common population, and (c) the nature and quality of the reference database. The results of this forensic method range from matching a specimen to a specific source with a high level of confidence to linking a sample only with a large geographic region and perhaps even more than one region.

This point can be understood through the example of recent research on the potential for use of strontium isotope ratios ($^{87}Sr/^{86}Sr$) to determine the geographic origins of marijuana, such as seized samples.[44] Strontium isotopes were considered in region-of-origin analyses, independent of the use of hydrogen isotopes to predict region of origin. Strontium isotope ratios from plants cultivated in seventy-nine counties throughout the United States were compared with the ratios expected from bedrock-based ages contained in U.S. Geological Survey data.[45]

The results showed that the marijuana strontium isotope ratios retained a primary geologic signal that would facilitate geologic sourcing.[46] But how precise the sourcing can be in a particular case will vary. A second approach is to predict region of origin using hydrogen isotopes. A survey of hydrogen isotope ratios of

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[40] *See* Arie Zeichner et al., *Application of Lead Isotope Analysis in Shooting Incident Investigations*, 158 FORENSIC SCI. INT'L 52 (2006).

[41] *See* James R. Ehleringer et al., *Hydrogen and Oxygen Isotope Ratios in Human Hair Are Related to Geography*, 105 PNAS J. 2788 (2008).

[42] *See* Ehleringer et al., *Applications*, *supra* note 23, at 415–16; Ehleringer et al., *Spatial Considerations*, *supra* note 16, at 42–44.

[43] *See* Sarah J. Benson et al., *Forensic Analysis of Explosives Using Isotope Ratio Mass Spectrometry (IRMS)—Preliminary Study on TATP and PETN*, 49 SCI. & JUST. 81 (2009). For a recent overview of forensic applications of stable isotope analysis, see MEIER-AUGENSTEIN, *supra* note 1, at 145–221.

[44] *See* Janet M. Hurley et al., *Stable Isotope Models to Predict Geographic and Cultivation Conditions of Marijuana*, 50 SCI. & JUST. 86 (2010); Jason B. West et al., *The Stable Isotope Ratios of Marijuana. II. Strontium Isotopes Relate to Geographic Origin*, 54 J. FORENSIC SCI. 1261 (2009).

[45] *See* West, *supra* note 44, at 1262–63.

[46] *See id.* at 1263–67.

marijuana from all fifty states was compared to maps of the water isotopes that are known to exhibit a coherent, repeatable pattern of differences across the United States.[47] Two independently measured stable isotopes can be used to predict region of origin. A Venn-diagram space can represent the region of origin with the highest probability of being the source region for the material of interest.

The study showed that some regions would be indistinguishable without more detailed information about the particular regions. On the other hand, where the strontium bedrock and hydrogen water isotope values vary considerably between two locations, isotope ratio analysis may be able to predict whether a specimen originated from one of two possible locations with a high degree of confidence.[48] This example not only illustrates the isotope method's range of precision in resolving the source of an unknown sample, but also shows how information from other investigative techniques (in the example here, narrowing the possible source locations to two) can influence that range. This example also shows the ability of the technique to address questions about the distribution of controlled substances, such as the origins of marijuana seized in different regions of the United States.[49]

What are the limitations of stable isotope ratio analysis? The principal limitations are both unique to stable isotope analysis and similar to other scientific applications. Five examples illustrate these points.

(1) In some cases, the heterogeneity within a sample results in a variance that is large enough to make it difficult to distinguish among samples that have similar stable isotope ratios.[50]

(2) As in any laboratory analysis in which there are multiple steps in a sequence, each step in the preparation, isolation, and purification of a specimen prior to its analysis can decrease the overall precision, even though the precision at any one step in the process can be high. This concern applies to other forensic identification techniques as well.[51]

(3) The quality of isotopic databases can vary based on the availability of authentic materials, the history and preservation of materials prior to analyses, and the confidence as to the exact origins of the materials. For some elements at some locations, the databases can be substantially

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[47] For various discussions of this study, see Gabriel J. Bowen & Justin Revenaugh, *Interpolating the Isotopic Composition of Modern Meteoric Precipitation*, 39 WATER RES. RESEARCH 1299 (2003); Gabriel J. Bowen et al., *Stable Hydrogen and Oxygen Isotope Ratios of Bottled Waters of the World*, 19 RAPID COMM. MASS SPECTROMETRY 3442 (2005); Gabriel J. Bowen et al., *Stable Isotope Ratios of Tap Water in the Contiguous United States*, 43 WATER RES. RESEARCH W03419 (2007) [hereinafter Bowen et al., *Tap Water*].

[48] *See* West, *supra* note 44, at 1267.

[49] *See* Janet M. Hurley et al., *Tracing Retail Cannabis in the United States: Geographic Origin and Cultivation Patterns*, 21 INT'L J. DRUG POL'Y 222 (2010).

[50] *See* Ehleringer et al., *Applications*, *supra* note 23, at 405.

[51] *See* ERICA BEECHER-MONAS, EVALUATING SCIENTIFIC EVIDENCE—AN INTER-DISCIPLINARY FRAMEWORK FOR INTELLECTUAL DUE PROCESS 101 (2007).

complete and very reliable. For other elements and other locations, the databases may not be as extensive.

(4) The limits of valid statistical analysis and sampling can affect the certainty levels of this methodology. It is important that expert witnesses in this field avoid the exaggerated testimony that has been criticized in other fields. As the NAS Report explained: "The insistence by some forensic practitioners that their disciplines employ methodologies that have perfect accuracy and produce no errors has hampered efforts to evaluate the usefulness of the forensic science disciplines."[52]

(5) Issues of contamination and degradation of samples as well as accurate evidence handling and storage apply to stable isotope samples, just as they do to other forensic sample evidence.

We will explore the precision and limitations of stable isotope ratio analysis further in our later discussion of the reliability considerations regarding this evidence.

II. ADMISSIBILITY STANDARDS AND STABLE ISOTOPE RATIO ANALYSIS

Although stable isotope ratio analysis has been used to facilitate investigations, it has not yet become a frequent source of expert evidence in the courtroom. We expect that it will. This Part discusses rules of admissibility applicable to stable isotope ratio analysis, with particular emphasis on the issues of scientific validity under the *Daubert* framework. We then turn to application of these standards to stable isotope ratio analysis. The goal is to develop the analytical framework to aid courts and litigants in framing and addressing the issues of admissibility under "the exacting standards of reliability such evidence must meet."[53]

A. The Federal Rules and Daubert

The admissibility of expert testimony depends on two key elements: the test used to evaluate the proposed evidence and the judge's role in applying that test.[54] Although both continue to differ from state to state, the Federal Rules of Evidence on expert testimony and the U.S. Supreme Court's interpretation of what those rules require have substantially shaped federal and state evidence law. Many states have adopted some version of the *Daubert* reliability standard.[55] This Article uses

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[52] NAS REPORT, *supra* note 7, at 47.

[53] Weisgram v. Marley Co., 528 U.S. 440, 455 (2000).

[54] *See* 1 MODERN SCIENTIFIC EVIDENCE—THE LAW AND SCIENCE OF EXPERT TESTIMONY 3–4 (David L. Faigman et al. eds., 2009–10 ed.).

[55] *See, e.g.*, People v. Shreck, 22 P.3d 68, 70 (Colo. 2001); M.G. Bancorp., Inc. v. Le Beau, 737 A.2d 513, 521 (Del. 1999); Gilbert v. DiamlerChrysler Corp., 685 N.W.2d 391, 407–09 (Mich. 2004); E.I. du Pont de Nemours and Co., Inc. v. Robinson, 923 S.W.2d 549, 554–58 (Tex. 1995); *see also* David E. Bernstein & Jeffrey D. Jackson, *The* Daubert *Trilogy in the States*, 44 JURIMETRICS 351, 357–61 (2004) (discussing states that have

the *Daubert* framework for admission of expert testimony in federal court to analyze stable isotope ratio evidence.

As the following recounts, in federal courts the responsibility for threshold evaluation of the validity of scientific evidence is placed on the judges, who make the admissibility decision. If scientific evidence is admitted, the trier of fact determines its weight. Current evidence law and practice leaves the search for and selection of experts primarily to the parties and anticipates that experts will testify in an adversarial system through which their views may be challenged by opposing experts and on cross-examination as biased and unreliable.[56] The legal framework for the admission of expert testimony in federal trials is found primarily in Federal Rule of Evidence 702, but other Federal Rules also play an important role. Rules 104(a), 702, 703, 706, and 403 will be addressed here.[57]

1. Rule 104(a)

The Federal Rules governing expert testimony divide responsibility between the judge and jury. The judge is responsible for determining the admissibility of expert testimony, including the qualifications of the expert witness and the helpfulness and reliability of the evidence. This is reflected in Rule 104(a), which provides:

> Preliminary questions concerning the qualification of a person to be a witness, the existence of a privilege, or the admissibility of evidence shall be determined by the court, subject to the provisions of subdivision (b) [concerning conditional admissions]. In making its determination it is not bound by the rules of evidence except those with respect to privileges.

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adopted the *Daubert* standard); Alice B. Lustre, *Post*-Daubert *Standards for Admissibility of Scientific and Other Expert Evidence in State Courts*, 90 A.L.R. 5th 453 (2001; updated 2010).

[56] *See* David E. Bernstein, *Expert Witnesses, Adversarial Bias, and the (Partial) Failure of the* Daubert *Revolution*, 93 IOWA L. REV. 451, 464–67 (2008). Professor Bernstein argues that *Daubert*'s primary failing is overreliance on the adversary system to weed out weak science. *Id.* at 456 (quoting Peter J. Neufield, *The (Near) Irrelevance of* Daubert *to Criminal Justice and Some Suggestions for Reform*, 95 AM. J. PUB. HEALTH 107, 110 (2005)).

[57] Federal Rules of Evidence 704 and 705 address expert testimony on an ultimate issue and disclosure of facts or data underlying an expert opinion, respectively. Although these rules may be pertinent to expert stable isotope testimony in a particular case, they are not central to the discussion presented here.

The proponent of expert evidence must establish these matters by a preponderance of proof.[58] Trial judges have the discretion to make Rule 104(a) determinations based on briefs and other materials submitted before trial, a pretrial evidentiary hearing, or testimony presented at trial.[59] Courts often dispense with a pretrial *Daubert* hearing if the expert evidence is well established and no novel challenge is raised.[60] If the judge determines that the expert witness is qualified to testify and that the other expert evidence requirements are met, then the evidence is admitted, and the jury's role is to evaluate the weight of that evidence.[61]

2. Rule 702

Federal Rule of Evidence 702 provides:

> If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.

The rule calls for consideration of scientific evidence based on three criteria: relevancy, qualifications, and reliability. The reliability component can in turn be divided into three issues: sufficiency of the facts or data, reliability of the principles and methods, and proper application of the principles and methods. With respect to the principles and methods, the reliability of the theory (principles) and the technique (methods) are distinct issues.[62]

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[58] *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 592 n.10 (1993); Bourjaily v. United States, 483 U.S. 171, 175–76 (1987); Lewis v. CITGO Petroleum Corp., 561 F.3d 698, 705 (7th Cir. 2009).

[59] *See* Millenkamp v. Davisco Foods Int'l, Inc., 562 F.3d 971, 979 (9th Cir. 2009); *In re* Scrap Metal Antitrust Litig., 527 F.3d 517, 532 (6th Cir. 2008); United States v. Kenyon, 481 F.3d 1054, 1061 (8th Cir. 2007).

[60] *See* United States v. Pena, 586 F.3d 105, 111 n.4 (1st Cir. 2009).

[61] *See* Bourjaily v. United States, 483 U.S. 171, 175 (1987); United States v. Iron Hawk, 612 F.3d 1031, 1039 (8th Cir. 2010); Diestel v. Hines, 506 F.3d 1249, 1268–69 (10th Cir. 2007); Quiet Tech. DC-8, Inc. v. Hurel-Dubois UK Ltd., 326 F.3d 1333, 1341 (11th Cir. 2003); Romano v. State, 909 P.2d 92, 112 (Okla. Crim. App. 1995).

[62] *See* PAUL C. GIANNELLI & EDWARD J. IMWINKELRIED, 1 SCIENTIFIC EVIDENCE 2 (4th ed. 2007).

(a) Relevancy

The "assist the trier of fact" language of Rule 702 is sometimes referred to as a "helpfulness" standard and is regarded as a relevance test for expert testimony.[63] As the *Daubert* Court noted, Rule 702's reference to "assist the trier of fact" "goes primarily to relevance."[64] Even if scientifically valid, the expert testimony must "fit"—it must relate to a disputed issue in the case.[65] This test is worded less rigorously than the "beyond the ken" standard that many courts applied before the Federal Rules were adopted.[66] The "beyond the ken" test only allowed expert testimony that would provide information which an ordinary person would not otherwise know or understand.[67] The "assist" or "helpfulness" threshold is commensurate with and complementary to the general relevance standard of Rule 401, which asks whether evidence makes a fact of consequence to the case more or less probable.[68]

(b) Qualifications

Experts must be qualified to testify. Rule 702 provides that an expert witness can be qualified "by knowledge, skill, experience, training, or education."[69] This language encompasses a wide array of experts who have developed their expertise through a variety of means, which suggests that courts can approach the qualification issue with flexibility.[70] For scientific testimony, the conventional approach is to scrutinize an expert's credentials, training, and experience.[71] Under

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[63] *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 591 (1993); FED. R. EVID. 702 advisory committee's note.

[64] *Daubert*, 509 U.S. at 591.

[65] *See id.* at 591–92.

[66] *See* United States v. Joyce, 511 F.2d 1127, 1131 (9th Cir. 1974) ("To warrant the use of expert testimony . . . the subject of the inference must be so distinctively related to some science, profession, business or occupation as to be beyond the ken of the average layman.").

[67] *See, e.g.*, Jenkins v. United States, 307 F.2d 637, 643 (D.C. Cir. 1962).

[68] FED. R. EVID. 401 ("'Relevant evidence' means evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than it would be without the evidence."). Courts have justified exclusion of proposed expert evidence as not helpful under Rule 702 if it falls within the jury's "common knowledge." *See* Persinger v. Norfolk & W. Ry. Co., 920 F.2d 1185, 1188 (4th Cir.1990); Mueller v. Auker, No. CIV 04-399-S-BLW, 2010 WL 2265867, at *3 (D. Idaho June 10, 2010); Meemic Ins. Co. v. Hewlett-Packard Co., No. 09-10155, 2010 WL 1949750, at *11-12 (E.D. Mich. May 13, 2010).

[69] FED. R. EVID. 702.

[70] *See* Watkins v. Telsmith, Inc., 121 F.3d 984, 988 (5th Cir. 1997); Raymond v. Raymond Corp., 938 F.2d 1518, 1526 (1st Cir. 1991).

[71] *See* United States v. Parra, 402 F.3d 752, 758 (7th Cir. 2005).

Rule 104(a), the judge must determine whether the proposed expert is qualified to present the proffered testimony. The jury can evaluate the relative strength of each expert's qualifications and credibility.[72]

(c) Reliability

The reliability determination is based on the U.S. Supreme Court's decision in *Daubert*, which determined "the proper standard for admission of expert testimony"[73] under Federal Rule of Evidence 702. The case was decided in the context of growing concern and controversy over the perceived flood of "junk science" admitted in courtrooms.[74]

The *Daubert* Court agreed that adoption of the Federal Rules of Evidence superseded "the dominant standard for determining the admissibility of novel scientific evidence at trial"[75]—the 70-year-old "general acceptance" test based on *Frye v. United States*.[76] Under the *Frye* test, scientific evidence "must be sufficiently established to have gained general acceptance in the particular field in which it belongs."[77]

At the time of *Daubert*, Rule 702 read: "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise." The Court found nothing in this language or the rule's drafting history to establish "general acceptance" as the exclusive test for admissibility.[78] It did find in the rules that "the trial judge must ensure that any and all scientific testimony or evidence admitted is not only relevant, but reliable."[79] Justice Blackmun, writing for the Court, found the basis for this obligation mainly in Rule 702, which requires "that an expert's testimony pertain to 'scientific knowledge,'" a term that "establishes a standard of evidentiary reliability."[80]

Rule 702 and *Daubert* shifted responsibility for determining whether new scientific and technological innovation should be admitted as courtroom evidence

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[72] *See In re* Scrap Metal Antitrust Litig., 527 F.3d 517, 529–31 (6th Cir. 2008); Diestel v. Hines, 506 F.3d 1249, 1268–69 (10th Cir. 2007).

[73] Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 585 (1993).

[74] *See* PETER HUBER, GALILEO'S REVENGE: JUNK SCIENCE IN THE COURTROOM 2–6 (1991); David L. Faigman et al., *Check Your Crystal Ball at the Courthouse Door, Please: Exploring the Past, Understanding the Present, and Worrying about the Future of Scientific Evidence*, 15 CARDOZO L. REV. 1799, 1811 (1994).

[75] *Daubert*, 509 U.S. at 585–89.

[76] Frye v. United States, 293 F. 1013, 1014 (1923).

[77] *Id.*

[78] *Daubert*, 509 U.S. at 588–89.

[79] *Id.* at 589.

[80] *Id.* at 590.

from the scientists to the judges.[81] Justice Blackmun stressed the "gatekeeping role" of the trial judge to determine whether the expert will testify about (1) scientific knowledge that (2) will assist the trier of fact to understand or determine a fact in issue.[82] He wrote, "We are confident that federal judges possess the capacity to undertake this review."[83] He pointed to Rule 104(a) as calling upon judges to make this admissibility determination.

For expert testimony, this task calls for a "preliminary assessment of whether the reasoning or methodology underlying the testimony is scientifically valid and of whether that reasoning or methodology properly can be applied to the facts in issue."[84] This inquiry focuses on the expert testimony's scientific foundation and rests on a preponderance of the evidence standard.[85] Although many factors may bear on whether expert testimony is based on sound methods and principles, the Court offered five considerations that are integral to the scientific method to determine "whether a theory or technique is scientific knowledge that will assist the trier of fact."[86]

First, can the theory or technique be and has it been tested under the scientific method of "'generating hypotheses and testing them to see if they can be falsified'"?[87] The judge must assess the research methods used to test the hypothesis in question. Justice Blackmun explained that the "focus, of course, must be solely on principles and methodology, not on the conclusions that they generate."[88] The gatekeeper judge therefore must concentrate on the reliability and validity of the general principles or methods on which an expert's conclusions are based.[89]

The *Daubert* Court referred to the scientific method as the cornerstone of scientific knowledge and cited the esteemed philosopher of science Karl Popper.[90] But no single scientific method applies to all theories, all fields, and all applications, as Popper himself observed.[91] The common element is that science be open to criticism and revision, the concept he called "falsifiability,"[92] one of the analytical factors the Court emphasized in *Daubert*.[93]

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[81] *See* Note, *Admitting Doubt: A New Standard for Scientific Evidence*, 123 HARV. L. REV. 2021, 2023 (2010).

[82] *Daubert*, 509 U.S. at 592, 597.

[83] *Id.* at 593.

[84] *Id.* at 600.

[85] *Id.* at 592 n.10.

[86] *Id.* at 593–94.

[87] *Id.* at 593 (quoting Michael D. Green, *Expert Witnesses and Sufficiency of Evidence in Toxic Substances Litigation: The Legacy of* Agent Orange *and Bendectin Litigation*, 86 NW. U. L. REV. 643, 645 (1992)).

[88] *Daubert*, 509 U.S. at 595.

[89] *See* GIANNELLI & IMWINKELRIED, *supra* note 62, at 52–57.

[90] *Daubert*, 509 U.S. at 593.

[91] *See* KARL POPPER, THE LOGIC OF SCIENTIFIC DISCOVERY 276–81 (5th ed. 1992).

[92] *See id.* at 279.

[93] *Daubert*, 509 U.S. at 593. *But see* FELDMAN, *supra* note 5, at 128–31 (noting criticism of falsification as "hallmark of true science").

Second, has the theory or technique "been subjected to peer review and publication"?[94] The Court explained that peer-reviewed publication makes detection of substantive flaws more likely.[95] Although peer-reviewed publication does not guarantee scientific validity,[96] and lack of peer-reviewed publication does not mean a theory or method is unsound,[97] this factor can facilitate critical evaluation of the principles and methods underlying the expert evidence. It contemplates refereed articles, scrutinized by an appropriate peer group, that report the testing of principles and methods and the underlying data so that other scientists can evaluate and verify.[98] Judges should be cognizant that both the quality of publications and of reviewers can vary and that the scientific community's reactions to the publications are part of assessing this factor.[99]

Third, what is the "known or potential rate of error" for the scientific technique?[100] Courts have not developed much guidance on how judges should approach this issue. *Daubert* did not specify an allowable error rate, suggesting a balancing analysis that accounts for the costs of mistakes. In criminal cases, false positive error rates are particularly important because a false positive is evidence of identification that supports a conviction.[101] In applied science, the test or the tester produces false positives and false negatives over a quantity of tests. Errors in applied scientific testing can arise in many ways, including sample size, the nature of the sample that is studied, and the equipment that is used. Errors can be random or systematic. Scientific reliability emerges through replication of studies that recognize their own limitations.[102]

Fourth, what are the standards controlling the scientific technique's operation?[103] The *Daubert* Court tied the error rate factor to the "existence and maintenance of standards controlling the technique's operation."[104] The quality of the standards[105] and such factors as standardization of procedures and laboratory accreditation are relevant to this part of the reliability analysis.[106]

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[94] *Daubert*, 509 U.S. at 593.

[95] *See id.*

[96] *See id.*

[97] *See id.*

[98] *See* GIANNELLI & IMWINKELRIED, *supra* note 62, at 45–46.

[99] *See* 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 63–66; State v. Brown, 687 P.2d 751, 769–70 (Or. 1984) (noting abundance of polygraph literature but "availability of this mass of literature may or may not be relevant in any given case").

[100] *Daubert*, 509 U.S. at 594.

[101] *See* United States v. Mitchell, 365 F.3d 215, 239 (3d Cir. 2004).

[102] *See* 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 63.

[103] *Daubert*, 509 U.S. at 594.

[104] *Id.*

[105] *See Mitchell*, 365 F.3d at 241.

[106] *See* United States v. Prime, 363 F.3d 1028, 1034 (9th Cir. 2004), *vacated on other grounds*, 543 U.S. 1101, 1101 (2005).

Fifth, is there "general acceptance" of the theory or technique in the relevant scientific community?[107] The general acceptance standard was the exclusive test under *Frye*, but under *Daubert* it is just one of several factors a court may consider in the reliability analysis to determine admissibility. The weight of this factor should vary directly with the rigor of scientific testing in the field. Some fields are more rigorous than others in their assessment of hypotheses.[108] Widespread general acceptance should not guarantee admissibility if the evidence comes from a field with lax research methodology; conversely, expert opinion based on methodology that has been extensively and rigorously tested may be admissible despite not yet achieving general acceptance.[109]

The Court stressed that the Rule 702 inquiry should be "flexible" and aimed at "scientific validity—and thus the evidentiary relevance and reliability" of the principles and methodology relied upon to generate conclusions.[110] The expert testimony must have "a reliable foundation" and be "relevant to the task at hand."[111] This calls for "[p]ertinent evidence based on scientifically valid principles."[112] After *Daubert*, federal district court judges have held "*Daubert* hearings" pursuant to Rule 104(a) to assess the validity of scientific evidence.[113] Even when no *Daubert* hearing is held, the trial court's gatekeeping duties call for development of a sufficient record on the basis for admissibility to facilitate meaningful appellate review.[114]

The Supreme Court insisted in *Daubert* and ensuing cases that the reliability determination can but need not be based on the factors just described. No specific factor is dispositive on the reliability of an expert's testimony.[115] For any given scientific evidence, the five-factor *Daubert* analysis is the starting point. As a practical matter, experts should assume courts and counsel will expect them to address these factors. But other reliability factors should be considered depending

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[107] *Daubert*, 509 U.S. at 594.

[108] *See* 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 47.

[109] *See* A Woman's Choice-East Side Women's Clinic v. Newman, 904 F. Supp. 1434, 1461 (S.D. Ind. 1995) (admitting scientific evidence that was not yet peer reviewed but had been published by a reputable institution); Becker v. Nat. Health Prods., Inc., 896 F. Supp. 100, 103 (N.D.N.Y. 1995) ("Neither peer review and publication nor general acceptance are dispositive in the reliability assessment."); 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 66–67.

[110] *Daubert*, 509 U.S. at 594–95 (1993). Justice Blackmun noted "that scientists typically distinguish between 'validity' (does the principle support what it purports to show?) and 'reliability' (does application of the principle produce consistent results?)." *Id.* at 590 n.9. He explained that the Court's concern is "*evidentiary* reliability—that is, trustworthiness." *Id.* He concluded that in cases "involving scientific evidence, *evidentiary reliability* will be based upon *scientific validity*." *Id.* (emphasis in original).

[111] *Id.* at 597.

[112] *Id.*

[113] *See* Moore v. Ashland Chem. Inc., 151 F.3d 269, 276 (5th Cir. 1998).

[114] *See* Goebel v. Denver Rio Grande W. R.R. Co., 215 F.3d 1083, 1088 (10th Cir. 2000).

[115] *See* Heller v. Shaw Indus., Inc., 167 F.3d 146, 155 (3d Cir. 1999).

on the nature of the evidence. Drawing from court opinions both before and after *Daubert*, the advisory committee note to the 2000 amendment of Rule 702 mentions additional factors, which include whether the expert:

(1) proposes to express an opinion based on research conducted independently of the litigation or based on research conducted for the purpose of testifying;
(2) "has unjustifiably extrapolated from an accepted premise to an unfounded conclusion";
(3) "has adequately accounted for obvious alternative explanations";
(4) has been as careful in developing and presenting expert courtroom testimony as the expert would be in his or her regular professional work; or
(5) relies on a field of expertise that produces reliable results for this type of expert opinion testimony.[116]

Because reliability is the touchstone for admissibility, the admissibility presentation should be tailored according to the theory and method of expertise and to the means by which it has been applied to the particular issue in the case at hand.

Two Supreme Court decisions following *Daubert* answered two critical questions. First, in *General Electric Co. v. Joiner*,[117] the Court held that the standard for appellate review of a trial court's application of Rule 702 and *Daubert* to expert testimony is abuse of discretion, thereby solidifying the trial judge's strategic role as a gatekeeper for scientific evidence by insulating admissibility rulings from a more exacting standard of review.

Second, in *Kumho Tire Co. v. Carmichael*,[118] the Court held that the *Daubert* gatekeeping function on evidentiary reliability applies not only to scientific expert testimony but also to expert testimony based on nonscientific technical or other specialized knowledge—in other words, all categories of expertise listed in Rule 702. The Court said that "whether *Daubert*'s specific factors are, or are not, reasonable measures of reliability in a particular case is a matter that the law grants the trial judge broad latitude to determine."[119]

Kumho also underscored the importance of analyzing factors that help assess the reliability of the wide variety of expertise underlying expert testimony.[120] Perhaps even more significant, *Kumho* re-emphasized the trial judge's "task of ensuring that an expert's testimony both rests on a reliable foundation and is relevant to the task at hand."[121] The "task at hand" analysis calls for a reliability

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[116] FED. R. EVID. 702 advisory committee's note to 2000 amendment (citations omitted).

[117] 522 U.S. 136, 138–39, 141–43 (1997).

[118] 526 U.S. 137, 141, 147–49 (1999).

[119] *Id.* at 153.

[120] *See id.* at 149–53; 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 71–72.

[121] 526 U.S. at 141 (quoting Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 597 (1993)).

determination of the expertise as applied to a specific issue in a given case.[122] Courts and lawyers have been criticized for failing to follow this task-specific approach.[123]

In 2000, Rule 702 was amended in response to *Daubert* and its case progeny:[124]

> If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.

The three elements added in 2000 at the end of the rule break down the reliability analysis in terms of "sufficient facts and data," "reliable principles and methods," and reliable application of the "principles and methods." The advisory note states that "[t]he term 'data' is intended to encompass the reliable opinions of other experts" and can include hypothetical facts that are supported by the evidence.[125]

The rule makes clear that judges must scrutinize not only principles and methods used by the expert but also whether those principles and methods have been properly applied.[126] The application issue raises questions of the accuracy and condition of the instruments that are used, compliance with protocols, and the competence of both the individuals performing the technique and the people interpreting the outcomes.[127]

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[122] *See* D. Michael Risinger, *Defining the "Task at Hand": Non-Science Forensic Evidence After* Kumho Tire Co. v. Carmichael, 57 WASH. & LEE L. REV. 767, 773–75, 778 (2000).

[123] *See* D. Michael Risinger, *Goodbye to All That, or A Fool's Errand, by One of the Fools: How I Stopped Worrying about Court Responses to Handwriting Identification (and "Forensic Science" in General) and Learned to Love Misinterpretations of* Kumho Tire v. Carmichael, 43 TULSA L. REV. 447, 466–75 (2007).

[124] *See* FED. R. EVID. 702 advisory committee's note to 2000 amendment.

[125] *Id.*

[126] Although Justice Blackmun wrote in *Daubert* that "[t]he focus, of course, must be solely on principles and methodology, not on the conclusions that they generate," 509 U.S. at 595, the Court in *General Electric Co. v. Joiner* questioned this methodology/conclusion distinction, explaining that "[a] court may conclude that there is simply too great an analytical gap between the data and the opinion proffered." 522 U.S. 136, 146 (1997). The 2000 amendment to Rule 702 made clear that reliability must be established not only for the "principles and methods" underlying expert testimony but also their application "to the facts of the case." *See* FED. R. EVID. 702 advisory committee's note to 2000 amendment.

[127] *See* GIANNELLI & IMWINKELRIED, *supra* note 62, at 3, 69–74.

Although the principles and methods underlying some forms of scientific evidence are so well established that a court may take judicial notice of reliability,[128] scientific evidence based on novel theories and techniques is an unlikely candidate for judicial notice when it is first offered at trial.[129] Stable isotope analysis has been applied in a variety of fields for some time, and the *Daubert* Court did not limit Rule 702's application to novel scientific techniques.[130] Moreover, the use of stable isotope ratio analysis in forensic investigation is relatively recent,[131] and it has not been widely presented in U.S. courts. Accordingly, even if the stable isotope theory and analytical techniques are well established, we think trial judges should and will insist on a reliability showing contemplated under *Daubert/*702.

3. Rule 703

Rule 703 provides:

> The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to the expert at or before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence in order for the opinion or inference to be admitted. Facts or data that are otherwise inadmissible shall not be disclosed to the jury by the proponent of the opinion or inference unless the court determines that their probative value in assisting the jury to evaluate the expert's opinion substantially outweighs their prejudicial effect.

Rule 703 allows an expert to base an opinion on firsthand personal knowledge of facts or data and on facts or data in the evidentiary record "made known to the expert at or before the hearing." Evidence law has long recognized these two bases for expert opinion.[132] Rule 703 added a third basis: facts not necessarily admissible in the record "[i]f of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject."

Rule 703's third basis should be understood in the context of the Rule 702/*Daubert* framework. As the Advisory Committee on the Rules of Evidence explained, the 2000 amendment to Rule 702 "makes clear that the sufficiency of the basis of an expert's testimony is to be decided under Rule 702" because

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[128] *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 593 n.11 (1993); GIANNELLI & IMWINKELRIED, *supra* note 62, at 3–8.

[129] *See* State v. Ito, 978 P.2d 191, 208 (Haw. Ct. App. 1999); FDIC v. Napert-Boyer P'ship, 671 A.2d 1303, 1308 (Conn. App. Ct. 1996).

[130] *Daubert*, 509 U.S. at 592 n.11.

[131] *See* Sarah Benson et al., *Forensic Applications of Isotope Ratio Mass Spectrometry—A Review*, 157 FORENSIC SCI. INT'L 1, 12–13 (2006).

[132] *See* FED. R. EVID. 703 advisory committee's note.

sufficiency analysis is integral to Rule 702's "overarching" reliability requirement.[133] Rule 703's reasonable reliance requirement applies to inadmissible facts or data and therefore "is a relatively narrow inquiry."[134] As one court described it, "Rule 702 examines the expert's testimony as a whole," while "Rule 703 governs the inquiry into the reliability of particular data underlying expert testimony,"[135] data that must be "of a type reasonably relied upon by experts in the particular field" but "need not be admissible in evidence."[136]

If there is an issue about an expert's reliance on inadmissible data for an opinion, the trial judge must make a Rule 104(a) gatekeeper decision as to whether such reliance is reasonable under Rule 703,[137] and, if the answer is yes, whether such data can be disclosed to the jury. In 2000, the last sentence of Rule 703 was added to prevent the rule from allowing pervasive and unrestricted disclosure to the jury of evidence, especially hearsay, that would otherwise be inadmissible under the evidence rules.[138]

4. Rule 706

Rule 706 provides, in part:

> The court may on its own motion or on the motion of any party enter an order to show cause why expert witnesses should not be appointed, and may request the parties to submit nominations. The court may appoint any expert witnesses agreed upon by the parties, and may appoint expert witnesses of its own selection.

In his opinion concurring in part and dissenting in part in *Daubert*, Chief Justice Rehnquist expressed concern about the Court's reliability factors and the trial court's gatekeeping function as "impos[ing] on [judges] either the obligation or the authority to become amateur scientists in order to perform that role."[139] In

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[133] FED. R. EVID. 702 advisory committee's note to 2000 amendment.

[134] *Id.*

[135] United States v. W.R. Grace, 504 F.3d 745, 759 n.7 (9th Cir. 2010). The close relationship of these analyses is indicated by the Supreme Court's citation of both Rule 702 and 703 to support this statement: "an expert is permitted wide latitude to offer opinions, including those that are not based on firsthand knowledge or observation." *Daubert*, 509 U.S. at 592.

[136] FED. R. EVID. 703.

[137] *See, e.g.*, United States v. Corey, 207 F.3d 84, 88–89 (1st Cir. 2000).

[138] *See* FED. R. EVID. 703 advisory committee's note to 2000 amendment. If the judge decides that an expert reasonably relied on inadmissible evidence and that this evidence can be disclosed to the jury, the judge would generally need to give a limiting instruction that such evidence can only be used to help the jury understand the expert's opinion. *See W.R. Grace*, 504 F.3d at 759 n.7.

[139] *Daubert*, 509 U.S. at 600–01 (Rehnquist, C.J., concurring in part and dissenting in part).

apparent response, Justice Blackmun noted that "Rule 706 allows the court at its discretion to procure the assistance of an expert of its own choosing."[140] Given the range of scientific and technical issues that enter the courtroom, and given the responsibility that Rule 702 and *Daubert* place on judges to assess the validity of expert testimony, the Rule 706 option would seem to be a logical and practical course.

Judges have been slow to use independent court-appointed experts for assistance even though the judiciary has received much post-*Daubert* urging. Justice Breyer has "strongly encouraged" judges "to make greater use of their inherent authority . . . to appoint experts."[141] A court-appointed Rule 706 expert must advise the parties of his or her opinions, may be deposed by either party, and may be called to testify at trial.[142]

Another option is for judges to appoint science advisors pursuant to their inherent authority,[143] a practice that has started to catch on in some district courts after *Daubert*.[144]

5. Rule 403

Rule 403 provides:

> Although relevant, evidence may be excluded if its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or misleading the jury, or by considerations of undue delay, waste of time, or needless presentation of evidence.

The *Daubert* Court confirmed that Rule 403 permits the exclusion of evidence even if the expert testimony has cleared the other rules' hurdles. Justice Blackmun quoted Judge Weinstein: "'Expert evidence can be both powerful and quite misleading because of the difficulty in evaluating it. Because of this risk, the judge in weighing possible prejudice against probative force under Rule 403 of the present rules exercises more control over experts than over lay witnesses.'"[145]

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[140] *Id.* at 595 (majority opinion).

[141] Gen. Elec. Co. v. Joiner, 522 U.S. 136, 149–50 (1997) (Breyer, J., concurring) (quoting Amicus Brief of New England Journal of Medicine at 18–19).

[142] FED. R. EVID. 706(a); *see* Monolithic Power Systems, Inc. v. O2 Micro Intern. Ltd., 558 F.3d 1341, 1346–48 (Fed. Cir. 2009); Leesona Corp. v. Varta Batteries, Inc., 522 F. Supp. 1304, 1312 (S.D.N.Y. 1981).

[143] *See* Ass'n of Mexican-Am. Educators v. California, 231 F.3d 572, 590–92 (9th Cir. 2000) (en banc); Reilly v. United States, 863 F.2d 149, 156 (1st Cir. 1988); *see also* Note, *Improving Scientific Gatekeeping: Technical Advisors and Scientific Evidence*, 110 HARV. L. REV. 941, 952–58 (1997).

[144] *See, e.g.*, Hall v. Baxter Healthcare Corp., 946 F. Supp. 1387, 1392 n.8 (D. Or. 1996); *see also* 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 120–23.

[145] *Daubert*, 509 U.S. at 595. *See* 4 JACK B. WEINSTEIN & MARGARET A. BERGER, WEINSTEIN'S FEDERAL EVIDENCE § 702.02[5] (Joseph M. McLaughlin ed., 2d ed. 2010).

As with other forms of evidence, judges retain discretion under Rule 403 to balance the probative value of expert evidence against substantial dangers of unfair prejudice, misleading the jury, or the other Rule 403 factors. For example, courts have relied on Rule 403 to exclude polygraph evidence, citing its potentially overwhelming impact on the jury and the risk that it may mislead.[146] The task of expert testimony proponents is to assure the judge of the evidence's probative value and to mitigate the potentially prejudicial, confusing, and misleading aspects.

6. Summary

The foregoing discussion describes the analytical framework under the rules to consider the admissibility of expert testimony. Further guidance can be found in *Daubert* and its progeny as well as the concerns expressed in the NAS Report on forensic science. We will now turn to application of these standards to stable isotope ratio analysis as courtroom evidence.

B. Application of Evidence Rules to Stable Isotope Ratio Analysis

1. Introduction

Although the basic science has been tested and applied in leading laboratories for many years, forensic use of stable isotope analysis has been relatively recent, and each forensic application may have its distinctive design, methods, and limits of confidence. When this evidence is offered in court, the challenge for the testifying expert is to identify and explain the basic principles and methods, the specific forensic application, and the limits of the particular application. The challenge for the lawyers is to elicit and contest this information. The challenge for the judge is to develop sufficient understanding of the evidence to make the admissibility decision based on the relevance and reliability standards.

A Rule 104(a) hearing applying the *Daubert*/702 standard to proffered expert testimony appears to lead to an all-or-nothing outcome: admissibility or non-admissibility.[147] But the intersection of law and science is rarely that straightforward.[148] The allure of science and the failure to understand its

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[146] *See* United States v. Gilliard, 133 F.3d 809, 815–16 (11th Cir. 1998) (upholding district court's exclusion of polygraph evidence under Rule 403 as potentially confusing); United States v. Pitner, 969 F. Supp. 1246, 1252–53 (W.D. Wash. 1997) (holding that even if polygraph evidence satisfied Rule 702, it "would still be excluded under Fed.R.Evid. 401 and 403. . . . [T]here is a substantial risk that the jurors will substitute the examination results for their own judgment."); 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 115–16.

[147] *See* Andrew Jurs, *Judicial Analysis of Complex & Cutting-Edge Science in the* Daubert *Era: Epidemiologic Risk Assessment as a Test Case for Reform Strategies*, 42 CONN. L. REV. 49, 75 (2009).

[148] *See* Susan Haack, *Irreconcilable Differences? The Troubled Marriage of Science and Law*, 72 L. & CONTEMP. PROBS. 1, 15–21 (2009).

limitations in resolving legal issues can lead to stronger conclusions than the applied science can support.[149] Scientists recognize that their work is often contingent, subject to retesting and verification, and includes therefore an element of uncertainty.[150] Perhaps this helps explain why the touchstone for admissibility—reliability—is a matter of degree in contrast to the categorical question of whether an expert witness is allowed to testify.[151]

The *Daubert* Court addressed this issue: "[T]here are important differences between the quest for truth in the courtroom and the quest for truth in the laboratory. Scientific conclusions are subject to perpetual revision. Law, on the other hand, must resolve disputes finally and quickly."[152] Judges have some tools to screen the evidence and assist the fact-finder in ways that acknowledge scientific contingency. For example, the admissibility ruling can account for the uncertainties of science through limits on the scope and content of expert testimony, instructions to counsel, and instructions to the jury. But these corrective measures assume that judges have developed the capacity to understand the science and the limits of its applications. One purpose of the Rule 104(a) hearing is to help develop that understanding. Courts also rely on cross-examination and testimony from opposing experts to reveal weaknesses and enable the fact-finder to reach more accurate conclusions.[153]

2. Inauspicious Debuts

Although widely used for investigative purposes, forensic stable isotope ratio analysis has not yet been offered as courtroom evidence on any regular basis. This Article anticipates that it will and aims to assist courts and counsel when it is. One attempt in 2003 in the United States and another in 2006 in the United Kingdom are noteworthy here.

An unreported federal district court opinion rejecting expert testimony on a particular application of isotope analysis demonstrates potential reliability challenges to this evidence. *Mejdrech v. Lockformer Co.* was a class action case alleging that defendant companies had exposed plaintiffs to trichloroethylene (TCE) in violation of federal environmental laws.[154] The plaintiffs moved to exclude a defense expert from testifying about an isotopic comparison between volatile organic compounds taken from plaintiff locations and the TCE found on defendant Lockformer's site.[155] The defense expert compared the isotopic ratios of

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[149] *See* FELDMAN, *supra* note 5, at 140.

[150] *See* Sander Greenland, *The Need for Critical Appraisal of Expert Witnesses in Epidemiology and Statistics*, 39 WAKE FOREST L. REV. 291, 293–94 (2004).

[151] *See* Susan Haack, *Proving Causation: The Holism of Warrant and the Atomism of* Daubert, 4 J. HEALTH & BIOMEDICAL L. 253, 286 (2008).

[152] 509 U.S. at 596–97.

[153] *See* FELDMAN, *supra* note 5, at 147.

[154] No. 01 C 6107, 2003 WL 22078388, at *1 (N.D. Ill. Sept. 5, 2003).

[155] *Id.*

carbon and chlorine in soil and groundwater samples.[156] He concluded that the differences in the chlorine isotope ratios showed that the groundwater in the plaintiff areas did not originate from the defendant Lockformer source.[157]

The judge concluded that this evidence did not meet the reliability requirements of Rule 702 and *Daubert*.[158] Relying in part on the plaintiff's stable isotope ratio expert, who challenged the defense expert's work, the court explained that the methodology, by using large water samples, departed from a peer-reviewed procedure. The method had not been tested or subjected to peer review or publication, appeared to have a high potential error rate, and was not generally accepted in the relevant scientific community.[159] A further problem was the expert's disregard of counter-findings in his research that showed matching carbon isotope ratios from the comparison areas.[160] The defense expert also had recanted an opinion about the origin of the TCE found on the plaintiff sites.[161]

A similar disposition occurred a few years later in the United Kingdom. Isotope analysis surfaced in *Ullises Shipping Corp. v. Fal Shipping Co*. The owners of a tanker sued the time charterers of the vessel. The tanker had been detained, confiscated, and sold at public auction in the United Arab Emirates based on the vessel holding Iraqi oil in violation of United Nations sanctions applicable to Iraq.[162] A central issue at trial was whether the oil on board originated in Iraq. An independent testing laboratory performed four levels of analysis of samples taken from the tanker, including a process using biomarkers and isotope analysis. The lab concluded that the tanker probably contained Iraqi oil.[163]

The court said a reliability evaluation of these analyses was difficult because no witness from the lab testified. Experts for the parties argued for and against the reliability of the testing methods. The court was not persuaded that the lab's methodology provided reliable conclusions about the likely origin of the oil, in part because the oil produced in southern Iraq comes from the same geologic formation as oil produced in southern Iran and Kuwait, and there was no reference sample used from Iran or Kuwait. The defense expert also pointed out that seawater contamination in the samples would affect the isotope analysis and that the lab did not follow the methodology set forth in a paper it cited on oil spill fingerprinting.[164]

In both *Mejdrech* and *Ullises Shipping*, the courts did not question the general principles and methods of stable isotope ratio analysis. They both found that the isotope evidence was not sufficiently reliable based upon shortcomings in the

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[156] *Id.*
[157] *Id.*
[158] *Id.* at *3.
[159] *Id.*
[160] *Id.*
[161] *Id.* at *2.
[162] Ullises Shipping Corp. v. Fal Shipping Co. Ltd. (The Greek Fighter), [2006] 2 C.L.C. 497, 501 (Q.B.).
[163] *Id.* at 546–50.
[164] *Id.* at 551–54.

specific applications of the science in those cases. The decisions therefore stand as examples of the need for courts under *Daubert* and Rule 702 not only to evaluate the reliability of the principles and methods of scientific evidence but also to determine whether the expert has applied the principles and methods reliably to the case at hand. Neither case challenges the basic stable isotope ratio theory or technique.

Stable isotope ratio expert testimony has been involved in other cases.[165] In addition to the Floyd Landis doping arbitration, one of the most prominent was the trial of the six men accused of plotting to set off explosions in 2005 in the London subway system. An isotope expert was called to rebut the lead defendant's claim that he diluted the hydrogen peroxide used in the bombs with London tap water. The expert said this was impossible based on his comparison of the isotopic profiles of the bomb residue and samples of London tap water.[166]

Against this modest backdrop of attempted use of stable isotope forensic evidence in court, we turn to a discussion about admissibility issues regarding stable isotope ratio analysis.

3. Rule 104(a) and the Daubert*/702 Analysis*

Formal implementation of the judge's gatekeeper role is the admissibility decision under Rule 104(a). Rule 104(a) does not require a pretrial hearing, but when novel applications of scientific evidence are proposed for admissibility, as in the early years of DNA identification evidence, parties can be expected to seek a pretrial ruling through a motion in limine. A pretrial *Daubert* hearing would generally be regarded as a reasonable and advisable step.

We expect courts will conduct *Daubert* pretrial hearings on the admissibility of stable isotope evidence. Whether or not such a hearing is held, the Rule 104(a) admissibility determination depends on how the stable isotope ratio analysis measures up under the *Daubert*/702 framework and related rules. Stable isotope evidence is based on the application of principles and methods that are amenable to testable hypotheses. Accordingly, we will focus our attention on the *Daubert* factors, which contemplate scientific methods of analysis. We will consider other reliability considerations as well, which we think are at least equal in importance to the traditional *Daubert* factors.

4. Rule 702 Analysis

The range of stable isotope forensic applications is so wide and varied that a general discussion applying Rule 702 standards will only provide threshold

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[165] *See, e.g.*, Kan.-Neb. Natural Gas Co. v. Marathon Oil Co., 109 F.R.D. 12, 21–23, 34 (D. Neb. 1985) (discussing depositions of experts on geochemistry carbon isotope ratios and isotopic identification of gas).

[166] *See* R v. Ibrahim (Muktar), [2008] 2 Crim. App. R. 578, 587 (Eng.); *Bomb Suspect's Claim "Impossible,"* BBC NEWS, Mar. 14, 2007, http://news.bbc.co.uk/2/hi/uk_news/6451511.stm (last visited June 1, 2010).

assistance for a particular case. Even the methods of stable isotope analysis will vary from application to application, thereby requiring a reliability showing for a particular methodology. We are mindful of Rule 702's requirement to show that stable isotope analysis has been reliably applied to the facts of the specific case.

For the foregoing reasons, and in acknowledgement of the Supreme Court's admonition to address the *Daubert* analysis to the "task at hand,"[167] we will include discussion of the application of stable isotope analysis to the investigation of the anthrax attacks of 2001 (referred to as Amerithrax), which the Federal Bureau of Investigation (FBI) recently closed.[168] In this case of a bio-weapons attack, spores from *Bacillus anthracisis* (anthrax) were contained within letters mailed to news media offices across the United States and to two U.S. Senators. As a result of the anthrax attack, five people were killed and an additional seventeen individuals were afflicted and survived. The chemical and biological analyses of spores recovered from the letters sought to determine the origins of the spores and the identity of the perpetrator(s) behind the attack. Among the many diverse tests employed were stable isotope ratio analyses of spores, culture medium, water used along with culture medium, and envelopes.

(a) Relevancy

The relevance and helpfulness of scientific evidence depends, of course, on the facts that are consequential to a particular case. Rule 702 asks whether expert evidence "will assist the trier of fact to understand the evidence or to determine a fact in issue."[169] Stable isotope evidence can help the fact-finder determine the likelihood that two or more evidence specimens are consistent with having originated from a common source, or the likelihood that a specimen is consistent with having been associated with a particular geographic location. If the likelihood of an evidence specimen having been associated with a specific location is low, stable isotope ratio analyses can, in many cases, provide data on the likelihood that an evidence specimen could have been associated with other geographic locations. If, in any of these instances, the isotope information would help the fact-finder in making the determination of a consequential fact more or less probable,[170] the stable isotope evidence should meet the "assist the trier" test of Rule 702.

Five applications of stable isotope ratio analysis were relevant to the Amerithrax case: (1) identification of the culture medium most likely to have been used to culture the anthrax; (2) characterization of the geographic region(s) most likely to have been associated with the culturing of the anthrax; (3) similarity comparisons among spore specimens recovered from different anthrax-containing

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[167] Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 597 (1993).

[168] *See* U.S. DEP'T OF JUST., AMERITHRAX INVESTIGATIVE SUMMARY (2010), http://www.justice.gov/amerithrax/docs/amx-investigative-summary.pdf (last visited June 1, 2010); *see also* Shane, *supra* note 3; U.S. DEP'T OF JUST., AMERITHRAX INVESTIGATION, http://foia.fbi.gov/foiaindex/amerithrax.htm (last visited June 1, 2010).

[169] FED. R. EVID. 702.

[170] FED. R. EVID. 401.

letters; (4) similarity comparisons between the anthrax spore evidence and the different culture medium used to culture bacteria (including anthrax); and (5) similarity comparisons of the cellulose composition of letters used to mail the spores.[171]

The following questions address two fundamental aspects of stable isotope analysis relevance: similarity and location.

First, were the Amerithrax specimens isotopically indistinguishable from each other and therefore more likely to be related and be consistent with having a common origin?

Second, were the isotopic compositions of the anthrax spore specimens consistent with bacterial spores that had been cultured in a particular geographic region? Additionally, based on the stable isotope ratio measurement, could some geographic regions be excluded as origin-of-culture possibilities?

Third, were the isotopic compositions of the anthrax spore specimens consistent with observations expected for the culture of the bacteria grown using a particular culture medium? Additionally, based on the stable isotope ratio measurement, could some culture medium be excluded from further consideration as culture medium possibilities?

These questions presume that reliable data could be obtained and that appreciable stable isotope ratio variations existed in culture water and culture medium to allow a meaningful interpretation of the data.

Answers to these questions should achieve a more probable understanding of the origin and location of the anthrax recovered from the 2001 letters and should assist a trier of fact. If stable isotope analysis assists to provide such answers, then it should be considered relevant and helpful under Rule 702.

(b) Qualifications

Rule 702 provides that the stable isotope testifying expert must be "qualified . . . by knowledge, skill, experience, training, or education." Stable isotope ratio analysis is a specialty field, and experts in this field become so through training and experience with stable isotope ratio measurement techniques. Often the strongest experts are familiar with both the stable isotope methodology and have the chemical or biological expertise to apply the technique to the specific applications. Examples of the diverse expertise areas might include diet reconstruction, pollution, explosives, food, and drugs.

In the case of stable isotope analysis, the judge should consider both the ability of the expert to comment on or interpret the stable isotope methodology and the limitations to the quality of the data presented. The judge should further assess the expert's ability to address the relevance of stable isotope ratio data to a

[171] *See* Juske Horita & Arpad A. Vass, *Stable-Isotope Fingerprints of Biological Agents as Forensic Tools*, 48 J. FORENSIC SCI., 1, 4–5 (2003); Helen W. Kreuzer-Martin & Kristin H. Jarman, *Stable Isotope Ratios and Forensic Analysis of Microorganisms*, 73 APPLIED & ENVTL. MICROBIOLOGY 3896, 3906–07 (2007).

particular topic. Stable isotope ratios have been applied extensively across the sciences, but not all stable isotope experts may be capable of interpreting isotope ratio data in such diverse fields as geochemistry, biology, food quality and origin, and biochemistry.

A stable isotope expert who would be qualified to testify about analyses used in the anthrax investigation should have training and experience in one or more of the relevant fields of biology and chemistry where this technique is practiced. The expert should have established credentials through advanced graduate education and peer-reviewed publications. There should be a relationship between the expert's publication and laboratory-based qualifications and the nature of the evidence being considered.

The most beneficial expertise would be experience with the techniques of handling and analyzing this particular type of biological evidence, ability to evaluate the data on the basis of a testable hypothesis, familiarity with the strengths and any weaknesses of specific methodologies involved in the isotope analyses of the evidence, and the skills to comment on the reliability and error rate associated with the analyses. The expert should be able to address both the relevance and strengths of the isotope measurements and also the necessary constraints when interpreting the data.

(c) Reliability

The heart of the Rule 702/*Daubert* analysis is the evaluation of reliability, which involves three inquiries: sufficiency of the facts and data, reliability of the principles and methods, and reliability of the application of the principles and methods to the facts of the case.

i. Facts and Data

This part of Rule 702 calls for careful consideration of what the facts and data are and whether they are sufficient to support the expert's testimony. For stable isotope evidence, the analysis will turn on (1) whether the samples meet the level of quantity and quality for accurate measurement; (2) whether the mass spectrometry or other appropriate instrumentation can produce interpretable results; (3) whether the databases are sufficiently populated to permit meaningful comparisons and reasonable conclusions; and (4) whether the mathematical models and relationships used to predict geospatial patterns are sufficiently differentiated to permit meaningful comparisons and reasonable conclusions.

The samples and data produced through the isotope measurement and comparison processes must be adequate to permit scientific interpretation. Accordingly, the sufficiency determination should take account of interpretation constraints. The expert should assist the court by identifying and explaining the strengths and limits associated with interpreting the stable isotope ratio data. Courts should focus on the closely intertwined issues of the differentiation of the

data and the interpretability of the data in analyzing Rule 702's "sufficient facts or data" requirement. The following questions and discussion address these issues.

First, are the differences in stable isotope ratio data sufficiently different in value that two or more specimens can be distinguished? The expert can assist the court with known information about the role of chemical complexity and heterogeneity affecting stable isotope ratio values of materials that are similar to the evidence under consideration. The expert can further assist the court with information on the ranges of stable isotope ratio values to be expected for material(s) that are similar to the evidence under consideration. The court may choose to recognize the value of established databases that contain observations quantifying the nature and extent of stable isotope ratio variations among materials/organisms related to the specimen evidence presented to the court.

Second, is there an accepted scientific basis to interpret and explain the stable isotope ratio measurements that are proposed to be offered as evidence in court? If so, to what extent can this basis be used to inform the court about the appropriateness of interpretation possibilities? The possibilities could include likely relatedness of specimens, likely region(s) of geographic origin(s) of one or more specimens, likely factors influencing the production of specimens, and/or likely relatedness between two or more materials such as starting materials and a finished product. The scientific basis to make each of these interpretations should be established through one or more peer-reviewed publications. The expert should address the strengths and limits of interpreting the stable isotope ratio data in these contexts.

As applied to the Amerithrax example, consider data (facts) and interpretation as two distinct but related issues as described above.

First, are there established methods to obtain data that would allow an expert to make interpretable measurements on Amerithrax spores? The answer may depend on the ability to isolate the spores from background matrix materials that could affect the measurement of an isotope ratio. For instance, the preparation and analysis method should be able to purify the spore from the growth medium to a sufficient level that trace amounts of residual growth medium do not affect the measurement of the spore isotope ratio. That is, are acceptable methodologies in place to provide sufficient confidence that repeatable and meaningful isotope ratio data can be obtained from the evidence specimen(s)?

In the Amerithrax case, sufficient information appeared to be available to establish data accuracy and reliability. As to the ability to measure reliable stable isotope ratio values for bacteria and bacteria spores, numerous publications on this topic have been published as peer-reviewed studies in the microbiological forensic science literature. A recent review of this specific topic by Kreuzer-Martin and Jarman describes no less than ten independent scientific studies involving forensic-related measurements of stable isotope ratios in bacteria and bacteria spores.[172]

This issue is distinguishable from whether isotope ratios can be measured using instrumentation commonly used for isotope ratio analyses in the biological

[172] Kreuzer-Martin & Jarman, *supra* note 171.

and chemical fields of study. Stable isotope ratio analyses are now a commonly accepted measurement. For Amerithrax evidence specimens, hydrogen, carbon, nitrogen, and oxygen isotope ratios were measured using an isotope ratio mass spectrometer. This instrumentation has been in place and accepted as an appropriate measurement instrument for more than five decades.[173] Preparation and analysis methodologies to analyze bacterial spores were refined from accepted practices in the field. In a series of peer-reviewed publications, Kreuzer-Martin and colleagues demonstrated how meaningful stable isotope ratio data could be acquired for bacteria and spores cultured under different combinations of source water, culture medium, culture practice, and geographic location.[174] If the preparation and analysis methodologies are accepted, then a reliable stable isotope ratio measurement can be obtained for the evidence specimen(s) that could be used for forensic investigation and possibly introduced as evidence in a court.[175]

Second, are there established methods to interpret the stable isotope ratio data? At this stage the expert should be able to identify the published experimental studies providing a framework for interpreting the data; describe the breadth, relevance, and limitations of any databases that are relevant to interpreting the data; and explain the strengths and limitations of mathematical/geospatial models and other mathematical relationships that are essential to interpreting the stable isotope ratio data. The expert should be able to evaluate testable hypotheses and provide a likelihood of accepting or rejecting these hypotheses.

ii. Principles and Methods

The principles and methods of stable isotope analysis have been described earlier in this paper. We will not repeat those descriptions here, but will focus on the reliability of those principles and methods. We will address the *Daubert* reliability factors and suggest some other reliability considerations.

a. Testability—Stable isotope evidence is based on the application of principles and methods resulting in stable isotope ratio data (facts) that are then amenable to testable hypotheses.[176] Although the conclusions reached from interpreting stable isotope ratio data can, in some limited circumstances, be influenced by the methodology, any rare influence is more likely to be based on

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[173] *See* SHARP, *supra* note 22, at 1–39; Budzikiewicz & Grigsby, *supra* note 12.

[174] *See* Kristin H. Jarman et al., *Bayesian-Integrated Microbial Forensics*, 74 APPLIED & ENVTL. MICROBIOLOGY 3573 (2008); Kreuzer-Martin et al., *Microbe Forensics*, *supra* note 38; Helen W. Kreuzer-Martin et al., *Stable Isotope Ratios as a Tool in Microbial Forensics—Part 1. Microbial Isotopic Composition as a Function of Growth Medium*, 49 J. FORENSIC SCI. 954 (2004) [hereinafter Kreuzer-Martin, *Part 1*]; Helen W. Kreuzer-Martin et al., *Stable Isotope Ratios as a Tool in Microbial Forensics—Part 2. Isotopic Variation Among Different Growth Media as a Tool for Sourcing Origins of Bacterial Cells or Spores*, 49 J. FORENSIC SCI. 961 (2004) [hereinafter Kreuzer-Martin, *Part 2*].

[175] *See* Kreuzer-Martin & Jarman, *supra* note 171.

[176] *See* Benson et al., *supra* note 131.

the sample-preparation methodology used than on the instrumentation methodology. Extensive research on analyses of hydrogen, carbon, nitrogen, and oxygen isotope ratios has been conducted in respected laboratories at many universities in the United States and other countries.[177]

The peer-reviewed literature on this subject is extensive and confirms this measurement approach as a reliable analytical instrumentation method applied to many different fields of science and medicine.[178] Testability (falsifiability) of the data should be examined to eliminate the possibility that a sample-preparation methodology can influence the data and therefore influence the conclusion. Where multiple established and commonly used sample-preparation techniques exist for stable isotope analyses of evidence, the expert should establish the reliability and validity of one method versus the other, the potential of differences in the testability of data from these approaches, and an evaluation of the likelihood that one methodology versus the other could lead to a different conclusion.

b. Peer Review and Publication—The testing of stable isotope ratio principles and methodology and the reduction of systematic and random errors are achieved through research, the peer-review process, and the availability of accepted methods and approaches in the open literature. The general utility of stable isotope ratio analysis as a valid, accurate, and reliable scientific measurement tool has been established for decades in diverse disciplines within natural, physical, and social sciences.[179] By extension, the utility of isotope analysis as a valid and reliable forensic approach has been established in a wide number of peer-reviewed publications that have appeared over the past two decades in different scientific journals, including the Journal of Forensic Sciences, which is the primary publication outlet of the American Academy of Forensic Sciences.[180]

The application of stable isotope ratio analysis to a particular case may require the use of specific sample-preparation methodologies with the general stable isotope ratio measurement instrumentation. Although many of the sample-preparation methodologies are now routinely accepted as valid, accurate, and reliable, the expert should establish that the sample-preparation methodology applied in a particular case is valid and reliable, and that a similar methodology has appeared in a peer-reviewed publication.

c. Error Rate—As in all areas of high-precision instrumentation science, measurements to obtain stable isotope ratio data and their interpretation are subject to various sources of error. These are not proficiency errors; they are the small potential errors associated with the accuracy and precision of an analytical instrument.[181] The error rates of stable isotope ratio measurements tend to be small because specimens are analyzed along with well-accepted international standards

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[177] *See id*.

[178] *See supra* note 174.

[179] *See* JOCHEN HOEFS, STABLE ISOTOPE GEOCHEMISTRY (3d ed. 1987); SHARP, *supra* note 22.

[180] *See, e.g.*, Casale et al., *supra* note 36.

[181] *See* Benson et al., *supra* note 131.

multiple times in each analytical run.[182] In addition, an analytical run includes blind reference materials and additional reference materials appropriate to the kinds of evidence specimens being analyzed, which help to improve the analytical quality of the acquired data.[183]

It is nonetheless important to recognize potential error rates associated with stable isotope ratio data. Small random errors can arise because of heterogeneity in the specimens being analyzed. That is, because the stable isotope ratio analysis uses such small sample sizes, it is possible that heterogeneity (degree of mixture) of a sample could affect the accuracy of a measurement. Error arising from heterogeneity can be minimized by increasing the number of replicate analyses of the specimen.[184]

As applied to the Amerithrax case, potential random errors were small based on replication of stable isotope analyses, variations in and among culture medium (within batch heterogeneity and batch-to-batch variation), and water used to culture bacteria.[185] Systematic errors in the analyses of stable isotope ratio data would likely be small if they were based on incorrect or biased sample-preparation methodologies. This latter point would relate to the appropriate application of stable isotope measurements rather than error rates associated with a measurement.

Another type of potential error can occur with the interpretation of stable isotope ratio data. These potential errors concern issues of statistical error and assessment of the data. Two approaches are considered for interpretation of hypothesis testing of stable isotope data: (1) significance tests and (2) likelihood ratios.

1. Significance tests—Significance testing of data associated with specimens and/or between data and expected values in models uses both parametric and nonparametric statistics, as appropriate for the individual data. These statistical tests are used as the independent evaluation method to accept or reject a hypothesis under consideration. The significance testing error rate can theoretically increase as greater complexity is considered.[186] This approach should be considered when interpreting stable isotope ratio data, but such an error rate is typically not an issue with biological organisms. In biological systems, such as bacterial spores, the variation in stable isotope ratio data among analyses will likely exceed the analytical error if there was heterogeneity, but not by much. Therefore, the potential propagation of the measurement errors does not typically exceed twice the error associated with an individual observation. For stable isotope data, these errors tend to be small.[187]

In the Amerithrax case, such errors were likely to have been small with, for example, carbon isotopes in bacteria spores having a precision of ±0.2‰ relative to

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[182] *See* Kreuzer-Martin & Jarman, *supra* note 171.

[183] *See* Thomas & Jamin, *supra* note 15.

[184] *See* Kreuzer-Martin & Jarman, *supra* note 171.

[185] *See id*.

[186] *See* C.G.G. Aitken & D. Lucy, *Evaluation of Trace Evidence in the Form of Multivariate Data*, 53 J. ROYAL STAT. SOC'Y. SERIES C (APPLIED STAT.) 109 (2004).

[187] *See* Benson, *supra* note 131.

an overall 95% confidence interval precision of ±0.4‰ that includes specimen heterogeneity.[188]

Another potential source of significance testing error can be associated with the interpretative precision of models (e.g., linear models and geospatial models) that relate stable isotope data to a known pattern or a geospatial distribution. These interpretative errors may exceed random analytical errors. The magnitude of an interpretive error will depend on the size and representativeness of any database used for assignment comparisons, and on the strengths and reliability of models used to interpret the data in a geospatial context. These systematic errors are reduced by considerations of larger and more representative databases and by development and testing of new geographic models used to interpret the data.[189]

Kreuzer-Martin and Jarman,[190] as well as Jarman and colleagues,[191] considered these issues with respect to the Amerithrax case and concluded that the errors were small and very unlikely to influence interpretation of the data. In addition, Jarman and colleagues provided a data interpretation framework based on Bayesian statistics that lends itself well to error rate analyses, considering stable isotope ratio analyses in conjunction with other chemical analyses of the evidence.[192] In each case, the errors are recognized here for the sake of completeness, but when incorporated individually and/or collectively, the overall error does not significantly affect the strengths of conclusions that can be derived from data through significance testing.[193]

2. Likelihood ratios—An emerging error rate analysis approach for quantitative scientific data is the application of likelihood ratios in addition to significance testing. A likelihood ratio analysis considers the data in the context of two contrasting hypotheses.[194] The likelihood ratio is the ratio of the probability that hypothesis one is correct relative to the probability that hypothesis two is correct. This can be viewed as the ratio of the true positive rate to the false positive rate.[195]

In the most straightforward approach, the application of likelihood ratios to the Amerithrax case would be, "What is the ratio of the probability that the anthrax spores originated from region 1 relative to the probability that they originated from any geographic region other than region 1?" The result would be a number that varied from near zero to a large number in excess of a million. At a likelihood value of 1, there is an equal probability that the "recovered" and "control" evidence did or did not share a common origin. The lower the likelihood ratio is from one, the greater the probability that "recovered" and "control" evidence do

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188 Kreuzer-Martin, *Part 2*, *supra* note 174.

189 *See* Kreuzer-Martin & Jarman, *supra* note 171.

190 *See id*.

191 *See* Jarman et al., *supra* note 174.

192 *See id.*

193 *See id*.

194 *See* Aitken & Lucy, *supra* note 186.

195 *See* COLIN G.G. AITKEN & FRANCO TARONI, STATISTICS AND THE EVALUATION OF EVIDENCE FOR FORENSIC SCIENTISTS 95–99, 153–55, 319–21, 365–70 (2d ed. 2004).

not share a common origin. In contrast, the more the likelihood ratio exceeds one, the higher the likelihood that the "recovered" and "control" evidence do share a common source.[196]

Farmer and colleagues applied likelihood ratio analyses to stable isotope ratio analyses of fifty-one specimens of white paint. The authors arbitrarily selected one of the paints as "recovered" and another as "control." They were able to calculate three results: the likelihood that "recovered" and "control" were from a common source, the likelihood of a false positive, and the likelihood of a false negative. This approach can be applied to all stable isotope ratio data, complementing traditional statistical testing approaches.[197]

d. Standards—In stable isotope ratio analyses, standards play an important role in enabling the investigator to determine the accuracy and precision of the measurements and to compare similar analyses conducted in different laboratories. This *Daubert* factor is therefore especially important to the reliability analysis of stable isotope evidence.

International standards have been recognized and made available to laboratories.[198] In each analytical run, it is typical for the laboratory to include working reference materials calibrated against international standards,[199] "blind" quality-control samples of known isotope ratio values, and replicate samples of the same piece of evidence (assuming sufficient material exists).[200] As we discussed in Part I of this Article, laboratories participate in round-robin exchange tests to ensure that different laboratories conducting the same stable isotope analysis will reach the same results.[201]

If the evidence specimen must be pretreated in any way prior to isotope ratio analysis, the principle of identical treatment should always be followed. That is, reference materials and "blind samples" should undergo the same pretreatment as the evidence specimen. By this means, it is possible to know the accuracy, precision, and error rate of an analytical run associated with analysis of evidence.[202]

The introduction of stable isotope evidence into a court proceeding requires confirmation of several practices that are common to the introduction of other scientific data. Two standard practices establish the quality and accuracy of the stable isotope ratio data.

First, acceptable technology and methodology must be used in the analysis of the evidence. The former can be accomplished by use of instruments that have sufficient precision and that are used in this field of science today for stable isotope

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[196] *See* N. Farmer et al., *Stable Isotope Analysis of White Paints and Likelihood Ratios*, 49 SCI. AND JUST. 114 (2009).

[197] *See id*.

[198] *See* M. Boner & H. Förstel, *Stable Isotope Variation as a Tool to Trace the Authenticity of Beef*, 378 ANALYTICAL AND BIOANALYTICAL CHEMISTRY 301 (2004).

[199] *See, e.g.*, N. Farmer et al., *supra* note 196.

[200] *See* Thomas & Jamin, *supra* note 15.

[201] *See id.*

[202] *See id.*

ratio measurements. The laboratory analyzing the evidence specimens must have written protocols to ensure that the instrumentation is in correct operating condition. These written practices must have been in effect at the time the stable isotope ratio measurements were conducted on evidence specimens.

These quality assurance and quality control protocols are typically written in a step-by-step fashion. Included in these practices is the use of laboratory reference gases to convert the electrical signals from the instrument associated with analysis of a specimen into raw stable isotope ratio values. The laboratory reference gases that are part of the analysis process must have been calibrated against internationally accepted reference standards (often referred to as primary standards). This can be accomplished by using methods appropriate to the evidence in hand and accepted in the scientific discipline through peer-reviewed publication(s). These methodological protocols are typically written in a step-by-step fashion for the analytical technician and based on peer-reviewed publication(s) to ensure quality, accuracy, and repeatability.

Second, acceptable (1) quality control practices and (2) reference and calibration materials must be used in the analytical run associated with the analyses of all evidence specimens. The former is achieved by determining whether the analytical run (typically up to 100 analyses that include specimens, calibration materials, and blind reference materials) met the threshold requirements established by written laboratory protocols and data templates that are used to correct or normalize the data from instrument voltage signals into stable isotope ratio values on an international scale.

The latter is achieved by use of laboratory reference materials that have been calibrated against internationally accepted reference standards. The known stable isotope ratio values of laboratory reference materials are used to make final calibration adjustments to the raw stable isotope ratio data of a specimen or blind reference sample. Most laboratories will also include blind reference materials that have been calibrated against established reference materials as part of the analytical run. This serves as an independent check on the accuracy of the measurements in the analytical run. The reference materials and blind reference materials should be selected to be as similar in composition as is feasible to the specimen(s) being evaluated for court presentation.

These practices are used to ensure that the stable isotope ratio analyses can be repeated in the same manner in another laboratory and obtain similar results.

e. General Acceptance—Stable isotope analyses are commonly used to trace the origins and movements of biological and non-biological materials in fields such as environmental science, ecology, atmospheric science, anthropology, food science, and oceanography.[203] The technique to measure stable isotope ratios of light elements by use of an isotope ratio mass spectrometer is widely accepted

[203] *See, e.g.*, Ehleringer et al., *Isoscapes*, *supra* note 39, at 369–82; STABLE ISOTOPES IN ECOLOGICAL RESEARCH (P.W. Rundel et al. eds., 1989); STABLE ISOTOPES IN ECOLOGY AND ENVIRONMENTAL SCIENCE (Robert Michener & Kate Lajtha eds., 2d ed. 2007); Martin et al., *Interpretation of Combined*, *supra* note 15, at 62–63.

within the scientific community.[204] The extension of isotope analyses into forensic sciences is robust, and results should be readily interpretable by forensic scientists and the courts.

Although the stable isotope analysis technique is accepted and well-respected for scientific investigation, its application to the forensic analysis of specific types of biological or nonbiological materials may be questioned in some unusual situations that may therefore require peer-reviewed publication in the scientific literature. This concern illustrates the general point that reliability of a theory or method must be established for the particular application in the case at hand. For stable isotope ratio analysis, this concern relates especially to evidence that can be lost over time. Is the material being analyzed stable or not over time? Put another way, does the evidence persist, or does it change or disappear over time (such as by evaporation)?

Examples of stable materials appropriate for stable isotope analysis are water in a closed container or a non-evaporating material. Examples of substances that can still be analyzed but possibly challenging to interpret are materials that evaporate over time unless sealed in a container. Two examples of such materials would be alcohol in an open jar allowed to evaporate continuously, or triacetone triperoxide (TATP) allowed to decompose or sublimate in an open room. The latter is the explosive used in the 2005 London subway bomb attacks. With evidence of the physical processes that influence the isotope ratios of evaporating or decomposing materials, these materials can still be interpreted in forensic cases.

f. Other Reliability Considerations—The Supreme Court stressed in *Daubert* and *Kumho* that the factors identified in *Daubert* for the reliability determination are illustrative. The reliability analysis should be tailored to fit the principles and methodology underlying the expert testimony and the application of those methods to the particular case.[205] Although our discussion of the five *Daubert* reliability factors is important to assess stable isotope ratio evidence, additional or refined considerations should also be evaluated, such as whether:

- The evidence analyzed was in a stabilized form and did not change in amount or abundance between the time that evidence was obtained and analyzed.
- The principle of identical treatment was applied to evidence, reference materials, and quality-control samples.
- The instrumentation used was appropriate and capable of achieving the high precision required for an isotope ratio analysis at natural abundance levels.

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[204] *See* I.T. PLATZNER, MODERN ISOTOPE RATIO MASS SPECTROMETRY (1997); J. Thomas Brenna et al., *High-Precision Continuous-Flow Isotope Ratio Mass Spectrometry*, 16 MASS SPECTROMETRY REVIEWS 227 (1997); Meier-Augenstein & Liu, *supra* note 22, at 150; Muccio & Jackson, *supra* note 12, at 213.

[205] Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 597 (1993); Kumho Tire Co. v. Carmichael, 526 U.S. 137, 141–42 (1999).

- The instrument had achieved quality assurance requirements established by the laboratory and found to be broadly acceptable by the scientific community.
- The stable isotope ratio analyses of quality-control samples were within the range of acceptable values.
- The variances among replicate analyses of stable isotope ratio analyses of the evidence were within acceptable ranges.

An expert who is interpreting stable isotope ratio evidence should consider the following before reaching a conclusion:

- An understanding of the extent, if any, that heterogeneity of composition of the evidence plays a role in interpreting the stable isotope ratio values. Significant sample heterogeneity must be considered in the final interpretation of the data.
- When two or more evidence samples are compared, knowledge that the evidence has been treated similarly since it was obtained. If evidence specimens were not handled in an identical fashion, then the potential consequence of this variance must be considered when interpreting the data.
- When interpreting stable isotope ratio observations where two or more evidence specimens are compared, an understanding of the typical variance affecting the precision of the isotope ratio measurement (e.g., handling, purity of preparation, and reductions in overall measurement precision associated with multiple preparation steps prior to isotope ratio analyses).
- An understanding that the conclusions to be reached may only answer whether the observations are "consistent with" or "not consistent with" a specific hypothesis or question. At this level, it may be appropriate to ask the expert to assign probabilities to each interpretation based on the facts provided to the expert.

iii. Application

Rule 702 requires the trial judge to "scrutinize not only the principles and methods used by the expert, but also whether those principles and methods have been properly applied to the facts of the case."[206] The "task at hand" analysis emphasized in *Daubert* and *Kumho* calls for a reliability assessment of the specific application. Even if courts have previously accepted a scientific method as a valid basis for expert testimony, the reliability of the method used in a given case must be assessed by the reasonableness of applying it to the facts of the case and by the validity of how conclusions are drawn from the data.[207] We already have used the

[206] FED. R. EVID. 702 advisory committee's note.

[207] *See Kumho Tire Co.*, 526 U.S. at 153–54; Hendrix v. Evenflo Co., 609 F.3d 1183, 1195 (11th Cir. 2010).

Amerithrax case to illustrate aspects of the reliability analysis. We will expand here on the application of stable isotope ratio analysis to the anthrax attacks.

A court presentation in the Amerithrax case would require a showing that the stable isotope ratio analyses were based on and consistent with peer-reviewed and validation studies in the field that demonstrate the testability and reliability of the principles and methods applied. It would also call for demonstrating a sufficiently small risk of error to allow for reliable conclusions. Reliability also would depend on a showing that laboratory protocols were followed, that the instrumentation was properly calibrated and used, that measurements were accurately recorded and interpreted, and that samples were properly handled. The level of certainty for conclusions about common source of origin and location of origin would need to be supported as set forth earlier.

To understand this application, consider the life cycle of bacteria. The spores that were mailed in the Amerithrax case represented the dormant or resting stage of bacterial growth.[208] Spores are a cell form produced by some, but not all, bacteria in the growth-phase transition from active vegetative growth, nutrient-rich bacteria cultures to a much slower growth. The transition to a dormant spore form occurs as medium becomes depleted in the essential nutrients to maintain the actively dividing bacteria form. During all stages of the bacteria growth cycle, the bacteria take up nutrients from their external environment (known as medium when bacteria are actively cultured).

The application of stable isotope methodology allows for the establishment of reliable patterns and for the testing of specific hypotheses. During bacteria growth, the compounds that are part of each bacterium are built within the bacteria cell based on the uptake and chemical conversion of nutrients derived from the external medium (e.g., water, salts, carbon source, nitrogen source). "You are what you eat" is an appropriate phrase to describe the stable isotope composition of both microbial and animal systems. There are precise, predictable, and reliable relationships between the carbon and nitrogen isotope ratios of the nutrient medium and those of the cell walls, proteins, and carbohydrates that characterize the bacteria.[209] Thus, from measurements of the carbon and nitrogen isotope ratios of a bacterial spore, it is possible to reconstruct the carbon and nitrogen isotope ratios of the growth medium used to culture the bacteria.

The studies by Kreuzer-Martin and colleagues additionally showed that different growth medium often had distinctive carbon and nitrogen isotope ratios. Thus, from analyses of the carbon and nitrogen isotope ratios of bacteria spores, it is possible to reconstruct or predict the carbon and nitrogen isotope ratios of the growth medium and, in some cases, to predict the specific culture medium used to produce the bacterial spores. From such analysis, relevance is clear. Carbon and nitrogen isotope ratio analyses allow the investigator to compare among samples to see whether they possibly share a common growth medium and to predict the

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[208] *See* AMERITHRAX INVESTIGATIVE SUMMARY, *supra* note 168, at 2, 13–16.

[209] *See* Kreuzer-Martin et al., *Part 1*, *supra* note 174; Kreuzer-Martin et al., *Part 2*, *supra* note 174.

growth medium type used to culture the bacteria. This in turn could provide a significant lead to determine whether the growth media in one or more laboratories are consistent with or not consistent with the growth media that were likely to have been used to cultivate the anthrax.

During bacterial growth, hydrogen and oxygen atoms from water in the culture medium are incorporated into the proteins, carbohydrates, and outer cell wall complex of the bacteria being cultured. There are very predictable relationships between the hydrogen and oxygen isotope ratios of bacteria spores and the hydrogen and oxygen isotope ratios of the water used to culture the bacteria.[210] The geographic patterns of hydrogen and oxygen isotope ratios of local waters differ across a continental landscape and exhibit predictable and reliable spatial patterns.[211] This observation allowed Kreuzer-Martin and colleagues to determine whether the isotope ratios of a spore were consistent with or not consistent with growth using a particular water source in different geographic regions of the United States. The predictability of the pattern was tested by culturing the same bacteria in different parts of the United States using the same medium and reliably reconstructing the region from which the different bacteria had been grown. The combination of experimental studies in the laboratory and then field validation of the technique to identify different geographic regions is possible for most stable isotope studies.

The methods used in the anthrax analysis included five sets of key observations, which established that:

(1) The hydrogen and oxygen isotope ratios of *Bacillus* spores were distinctly, linearly, and predictably related to the hydrogen and oxygen isotope ratios of the local water source used to culture the bacteria.[212]

(2) There were distinctive and predictable spatial zones of hydrogen and oxygen isotope ratios of local water sources and geographic regions across the United States.[213]

(3) The carbon and nitrogen isotope ratios of the *Bacillus* spores were distinctly, linearly, and predictably related to the carbon and nitrogen isotope ratios of the growth medium.[214]

(4) There were distinct and predictable differences in the relationships between hydrogen and oxygen isotope ratios of *Bacillus* spores that allowed determination of their culture in liquid vessels versus agar

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[210] *See* Kreuzer-Martin et al., *Microbe Forensics*, *supra* note 38.

[211] *See* INT'L ATOMIC ENERGY AGENCY, STABLE ISOTOPE HYDROLOGY: DEUTERIUM AND OXYGEN-18 IN THE WATER CYCLE 103–42 (J.R. Gat & R. Gonfiantini eds., 1981); Gabriel J. Bowen, *Isoscapes: Spatial Pattern in Isotopic Biogeochemistry*, 38 ANN. REV. EARTH & PLANETARY SCI. 161, 165–76 (2010); Gabriel J. Bowen & Bruce Wilkinson, *Spatial Distribution of $\delta^{18}O$ in Meteoric Precipitation*, 30 GEOLOGY 315 (2002).

[212] Kreuzer-Martin et al., *Microbe Forensics*, *supra* note 38.

[213] *Id.*

[214] Kreuzer-Martin, *Part 1*, *supra* note 174.

plates, and if grown on agar plates, a timeline of spore harvest from agar plates.[215]

(5) The patterns observed for *Bacillus* spores from several taxa applied to both virulent and non-virulent *Bacillus anthracis* (anthrax) spores.[216]

Although this specific example shows the relevance and reliability of stable isotope analyses for establishing bacterial relationships, the same approach also can be applied to animal-production systems, such as cattle fed at a feedlot. An investigation may attempt to link the location of that feedlot with the types of grain the animals were fed. The isotope ratios of many biological products (e.g., beef) record useful information related to the region of growth of that product.[217] Stable isotope ratio analysis may be useful when illegal import of animal products is alleged or when location and growth type need to be distinguished. In the future, courts are likely to face cases where the authenticity or purported origin of a food product is challenged or the designation of "natural" is challenged.

5. Rule 703—Facts or Date Relied Upon—Otherwise Inadmissible

As noted earlier, Rule 703 lists three bases of facts or data for an expert opinion: those facts or data (1) perceived by the expert, (2) made known to the expert at or before the hearing, and (3) of a type reasonably relied upon by experts in the particular field that need not be admissible in evidence. The third basis primarily concerns us here.

The 2000 amendment to Rule 702 "makes clear that the sufficiency of the basis of an expert's testimony is to be decided under Rule 702."[218] The Advisory Committee explained: "Rule 702 sets forth the overarching requirement of reliability, and an analysis of the sufficiency of the expert's basis cannot be divorced from the ultimate reliability of the expert's opinion."[219] Accordingly, whether the expert "reasonably relied" on otherwise inadmissible evidence in "forming opinions or inferences"[220] is a "relatively narrow inquiry."[221]

Under this inquiry, the stable isotope expert can only rely on such evidence if it is "a type reasonably relied upon by experts in the particular field" of stable

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[215] Kreuzer-Martin, *Part 2*, *supra* note 174.

[216] Kreuzer-Martin & Jarman, *supra* note 171.

[217] *See* Bojlul Bahar et al., *Alteration of the Carbon and Nitrogen Stable Isotope Composition of Beef by Substitution of Grass Silage with Maize Silage*, 19 RAPID COMM. MASS SPECTROMETRY 1937 (2005); Boner & Förstel, *supra* note 198; Lesley A. Chesson et al., *Variation in Hydrogen, Carbon, Nitrogen, and Oxygen Stable Isotope Ratios in the Modern American Diet: Fast Food Meals*, 56 J. AGRIC. & FOOD CHEMISTRY 4084 (2008); Ehleringer et al., *Applications*, *supra* note 23, at 411–12; Karl Heaton et al., *Verifying the Geographical Origin of Beef: The Application of Multi-Element Isotope and Trace Element Analysis*, 107 FOOD CHEMISTRY 506 (2008).

[218] FED. R. EVID. 702 advisory committee's note to 2000 amendment.

[219] *Id.*

[220] FED. R. EVID. 703.

[221] FED. R. EVID. 702 advisory committee's note to 2000 amendment.

isotope ratio analysis.[222] As with the other admissibility requirements discussed here, this one is very case-specific. However, because stable isotope analysis is the product of precise laboratory measurement and analysis, reliance on inadmissible hearsay or other inadmissible evidence to form an opinion should be rare.

The use of geospatial mapping of isotope abundance in evaluating laboratory measurements of specific samples may call for Rule 703 analysis if admissibility issues arise regarding this basis of the expert evidence. Whether treated under Rule 702 or 703, the issue comes down to the reliability of this source of data as a basis for expert opinion, and a showing would be needed that stable isotope experts reasonably rely upon this source of facts or data.

6. Rule 706—Court-Appointed Experts

Stable isotope analysis has a long tenure in the laboratory but not in the courtroom. It will be new to most judges, lawyers, and jurors. At least with its initial forays into the courtroom, stable isotope evidence may be a good candidate for a court-appointed expert or technical adviser to assist the judge in making the reliability assessment and the admissibility decision. Technical advisers (or scientific consultants) have a less formal role than court-appointed experts. They provide advice and guidance to the judge and do not typically testify and undergo cross-examination at deposition or trial.[223] We think that either an appointed expert or technical adviser could serve a judge well in the early days of stable isotope courtroom evidence.

The U.S. judicial system relies largely on parties to call experts who explain, challenge, and defend scientific evidence. But even with the benefit of testimony from party-called experts, judges face challenges in assessing the reliability of complex expert testimony. Justice Breyer has observed that "most judges lack the scientific training that might facilitate the evaluation of scientific claims or the evaluation of expert witnesses who make such claims."[224] Many state court judges reported in a survey that they lacked adequate training to evaluate all of the expert evidence presented in their courtrooms.[225] Another survey of judges showed a dearth of training in math and science.[226]

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[222] FED. R. EVID. 703.

[223] *See* David Cooper & Jonathan T. Tomlin, *Expert Testimony,* Daubert*, and the Determination of Damages*, 4 REV. L. & ECON. 213, 225 (2008); *see also* Jurs, *supra* note 147, at 84–85 (2009) (suggesting technical advisors as a way to assist with judicial explanation of complex science).

[224] Stephen Breyer, *Introduction* to FEDERAL JUDICIAL CENTER REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 1, 4 (2d ed., 2000); *see also* NAS REPORT, *supra* note 7, at 12.

[225] *See* Sophia I. Gatowski et al., *Asking Gatekeepers: A National Survey of Judges on Judging Expert Evidence in a Post*-Daubert *World*, 25 L. & HUM. BEHAV. 433, 433 (2001).

[226] *See* Valerie P. Hans, *Judges, Juries, and Scientific Evidence*, 16 J.L. & POL'Y 19, 30 (2007).

A court-appointed expert or technical adviser could educate and prepare the judge to address expert issues in a particular case, and may help judges exclude or deter unreliable, inaccurate, or biased testimony.[227] Just the possibility of using this approach can discourage biased testimony and lead to more accurate results.[228]

It is likely for the near term that courts will need to rely on experts who are familiar with the strengths and weaknesses of isotope ratio analytical measurement, the application of stable isotope analyses to a particular discipline (e.g., biochemistry, anthropology, food science, explosives) rather than simply familiarity with the instrumentation, and the constraints on the interpretability of isotope ratio data. Until this type of evidence is well established within the courts, judges should consider relying on court-appointed experts or technical advisers who have attained a PhD degree in one of the sciences, have familiarity with operating a stable isotope ratio laboratory, and have demonstrated experience in the field broadly associated with the evidence being presented to the court.

Judges seeking expert assistance on stable isotope analysis of anthrax should look for isotope scientists who fit the qualifications presented previously for a testifying expert on the application of stable isotope techniques to the anthrax case.

7. Rule 403—Exclusion Based on Prejudice, Confusion, or Duplication

Even if expert evidence meets Rule 702 reliability and all the other foregoing requirements, it can still be excluded under Rule 403 if "its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or misleading the jury, or by considerations of undue delay, waste of time, or needless presentation of cumulative evidence."[229]

In response to appropriate and relevant questions, testimony interpreting stable isotope ratio evidence can and should be clear, not misleading, and not confusing to the court or jury. Similarly, an expert who recognizes the limits and weaknesses of an application of this technique should not present a danger of unfair prejudice. Critical elements to avoid these problems include calling an expert to testify who has the appropriate qualifications and experience, and having counsel who can elicit responses from the expert that are understandable to the court and jury.

Interpretation of stable isotope data is usually a matter of looking at two data values and asking whether the values are the same or different. An advantage of this approach is that multiple elements or molecules can be analyzed for their stable isotope ratios. Two evidence specimens may have the same carbon isotope ratio value, but for them to be consistent with each other, they should be consistent in stable isotope ratios of all of the elements in each specimen presented as

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[227] *See* Cooper & Tomlin, *supra* note 223, at 225–26; Jurs, *supra* note 147, at 86.

[228] *See* Timothy Hillman, *Using Court-Appointed Experts*, 36 NEW ENG. L. REV. 587, 591 (2002).

[229] FED. R. EVID. 403.

evidence. This basic comparative presentation should not confuse or mislead the fact-finder.

Associated with the stable isotope ratio value of an element is the precision and reliability of that observation. When two or more specimens are being compared, it should be clear these specimens are different if they differ in their values. Again, the training and experience of the expert and the ability to explain this point should avoid Rule 403 problems.

When the expert is asked to provide an interpretation of the evidence, the expert's comments should address whether the observations are consistent with a stated question or hypothesis. The expert may provide a level of precision to that statement. If such a dialogue is approached when presenting stable isotope ratio data to the court, the interpretation should not induce prejudice or mislead the jury.

It is possible that other evidence in a case has been or can be presented to establish the identification or associative evidence that stable isotope analysis would also establish. For example, stable isotope analysis may be relied upon in an investigation to assist in identifying the geographic origin of an evidence sample. If that information is relevant at trial, and if it can be established more easily by other means (e.g., statements of admission by a party), the stable isotope evidence, just like other information from the investigative phase of a case, may be challenged under Rule 403 as presenting cumulative evidence at trial.

III. FORENSIC IDENTIFICATION, DNA PROFILING, AND STABLE ISOTOPE RATIO ANALYSIS

A. DNA Profiling and Traditional Forensic Techniques

In the post-*Daubert* era, forensic identification has received both praise and criticism, depending on the identification technique in question. Traditional applications such as analysis of bite marks, hair samples, handwriting, fingerprints, and firearms have long been accepted in criminal proceedings. But, recently called "the problem children of forensic science,"[230] they have been criticized for lacking sufficient empirical research to satisfy rigorous reliability and validity analysis.[231] This criticism has led some to diagnose a crisis in forensic science[232] and to predict

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[230] D. Michael Risinger, *The NAS/NRC Report on Forensic Science: A Path Forward Fraught with Pitfalls*, 2010 UTAH L. REV. 225, 230.

[231] "These [techniques] have not undergone the type of extensive testing and verification that is the hallmark of science elsewhere." Donald Kennedy & Richard A. Merrill, *Assessing Forensic Science*, ISSUES SCI. & TECH., Fall 2003, at 33, 34; *see also* 1 MODERN SCIENTIFIC EVIDENCE, *supra* note 54, at 89–94; NAS REPORT, *supra* note 7, at 43–44, 127–82; Paul C. Giannelli, *Forensic Science: Under the Microscope*, 34 OHIO N.U. L. REV. 315, 318–25, 330–33 (2008); D. Michael Risinger & Michael J. Saks, *A House with No Foundation*, ISSUES SCI & TECH., Fall 2003, at 35.

[232] *See generally* JIM FISHER, FORENSICS UNDER FIRE: ARE BAD SCIENCE AND DUELING EXPERTS CORRUPTING CRIMINAL JUSTICE? (2008); KELLY M. PYREK, FORENSIC SCIENCE UNDER SIEGE: THE CHALLENGES OF FORENSIC LABORATORIES AND THE MEDICO-

a paradigm shift based on growing recognition that certain forensic claims of discernable uniqueness for comparison matches may not stand up to proficiency testing or empirical research.[233]

These issues have been aired prominently with the 2009 release of the much-anticipated NAS Report on forensic science.[234] Shortly thereafter, Justice Scalia cited the report in a majority opinion. He wrote that "[s]erious deficiencies have been found in the forensic evidence used in criminal trials,"[235] and that "[f]orensic evidence is not uniquely immune from the risk of manipulation."[236] The president of the American Academy of Forensic Sciences has called for validation studies on a variety of forensic applications—e.g., analysis of bite marks, tool marks, handwriting, and latent fingerprints—that courts routinely have admitted for some time.[237]

Daubert has prompted some trial judges to increase their scrutiny of expert credentials.[238] Attorneys have become more aggressive in attacking the admissibility of forensic evidence,[239] which has required courts to "confront[] challenges to testimony . . . whose admissibility had long been settled."[240] Most of these challenges have failed to exclude evidence, but some have exposed empirical weaknesses of common forensic techniques.[241] Despite the stringent standard of proof in criminal proceedings, various evidence commentators have suggested that trial judges have been more rigorous *Daubert* gatekeepers in scrutinizing expert evidence in civil cases than in criminal cases.[242]

Many traditional forensic techniques were developed largely within the setting of crime laboratories' efforts to aid criminal investigation and prosecution.[243] *Daubert* challenges to these techniques ask judges to reassess not

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LEGAL DEATH INVESTIGATION SYSTEM (2007); Craig M. Cooley, *Reforming the Forensic Science Community to Avert the Ultimate Injustice*, 15 STAN. L. & POL'Y REV. 381 (2004).

[233] *See* Michael J. Saks & Jonathan J. Koehler, *The Coming Paradigm Shift in Forensic Identification Science*, 309 SCIENCE 892, 895 (2005).

[234] *See* NAS REPORT, *supra* note 7, at 5–8.

[235] Melendez-Diaz v. Massachusetts, 129 S. Ct. 2527, 2537 (2009).

[236] *Id.* at 2536.

[237] *See* Thomas L. Bohan, *Strengthening Forensic Science: A Way Station on the Journey to Justice*, 55 J. FORENSIC SCI. 5, 6–7 (2010).

[238] *See* GIANNELLI & IMWINKELRIED, *supra* note 62, at 39.

[239] *See* Graham R. Jones, *President's Editorial—The Changing Practice of Forensic Science*, 47 J. FORENSIC SCI. 437, 437 (2002).

[240] United States v. Hidalgo, 229 F. Supp. 2d 961, 966 (D. Ariz. 2002).

[241] *See* GIANNELLI & IMWINKELRIED, *supra* note 62, at 39; NAS REPORT, *supra* note 7, at 11; Peter J. Neufeld, *The (Near) Irrelevance of* Daubert *to Criminal Justice and Some Suggestions for Reform*, 95 AM. J. PUB. HEALTH (Supp. 1) S107, S107 (2005).

[242] *See, e.g.*, NAS REPORT, *supra* note 7, at 11, 106–09; BEECHER-MONAS, *supra* note 51, at 94–96; Margaret A. Berger, *Expert Testimony in Criminal Proceedings: Questions* Daubert *Does Not Answer*, 33 SETON HALL L. REV. 1125, 1125 (2003).

[243] *See, e.g.*, NAS REPORT, *supra* note 7, at 42; David S. Caudill, *Arsenic and Old Chemistry: Images of Mad Alchemists, Experts Attacking Experts, and the Crisis in Forensic Science*, 15 B.U. J. SCI. & TECH. L. 1, 29–32 (2009).

only the reliability and validity of expert evidence but also the strength of claims that can be made based on application of these methods to particular cases. The risk of overreliance on expert evidence that lacks rigorous scientific grounding can carry over to techniques developed through basic scientific research.[244] To whatever extent the principles and methods underlying expert evidence are based on empirical research and testing, forensic science witnesses should guard against claiming too much.[245] If they attempt to overstate, *Daubert* expects judges to perform their gatekeeping role.

In contrast to many of the traditional forensic methods, DNA profiling is the product of extensive basic science research. It often is called the "gold standard" of forensic identification[246] and has "revolutionized forensic investigations."[247] Indeed, the NAS Report states that "no forensic method other than nuclear DNA analysis has been rigorously shown to have the capacity to consistently and with a high degree of certainty support conclusions about 'individualization' (more commonly known as 'matching' of an unknown item of evidence to a specific known source)."[248] Like DNA, stable isotope analysis was developed in academic science settings and relies on analysis of measurements from high-precision instruments.

Exonerations based on DNA analysis often have corrected wrongful convictions based on forensic science testing errors.[249] The forensic geneticist seeks to identify the source of a biological sample.[250] The scientific community has devoted substantial attention to establishing the accuracy and reliability of DNA profiling for forensic uses.[251] Unlike their approach to certain other methods of

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[244] *See id*.

[245] *See id.* at 32–33; Saks & Koehler, *supra* note 21, at 202 (contending that forensic scientists routinely overstate individualization claims for identification evidence and that individualization is not scientifically valid). *But see* David H. Kaye, *Probability, Individualization and Uniqueness in Forensic Science Evidence: Listening to the Academics*, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1261970 (last visited June 1, 2010) (arguing that individualization claims—that a trace sample came from a person or object—can be scientifically defensible in courtroom explanation of forensic identification when random match probability is negligible).

[246] *See, e.g.*, BEECHER-MONAS, *supra* note 51, at 103; Berger, *supra* note 19, at 1126; Michael Lynch, *God's Signature: DNA Profiling, The New Gold Standard in Forensic Science*, 27 ENDEAVOR 2, 93 (2003); Thornton & Peterson, *supra* note 20, at 82; *see also* NAS REPORT, *supra* note 7, at 40–41.

[247] Mark A Jobling & Peter Gill, *Encoded Evidence: DNA in Forensic Analysis*, 5 NATURE REVIEWS GENETICS 739, 739 (2004).

[248] NAS REPORT, *supra* note 7, at 87.

[249] *See* Saks & Koehler, *supra* note 233, at 892; NAS REPORT, *supra* note 7, at 42.

[250] Jobling & Gill, *supra* note 247, at 739.

[251] The National Research Council produced two book-length reports for the National Academy of Sciences on DNA forensic identification, including recommendations for strengthening the rigor of laboratory practices and improving courtroom presentation of the evidence. COMMITTEE ON DNA TECHNOLOGY IN FORENSIC SCIENCE, NATIONAL RESEARCH COUNCIL, DNA TECHNOLOGY IN FORENSIC SCIENCE (1992); COMMITTEE ON DNA

forensic identification, courts have insisted on a strong showing of scientific validity for admission of DNA evidence, including written protocols and proficiency testing.[252] Indeed, DNA has received more extensive judicial scrutiny than any other area of forensic criminal investigation.[253]

The NAS Report observed: "Among existing forensic methods, only nuclear DNA analysis has been rigorously shown to have the capacity to consistently, and with a high degree of certainty, demonstrate a connection between an evidentiary sample and a specific individual or source."[254] The report's Recommendation 3 calls for research to determine "accuracy, reliability, and validity in the forensic science disciplines."[255] The report concluded that many forensic methods lack sufficient empirical research support and called for further research on such familiar techniques as fingerprint examination, handwriting comparison, firearms identification, bite mark identification, and hair analysis.[256]

B. DNA Profiling—Brief Overview

When DNA profiling evidence is presented in the courtroom, the usual question is whether an evidentiary DNA sample matches a known DNA sample taken from a victim or a suspect. If a match is seen, a random match probability must be calculated to assess the likelihood that the evidentiary sample also matches somebody else in the general population (i.e., whether the DNA profile is unique to the suspect). This number is routinely so low that its reciprocal often exceeds the world's entire population.[257]

As noted previously, forensic identification is based on differentiation. Variations in genetic material differentiate individuals from each other. The extreme probabilities found in DNA profiling are based on the extraordinary range of genetic variation. The scientific and legal literature on this subject is

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FORENSIC SCIENCE: AN UPDATE, NATIONAL RESEARCH COUNCIL, THE EVALUATION OF FORENSIC DNA EVIDENCE (1996).

[252] GIANNELLI & IMWINKELRIED, *supra* note 62, at 326–28. The 1992 National Research Council report on DNA profiling concluded: "No laboratory should let its results with a new DNA typing method be used in court, unless it has undergone . . . proficiency testing via blind trials." NATIONAL RESEARCH COUNCIL, DNA TECHNOLOGY IN FORENSIC SCIENCE 55 (1992).

[253] *See* NATIONAL COMMISSION ON THE FUTURE OF DNA EVIDENCE, NATIONAL INSTITUTE OF JUSTICE, THE FUTURE OF FORENSIC DNA TESTING: PREDICTIONS OF THE RESEARCH AND DEVELOPMENT WORKING GROUP 7 (2000).

[254] NAS REPORT, *supra* note 7, at 100.

[255] *Id*. at 22–23, 190.

[256] *See id*. at 8, 42–44, 136–76.

[257] Jobling & Gill, *supra* note 247, at 743; *see also* People v. Nelson, 185 P.3d 49, 52 (Cal. 2008) ("The prosecution presented evidence that the odds that a random person unrelated to defendant . . . could have fit the profile of some of the crime scene evidence are one in 930 sextillion (93 followed by 22 zeros).").

extensive.[258] A brief explanation is presented here to allow comparison with stable isotope ratio analysis as a forensic identification tool.

Within each cell (except red blood cells), the nucleus contains a person's entire genetic code in forty-six chromosomes. Twenty-three chromosomes from the mother combine with twenty-three from the father. About 20,000 to 25,000 genes composed of DNA sequences are located on the chromosomes. DNA's basic material consists of four nucleotide bases consisting of sugar and phosphate compounds joining in base pairs—adenine with thymine, cyclosine with guanine. Of the approximately three billion base pairs, about three million (0.1 percent) vary (except identical twins), which allows us to distinguish individuals from one another. This differentiation is found mostly in the noncoding DNA. Only about one percent of our DNA encodes to enable transcription to RNA and the production of proteins.

DNA identification analysis focuses on the variation in noncoding DNA. The profiling process uses a primer to find a given location (or locus) of noncoding DNA. People vary in how many times a sequence of base pairs repeats itself at the locus. This variation is called polymorphism. The repeating sequence at the locus is called an allele. The frequency in the population of an allele having a certain number of base pair sequence repeats at a given locus has been determined through compilation of genetic databases. A person's genotype or genetic profile is based upon which alleles are present at the various chosen loci.

The frequencies of a person's DNA sequences at up to thirteen locations are multiplied against each other to produce the probability of a random match, an infinitesimally small number. The random match probability is based on the product rule, which yields a probability that a series of independent facts—in this case, the frequencies of alleles at typically thirteen different loci on the DNA strand—will occur. It is derived by multiplying each of the frequencies against each other.[259]

C. DNA Profiling and Stable Isotope Ratio Analysis

Stable isotope analysis, like DNA profiling, originated in mainstream science laboratories primarily associated with university scientists and the geochemistry-petroleum industry. Like other laboratory-based forensic science, such as toxicology and drug analysis, DNA and stable isotope ratio analysis can be

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[258] For further explanation of DNA profiling, see, e.g., LYNN B. JORDE ET AL., MEDICAL GENETICS 29–56 (3d ed. 2003); John M. Butler, *Genetics and Genomics of Core Short Tandem Repeat Loci Used in Human Identity Testing*, 51 J. FORENSIC SCI. 253 (2006); Peter Gill, *DNA as Evidence–The Technology of Identification*, 352 NEW ENG. J. MED. 2669 (2005); David H. Kaye & George F. Sensabaugh, Jr., *Reference Guide on DNA Evidence*, *in* REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 485 (2d ed. 2000); *see generally* JOHN M. BUTLER, FORENSIC DNA TYPING–BIOLOGY, TECHNOLOGY, AND GENETICS OF STR MARKERS (2d ed. 2005).

[259] *See* Richard A. Posner, *An Economic Approach to the Law of Evidence*, 51 STAN. L. REV. 1477, 1512–14 (1999); Saks & Koehler, *supra* note 21, at 217–18.

distinguished from forensic disciplines based on expert interpretation and comparison of observed patterns, such as fingerprints, writing samples, bite marks, and tool marks.

Stable isotope ratio analysis cannot claim the same level of extensive basic research, practical applications, federal oversight, private support for applied research, and national quality assurance and control as has been afforded DNA.[260] However, stable isotope analysis should be subjected to the same rigorous courtroom scrutiny as DNA profiling.

DNA evidence has been compared to and contrasted with a variety of other forms of evidence, such as hair analysis, fingerprint identification, and handwriting comparison, arguably obscuring rather than improving understanding of the nature and the reliability of the non-DNA evidence.[261] Analogizing novel scientific forensic evidence to a well-analyzed form of expertise risks a less strenuous analysis of the former rather than rigorous scrutiny of the novel evidence on its own terms,[262] a risk we seek to avoid in the following discussion.

1. Some Similarities and Differences

We note here some similarities and differences between DNA profiling and stable isotope ratio analysis to help develop better understanding of the latter. Both techniques are used forensically to help answer whether an unknown sample and a known sample have a common origin.

DNA profiling is used to determine the origin of biological evidence. Stable isotope analysis can be used for this purpose, but it also can be used to determine the origin of nonbiological evidence and also the geographic origin of evidence. The two methods can complement each other in an investigation and corroborate each other for proof in court. For example, stable isotope evidence can be used to distinguish among different possible regions from which the same DNA evidence might have been found.

In a case involving an unidentified murder victim found during 2005 in Dublin, Ireland, stable isotope analysis of the victim's tissue was conducted to determine the body's geographic point of origin and life history. This analysis helped the investigation to identify the victim by serving as the basis to seek a DNA parental cross-matching between the victim and a child. Once the true identity of the victim was established, two murder suspects were quickly identified, followed by arrest and conviction.[263]

Similar to the use of multiple loci on the DNA strand for DNA analysis, multiple chemical elements from a sample can be measured for stable isotope analysis. Just as the probabilities of multiple DNA loci can be multiplied to

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[260] *See* NAS REPORT, *supra* note 7, at 101.

[261] *See* Roberts, *supra* note 18, at 248–56.

[262] *See id.* at 269–70.

[263] *See* Wolfram Meier-Augenstein & Isla Fraser, *Forensic Isotope Analysis Leads to Identification of a Mutilated Murder Victim*, 48 SCI. & JUST. 153 (2008).

determine a random match probability, the frequencies of the stable isotope ratios from multiple elements can be multiplied to determine a random match probability.

Despite the foregoing, DNA profiling produces a much smaller random match probability than stable isotope ratio analysis and other forensic identification techniques. The probability of a random DNA match is so low that DNA profiling is easily the most powerful forensic identification method to produce evidence supporting conviction or exoneration in criminal cases and identifying unknown victims of crimes, accidents, or natural disasters.

The resolving power of stable isotope analysis is rarely as strong as DNA because there is not as much naturally occurring isotopic variation as there is DNA variation, especially when you consider that the number of DNA loci that can be analyzed is much greater than the number of chemical elements in an evidence sample submitted for stable isotope analysis. DNA identification evidence is exceptionally reliable because people other than identical twins have a unique genetic pattern with extraordinary variation.[264]

The random match probabilities of DNA profiling are the product of well-developed reference population databases that provide the frequency of various alleles occurring at different locations on the DNA strand. The stable isotope databases are based on sample measurements and are not as expansive as DNA databases. In some cases, two samples that are distinguishable through DNA profiling may have the same stable isotope ratios or be sufficiently close in value so that the samples cannot be distinguished with the stable isotope technique.

This distinction in the resolving power of the two methods points to the importance of recognizing what a particular forensic method can accurately tell us.[265] Stable isotope analysis can provide forensic evidence that DNA profiling may not or cannot supply. For example, depending on the nature of the sample and the reference database, stable isotope analysis may be able to identify an unknown sample with a precise geographic source. Short of that, it may provide reliable evidence of a geographic area as a sample's source or exclude a geographic area as a source or origin. In all of these instances, the evidence may not be otherwise obtainable, including through DNA analysis.

Stable isotope analysis can do something that other forensic identification techniques cannot do: relate or distinguish two pieces of evidence that have identical chemical composition, even samples having identical DNA. For example, blood or hair samples from identical twins will produce a DNA match, but if the twins have been located in different geographic regions and have therefore consumed different water and food, the samples will likely exhibit different stable isotope ratios for one or more different elements.

A further advantage of stable isotope analysis is that it can be applied to samples that do not contain DNA. DNA analysis can, of course, be applied to

[264] Berger, *supra* note 19, at 1126–27.
[265] *See* NAS REPORT, *supra* note 7, at 188.

plants and animals,[266] but stable isotope analysis can be applied to nonbiological samples. Even if samples do contain DNA, and even if DNA analysis can show specific genetic information about the strain of an organism, stable isotope analysis may supplement that information by identifying the range of regions from which that organism—for example, microbiological materials constituting a bioterrorism threat—may have originated.[267]

2. Principles and Methods

DNA profiling has reached a point where its principles and methods and its laboratory techniques are well accepted in the scientific community and the courtroom.[268] The principles and methods of stable isotope ratio analysis are similarly well established in the scientific community but have not received the rigorous judicial scrutiny for courtroom presentation required under *Daubert* and Rule 702. Peer-reviewed scientific publications and testimony from experts in the field can demonstrate that an application that is new to the legal system is nonetheless well established in its scientific field.[269]

The DNA profiling methodology has taken various forms, and still more will be developed. Each new technique must be validated under the *Daubert*/702 framework. The PCR STR technique used in most forensic applications today does not vary significantly from case to case. Its principles and methods have met the reliability test in the courtroom and are routinely accepted as reliable to the point where courts take judicial notice of reliability.[270] This does not preclude, of course, the need to ensure that the technique was properly applied in the particular case.

Although stable isotope analysis has a solid scientific foundation and follows a baseline methodology, the precision of the technique could vary depending on the abundances of substances analyzed. For courtroom presentation, this means that the reliability showing for stable isotope methodology would likely need to be tailored to the particular application or "task at hand."

The principles and methods of both DNA and stable isotope analysis may require a fresh reliability analysis if a new method is used or an unusual application is involved. For example, the inquiry may concern whether there is

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[266] *See* Jobling & Gill, *supra* note 247, at 748–49; Kaye & Sensabaugh, *supra* note 258, at 548–59; Melissa Kidder, Comment, *Human DNA v. Non-Human DNA: A Look at the General Admissibility of Non-Human DNA in the Courts*, 35 OHIO N.U. L. REV. 397, 399–401 (2009).

[267] *See* Kreuzer-Martin et al., *Microbe Forensics*, *supra* note 38, at 818–19.

[268] *See* Wilson v. Sirmons, 536 F.3d 1064, 1102 (10th Cir. 2008) ("Numerous federal and state courts as well as scientific investigators have found that PCR DNA analysis is reliable."); United States v. Boswell, 270 F.3d 1200, 1204–05 (8th Cir. 2001); United States v. Morrow, 374 F. Supp. 2d 51, 61 (D.D.C. 2005).

[269] *See* Kaye & Sensabaugh, *supra* note 258, at 550.

[270] *See, e.g.*, State v. Butterfield, 2001 UT 59, ¶¶ 32–35, 27 P.3d 1133.

scientific literature and precedent for the analysis applied to a specimen in a specific case.[271]

3. Application of Principles and Methods

The disputed issues in DNA profiling evidence concern specific forensic applications and laboratory techniques—whether the DNA sample was collected, processed, and analyzed properly. The issues include whether evidence samples were mishandled or mislabeled, whether samples that are degraded or contaminated or mixed can still be tested, whether the laboratory followed validated protocols and met quality control and assurance standards, whether the probability of a match between known and unknown DNA samples is valid based on an appropriate reference population and calculation, and whether presentation of the match probability may be unfairly misleading or prejudicial to the fact-finder.[272]

For stable isotope ratio analysis, similar issues regarding collection, processing, and analysis of evidence apply, as explained previously in Part II.B.

4. DNA Experts and Isotope Experts

Whether the proposed testifying expert is truly an expert under Rule 702 should be established in every case. DNA profiling testimony may require expertise in several fields—e.g., molecular biology, laboratory procedures, probability and statistics—to establish admissibility or to explain the technique to the jury.[273] Stable isotope ratio analysis also may require expertise in several fields, such as biology, chemistry, and laboratory procedures. In DNA cases where the reliability of principles and methods has been established as a matter of judicial notice, a lab technician may suffice as the expert witness to describe the application and results.[274] Stable isotope cases initially will require expert testimony in all pertinent areas of expertise to establish *Daubert* reliability. Only when the technique has been accepted in enough cases to set a sound reliability precedent would a lab technician be sufficient.

5. Helping—Not Confusing—the Jury

Even if the proponent of expert testimony satisfies Rule 702 and *Daubert*, the judge still can exclude the evidence under the Rule 403 balancing test if its probative value is substantially outweighed by its potential to mislead, confuse, or

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[271] *See* Kaye & Sensabaugh, *supra* note 258, at 552.

[272] *See id. at* 489, 503–48; NAS REPORT, *supra* note 7, at 100; Dan E. Krane et al., Letter to the Editor, *Sequential Unmasking: A Means of Minimizing Observer Effects in Forensic DNA Interpretation*, 53 J. FORENSIC SCI. 1006 (2008).

[273] *See* Kaye & Sensabaugh, *supra* note 258, at 489–90.

[274] *Butterfield*, 2001 UT 59 at ¶¶ 23–26; *see* People v. Lehmkuhl, 117 P.3d 98, 103 (Colo. App. 2004); State v. Lewis, 654 So. 2d 761, 765–66 (La. Ct. App. 1995).

prejudice the jury.[275] If the judge decides this balance favors allowing admissibility of the evidence, the proponent of the evidence should have ample incentive to present it in a way that is helpful and understandable to the jury.

With DNA evidence, in addition to explaining the principles and methods and their application in the particular case, the expert needs to explain the random match probability. This part of DNA testimony has been challenged as unduly confusing and prejudicial. The expert's task is to present the random match probability analysis to avoid this risk as much as possible.[276] As we have discussed previously, stable isotope expert testimony faces similar issues.

The NAS Report noted that judicial education programs have been offered for years on DNA identification evidence, but such programs have not focused to any comparable degree on other forensic disciplines.[277] We suspect the same is true for lawyer continuing education. We recommend educational opportunities for judges and lawyers to learn more about forensic science, including stable isotope ratio analysis.

CONCLUSION

Stable isotope analysis has undergone a long gestation in university and other well-respected commercial laboratories. It is based on precise measurements using sophisticated instrumentation. Its reliability and validity for use in many fields and applications are well documented. Like DNA identification analysis, the scientific foundation for stable isotope evidence provides a strong starting point for its use in the courtroom.

Forensic application of stable isotope analysis has been growing in recent years, and its appearance in courtrooms is reasonably certain and just around the corner. As a newcomer to that setting, it should receive judicial scrutiny of its reliability as required under Rule 702 and *Daubert*. We have written this Article in anticipation of this happening.

We have attempted to explain the science and law that will guide this process. Using the *Daubert*/702 framework, we have identified the issues that should be addressed. We have stressed that a general showing of reliability of principles and

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[275] *See* United States v. Gilliard, 133 F.3d 809, 815–16 (11th Cir. 1998) (upholding district court's exclusion of polygraph evidence under Rule 403 as potentially confusing); United States v. Pitner, 969 F. Supp. 1246, 1252–53 (W.D. Wash. 1997) (holding that even if polygraph evidence satisfied Rule 702, it "would still be excluded under Fed.R.Evid. 401 and 403 . . . [if] there is a substantial risk that the jurors will substitute the examination results for their own judgment").

[276] One court addressed this issue as follows: "Although I acknowledge that a jury could become confused concerning the meaning and potential significance of a random match probability estimate, I am confident that the risk of confusion is acceptably small if the concept is properly explained." United States v. Shea, 957 F. Supp. 331, 345 (D.N.H. 1997).

[277] *See* NAS REPORT, *supra* note 7, at 235.

methods is only the beginning. The expert's work on the particular case must also satisfy the reliability evaluation.

Because there are so many actual and potential forensic applications of stable isotope analysis, this Article only sets the stage for a judge or lawyer confronted with this evidence. We hope the discussion of the Amerithrax case and the comparisons between stable isotope analysis and DNA identification evidence will be useful. We also hope we have kept faith with the NAS Report by calling for stable isotope evidence to satisfy rigorous reliability scrutiny. Finally, as a scientist and a lawyer, we hope this Article serves the causes of good science and just results.