This document sets forth background materials on the scientific research supporting examinations as conducted by the forensic laboratories at the Department of Justice. It also includes a discussion of significant policy matters. This document is provided to assist a public review and comment process of the related Proposed Uniform Language for Testimony and Reports (posted separately). It is not intended to, does not, and may not be relied upon to create any rights, substantive or procedural, enforceable by law by any party in any matter, civil or criminal, nor does it place any limitation on otherwise lawful investigative and litigative prerogatives of the Department.

SUPPORTING DOCUMENTATION FOR DEPARTMENT OF JUSTICE PROPOSED UNIFORM LANGUAGE FOR TESTIMONY AND REPORTS FOR THE FORENSIC GLASS DISCIPLINE

Background

Glass manufacturing began at approximately 4000 years B.C., but in the past three centuries, glass compositions and manufacturing processes for commercial production have evolved greatly.[1] The field of glass science developed as a result of the major commercial use of glass.[2]

Today, glass is produced in a wide variety of forms and compositions, and these affect the properties of this material. Glass can occur as evidence when it is broken during the commission of a crime. Broken glass fragments ranging in size from large pieces to tiny shards may be transferred to and retained by nearby persons or objects.

Numerous studies have been conducted to determine the background level of glass on clothing from randomly selected individuals.[3] These studies and many others demonstrate that it is unlikely that glass fragments will be found on people who have not

[1] Koons, R. D., Buscaglia, J., Bottrell, M., and Miller, E. T. Forensic glass comparisons. In: *Forensic Science Handbook.* Vol. I, 2nd ed. Richard Saferstein, Ed., Prentice Hall, Upper Saddle River, New Jersey, 2002, p. 161–213.

[2] Varshneya, A.K., *Fundamentals of Inorganic Glasses,* 2nd ed., The Society of Glass Technology, Sheffield, UK, 2006, p. 2.

[3] Lau, L., Beveridge, A. D., Callowhill, B. C., Conners, N., Foster, K., Groves, R. J., Ohashi, K. N., Sumner, A. M., and Wong, H. The frequency of occurrence of paint and glass on the clothing of high school students, *Canadian Society of Forensic Science Journal* (1997) 30:233–240; Petterd, C. I., Hamshere, J., Stewart, S., Brinch, K., Masi, T., and Roux, C. Glass particles in the clothing of members of the public in south-eastern Australia—A survey, *Forensic Science International* (1999) 103:193–198.; Roux, C., Kirk, R., Benson, S., Van Haren, T., and Petterd, C. I. Glass particles in footwear of members of the public in south-eastern Australia—A survey, *Forensic Science International* (2001) 116:149–156.; Lambert, J. A., Satterthwaite, M. J., and Harrison, P. H. A survey of glass fragments recovered from clothing of persons suspected of involvement in crime, *Science and Justice* (1995) 35:273–281.; McQuillan, J. and Edgar, K. A. Survey of the distribution of glass on clothing, *Journal of the Forensic Science Society* (1992) 32:333–348.; Zoro, J. A. and Fereday, M. J. Unpublished report. *Report of a Survey Concerning the Exposure of Individuals to Breaking Glass*. CRE Report No. 458. Central Research Establishment, Forensic Science Service, Reading, England, 1982..

been present when a glass object is broken or who have not come into contact with broken glass.

Glass evidence has been used in criminal cases at least as far back as 1933[4] and the FBI Laboratory has been conducting forensic glass examinations by physical and optical methods since the 1950s.[5] The addition of precise methods of elemental analysis of very small glass fragments like those seen in criminal cases became prevalent in the late 1980s and added additional discrimination capabilities. This advancement greatly enhanced the value of comparative glass examinations.[6]

Principles of Forensic Glass Examinations

Forensic examination, identification and comparison of materials demands rigorous protocols and any conclusions drawn from such analysis must be based on a strong scientific foundation.[7] The preferred methods employed in the analysis of glass at the Department are derived from geology, optical mineralogy, petrography, glass and ceramic engineering, fractography, chemistry, physics, and their subdisciplines. Abundant data have been published in peer-reviewed journals in both industry and forensic literature that validate the analytical techniques used in glass analysis and the theory behind comparisons. Glass analysis has been demonstrated to provide excellent discrimination potential, making it an outstanding tool for forensic analysis.[8]

It has long been reported by forensic glass examiners that two glass objects that physically fit together were once part of the same broken object.[9] In the absence of

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[4] Curran, J. M., Hicks, T. N., Walsh, K. A. and Buckleton, J. S. *Forensic Interpretation of Glass Evidence*. CRC Press, Boca Raton, Florida.

[5] "Don't Overlook Evidentiary Value of Glass Fragments", *Law Enforcement Bulletin*, Vol. 33, No. 10, October 1964, p. 19.

[6] Koons, R. D., Buscaglia, J., Bottrell, M., and Miller, E. T. Forensic glass comparisons. In: *Forensic Science Handbook.* Vol. I, 2nd ed. Richard Saferstein, Ed., Prentice Hall, Upper Saddle River, New Jersey, 2002, p. 161–213.

[7] Kirk, P., *Density and Refractive Index: Their Application in Criminal Identification,* Charles C. Thomas, Springfield, IL, 1951, p. 4-5.

[8] Bottrell, M.C., "Forensic Glass Comparison: Background Information Used in Data Interpretation", Forensic Science Communications [Online], (April, 2009). Available: http://www.fbi.gov/about-us/lab/forensic-science-communications/fsc/april2009/review/2009_04_review01.htm. accessed on May 24, 2016.; Curran, J. M., Hicks, T. N., Walsh, K. A. and Buckleton, J. S. *Forensic Interpretation of Glass Evidence*. CRC Press, Boca Raton, Florida.; Stoecklein, W., et al., "The Forensic Analysis of Float-Glass: Characterization of Glasses from International Sources, *ENFSI EWG Paint and Glass Newsletter*, Wiesbaden, 2009.; Caddy, B., *Forensic Examination of Glass and Paint,* Taylor & Francis, London, 2001.; Ryland, S. G. Sheet or container?—Forensic glass comparisons with an emphasis on source classification, *Journal of Forensic Sciences* (1986) 31:1314–1329.

[9] Kirk, P., *Density and Refractive Index: Their Application in Criminal Identification,* Charles C. Thomas, Springfield, IL, 1951, p. 4-5.; "Don't Overlook Evidentiary Value of Glass Fragments", *Law Enforcement Bulletin*, Vol. 33, No. 10, October 1964, p. 19.; Bottrell, M.C., "Forensic Glass Comparison: Background Information Used in Data Interpretation", Forensic Science Communications [Online], (April, 2009). Available: http://www.fbi.gov/about-us/lab/forensic-science-

a physical fit, the value of glass evidence lies with the fact that the variations in the observed and measured properties within a glass object are typically smaller than the variations among objects.[10] The ability to detect these differences between objects allows them to be distinguished. Therefore, the examiner must use the most discriminating analytical methods available and appropriate for each case.[11] Glass forensic analysis is based upon well established techniques that are generally accepted in the scientific community. These techniques are not limited to forensics and are routinely used in a variety of industries as well as academia.

Forensic Glass Examinations

There are different methodologies and processes for conducting a glass examination. The Department shares information regarding some appropriate processes below. The Department does not suggest that the processes outlined here are the only valid or appropriate processes.

A. Analysis

Because there are many materials that can be mistaken for glass at a casual glance, an examination must first be performed to determine if the specimen is actually glass. Methods typically employed to identify glass include the observation of conchoidal fracture, determination of hardness, reaction to a hotpoint, microscopy, and spectroscopy.[12]

communications/fsc/april2009/review/2009_04_review01.htm. accessed on August 15, 2013.; Koons, R. D., Buscaglia, J., Bottrell, M., and Miller, E. T. Forensic glass comparisons. In: *Forensic Science Handbook.* vol. I, 2nd ed. Richard Saferstein, Ed., Prentice Hall, Upper Saddle River, New Jersey, 2002, p. 161–213.

[10] Bottrell, M. C., Webb, J. B., Buscaglia, J., and Koons, R. D. *Distribution of Elemental Concentrations Within Individual Sheets of Float Glass.* Presented at the American Academy of Forensic Sciences Annual Meeting, San Antonio, February 2007; Hickman, D. A. Elemental analysis and the discrimination of sheet glass samples, *Forensic Science International* (1983) 23:213–223.; Koons, R. D., Fiedler, C., and Rawalt, R. C. Classification and discrimination of sheet and container glasses by inductively coupled plasma-atomic emission spectrometry and pattern recognition, *Journal of Forensic Sciences* (1988) 33:49–67.; Koons, R. D. and Buscaglia, J. The forensic significance of glass composition and refractive index measurements, *Journal of Forensic Sciences* (1999) 44:496–503.; Koons, R. D. and Buscaglia, J. Interpretation of glass composition measurements: The effects of match criteria on discrimination capability, *Journal of Forensic Sciences* (2002) 47:505–512.; Boyd, D. C., Danielson, P. S., and Thompson, D. A. Glass. In: *Kirk-Othmer Encyclopedia of Chemical Technology.* 4th ed., vol. 12. John Wiley & Sons, New York, 1994.; Corning, Incorporated, *Specialty Glass and Glass Ceramic Materials*. Corning, Incorporated, Corning, New York, 1998.; Doyle, P. J., Ed. *Glass-Making Today: An Introduction to Current Practice in Glass Manufacture*. R. A. N. Publishers, Marietta, Ohio, 1994.; Varshneya, A. K. *Fundamentals of Inorganic Glasses*. Academic Press, Boston, Massachusetts, 1994.

[11] Koons, R. D. and Buscaglia, J. The forensic significance of glass composition and refractive index measurements, *Journal of Forensic Sciences* (1999) 44:496–503.

[12] Gemological Institute of America (GIA). Imitations (translucent to opaque): Glass and plastic; chalcedony, jadeite, and lapis; pearls and other organics. In: *GIA Gem Identification*. Gemological Institute

Analysis of broken glass items for the purposes of determining the possibility of a common origin, compositional class or product type is accomplished by using one or more analytical techniques. These techniques include:

- Determination of a physical fit. This is done visually with the aid of light microscopy as necessary.[13]
- Determination of physical properties such as glass type, glass color, and thickness[14], fluorescence[15], surface features, and curvature[16]. The physical properties of the glass are determined using stereobinocular and petrographic microscopes, micrometers, and ultraviolet lights, or additional methods as needed (e.g. interferometry, scanning electron microscopy).[17]
- Measurement of the refractive index at up to three wavelengths, 488 nanometers (nm), 589 nm, and 656 nm. Refractive index of the glass is measured using the Foster + Freeman, Ltd. Glass Refractive Index Measuring system (GRIM3).[18]

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of America, Carlsbad, California, 1996, pp. 1–19; Hurlbut, C. S. Jr. and Klein, C. *Manual of Mineralogy (After James D. Dana)*. 19th ed. John Wiley & Sons, New York, 1977.

[13] Scientific Working Group for Materials Analysis (SWGMAT). Glass fractures, *Forensic Science Communications* [Online]. (January 2005c). Available: https://www.fbi.gov/about-us/lab/forensic-science-communications/fsc/jan2005/index.htm/standards/2005standards7.htm; Kirk, P., *Density and Refractive Index: Their Application in Criminal Identification*, Charles C. Thomas, Springfield, IL, 1951, p. 4-5.; "Don't Overlook Evidentiary Value of Glass Fragments", *Law Enforcement Bulletin*, Vol. 33, No. 10, October 1964, p. 19.; Frechette D., *Failure Analysis in Brittle Materials*, Advances in Ceramics, Volume 28; V.; The American Ceramic Society, Westerville, Ohio, 1990.

[14] ASTM International. *ASTM C1036-06 Standard Specification for Flat Glass*. ASTM International, West Conshohocken, Pennsylvania. Available: http://www.astm.org/Standards/C1036.htm.

[15] Lloyd, J. B. F. Fluorescence spectrometry in the identification and discrimination of float and other surfaces on window glasses, *Journal of Forensic Sciences* (1981) 26:325–342.

[16] Locke, J. New Developments in the Forensic Examination of Glass, *The Microscope* (1984) 32:1–11.

[17] Scientific Working Group for Materials Analysis (SWGMAT). Initial examination of glass, *Forensic Science Communications* [Online]. (January 2004e). Available: http://media.wix.com/ugd/4344b0_292c63e8448a46eb84252b6e62603680.pdf.

[18] Curran, J. M., Hicks, T. N., Walsh, K. A. and Buckleton, J. S. *Forensic Interpretation of Glass Evidence*. CRC Press, Boca Raton, Florida.; Scientific Working Group for Materials Analysis (SWGMAT). Glass refractive index determination, *Forensic Science Communications* [Online]. (January 2005d). Available: http://www.fbi.gov/hq/lab/fsc/backissu/jan2005/standards/2005standards9.htm; Andrasko, J. and Maehly, A. C. The discrimination between samples of window glass by combining physical and chemical techniques, *Journal of Forensic Sciences*, Vol. 23, 1978, p. 250–262.; Cassista, A. R. and Sandercock, P. M. L. Precision of glass refractive index measurements: Temperature variation and double variation methods and the value of dispersion, *Canadian Society of Forensic Science Journal*, Vol. 27, No. 3, 1994, p. 203–208.; Dabbs, M. D. G. and Pearson, E. F. The variation in refractive index and density across two sheets of window glass, *Journal of the Forensic Science Society, Vol. 10*, 1970, p. 139–148.; Locke, J. GRIM: A semi-automatic device for measuring the refractive index of glass particles, *Microscope, Vol. 33, No. 3*, 1985, p. 169–178.; ASTM International. *ASTM E1967-11a Standard Test Method for the Automated Determination of Refractive Index of Glass Samples Using the Oil Immersion Method and a Phase Contrast Microscope*. ASTM International, West Conshohocken, Pennsylvania. Available: http://www.astm.org/Standards/E1967.htm.; Garvin, E.J. and Koons, R.D., "Evaluation of Match Criteria Used for the Comparison of Refractive Index of Glass Fragments," *Journal of Forensic Sciences*, Vol. 56. No. 2, March 2011, p. 491-500.; Sandercock, P.M.L., "Sample Size Considerations for Control Glass in Casework," *Canadian Society Forensic Science Journal*, Vol. 33, 2000, p. 169-178.

- Determination of the concentrations of aluminum, barium, calcium, iron, magnesium, manganese, sodium, strontium, titanium, and zirconium. The elemental concentrations are determined using an inductively coupled plasma - optical emission spectrometer (ICP-OES).[19]
- Additional methods may be used as needed.

The actual tests performed are dependent on the size and shape of the glass fragments, the needs of the examination and analytical requirements. All results are confirmed by a second qualified examiner.

B. Interpretation

The physical properties expressed in the glass, and the refractive index and chemical composition data are used as the comparison criteria when compared items do not physically fit together. When physical properties assessed are the same and the refractive indices and chemical composition values are indistinguishable, the possibility that the compared fragments originated from the same source of broken glass cannot be eliminated.

The variations in the observed and measured properties within a glass object are typically smaller than the variations among objects. Studies have shown that refractive index measured at 589 nm and chemical composition of glass used in conjunction are highly discriminating,[20] differentiating most glass that is not the actual source. This finding strongly supports the supposition that a recovered glass fragment and a broken object with indistinguishable refractive index at 589 nm and elemental composition are unlikely to be from another source. While this finding is not a direct indicator of the rarity of a particular glass in any specific case, it can be used to indicate that the occurrence of coincidentally indistinguishable glass is rare. In glass specimens where only refractive index data can be measured, the chance of finding coincidentally indistinguishable glass is significantly higher.

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[19] Scientific Working Group for Materials Analysis (SWGMAT). Elemental analysis of glass, *Forensic Science Communications* [Online]. (January 2005a). Available: http://media.wix.com/ugd/4344b0_5308b93b07644d148dd7614268304857.pdf; Koons, R. D. and Buscaglia, J. The forensic significance of glass composition and refractive index measurements, *Journal of Forensic Sciences* (1999) 44:496–503.; Koons, R. D. and Buscaglia, J. Interpretation of glass composition measurements: The effects of match criteria on discrimination capability, *Journal of Forensic Sciences* (2002) 47:505–512.; Ryland, S. G. Sheet or container?—Forensic glass comparisons with an emphasis on source classification, *Journal of Forensic Sciences* (1986) 31:1314–1329.; Koons, R. D., Fiedler, C., and Rawalt, R. C. Classification and discrimination of sheet and container glasses by inductively coupled plasma-atomic emission spectrometry and pattern recognition, *Journal of Forensic Sciences* (1988) 33:49–67.; Koons, R. D., Peters, C. A., and Rebbert, P. S. Comparison of refractive index, energy dispersive X-ray fluorescence and inductively coupled plasma atomic emission spectrometry for forensic characterization of sheet glass fragments, *Journal of Analytical Atomic Spectrometry* (1991) 6:451–456.

[20] Koons, R. D. and Buscaglia, J. The forensic significance of glass composition and refractive index measurements, *Journal of Forensic Sciences* (1999) 44:496-503.

The Department relies on five possible conclusions when comparing glass fragments:[21]

- The glass fragments were once part of the same broken object. This conclusion is reached when two or more pieces of broken glass physically fit together.
- The glass fragments either originated from the same broken glass source or from another source(s) of broken glass indistinguishable in all of the measured or observed physical properties, refractive indices, and elemental composition. This conclusion is reached when two or more broken glass fragments are indistinguishable in their physical characteristics, refractive indices and chemical composition.
- The possibility that the glass fragments originated from the same source of broken glass cannot be eliminated. This conclusion is reached when two or more fragments of glass are indistinguishable in their physical characteristics and/or refractive indices, but are of insufficient size or quality for chemical analysis.
- The glass fragments are eliminated as originating from the same source(s). This can be concluded when two or more fragments of glass are different in their physical properties, refractive indices or chemical composition.
- The possible source(s) of broken glass cannot be determined. This conclusion is reached when a glass particle is too limited in size or quality.

C. Limitations

It is not always possible to assess every potential point of comparison in each glass item because not all fragments transferred, recovered, and submitted for forensic analysis will express every feature. Comparison analyses assess class characteristics that may associate objects with a group of similar objects such as containers, but never to a single object.

It is important to note, however, that although there may be several objects with identical properties, glass fragments can originate only from broken and not intact objects. Only when two or more broken glass fragments physically fit together can it be said that they were once part of the same object.

[21] The following statements are those currently used by the FBI Mineralogy Group (January, 2015). These conclusions will change as the discipline progresses, instrumentation improves, and as the needs of the judicial system dictate and are based on the question being evaluated and the evidence provided. Therefore, the statements given should be taken as a guide and will not necessarily mirror all reports written by the Mineralogy Group.

Policy Considerations

In 2006, Congress authorized the National Academy of Sciences (NAS) to conduct a study on forensic science which culminated in a 2009 report.[22] Although the NAS report did not provide specific criticism or guidance regarding forensic glass examinations, it did recommend that all forensic reports include the following: identification of the tests conducted, certain results of testing, and potential sources of error and statistical error. To conform with the NAS recommendations, glass reports include a discussion of the tests performed, the relative strength of the findings and the limitations associated with a given series of examinations.

The following studies have provided additional support for the comparison criteria currently used by the Department.

Using the Department's "Elemental Analysis of Glass by ICP-OES" Standard Operating Procedure (SOP),[23] a study measuring the concentrations of 10 elements in automobile side-window glasses determined the probability that two glasses from different vehicles would be indistinguishable to be one in 1,080, compared with one in five for refractive index alone.[24]

In a subsequent FBI study using statistical analysis of samples collected in casework, it was reported that ICP-OES measurements in conjunction with refractive index data (n_D) provide very high discrimination capability, on the order of 1 in 100,000 to 1 in 10 trillion.[25]

Garvin and Koons (2011) evaluated the match criteria for forensic glass analysis by GRIM and determined that the rate of false exclusions is minimized if the known exemplar is adequately characterized. The Department has adopted their recommendations for sampling of the known exemplar and comparison criteria.[26]

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[22] National Research Council. (2009) Strengthening Forensic Science in the United States: A Path Forward, National Academy Press, Washington, D.C. (http://nap.edu/catalog/12589.html)

[23] Federal Bureau of Investigation. Laboratory Division. Trace Evidence Unit: Elemental Analysis of Glass by Inductively Coupled Plasma – Optical Emission Spectrometry. In: *Trace Evidence Unit Standard Operating Procedures manual.* FBI Laboratory, Quantico, Virginia, July 10, 2006.

[24] Koons, R. D., Peters, C. A., and Rebbert, P. S. Comparison of refractive index, energy dispersive X-ray fluorescence and inductively coupled plasma atomic emission spectrometry for forensic characterization of sheet glass fragments, *Journal of Analytical Atomic Spectrometry* (1991) 6:451–456.

[25] Koons, R. D. and Buscaglia, J. The forensic significance of glass composition and refractive index measurements, *Journal of Forensic Sciences* (1999) 44:496–503.

[26] Garvin, E.J. and Koons, R.D., "Evaluation of Match Criteria Used for the Comparison of Refractive Index of Glass Fragments," *Journal of Forensic Sciences,* Vol. 56. No. 2, March 2011, p. 491-500.

Trejos et al.[27] evaluated the performance of several comparison criteria for the elemental analysis of glass. The Department has adopted their recommended criteria for ICP methods that minimize type I and type II errors.

[27] Trejos, Tatiana, et al. "Cross-validation and evaluation of the performance of methods for the elemental analysis of forensic glass by μ-XRF, ICP-MS, and LA-ICP-MS." *Analytical and bioanalytical chemistry* 405.16 (2013): 5393-5409; Trejos, Tatiana, et al. "Forensic analysis of glass by μ-XRF, SN-ICP-MS, LA-ICP-MS and LA-ICP-OES: evaluation of the performance of different criteria for comparing elemental composition." *Journal of Analytical Atomic Spectrometry* 28.8 (2013): 1270-1282.