OSAC 2023-N-0005 Standard Practice for Training a Forensic Glass Practitioner

Trace Materials Subcommittee
Chemistry: Trace Evidence Scientific Area Committee
Organization of Scientific Area Committees (OSAC) for Forensic Science

Draft OSAC Proposed Standard

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Rationale: The OSAC Materials (Trace) Subcommittee has developed a training document for the forensic analysis of glass. This document was created through a consensus process. It is anticipated that the standard will be used by practitioners and laboratories to develop a training program for the forensic analysis of glass. Legal or scientific terms that are generally understood or defined adequately in other readily available sources may not be included in this standard.

Standard Practice for Training a Forensic Glass Practitioner

1 Scope

1.1 This practice covers training elements and program objectives for use by forensic science service provider (FSSP) personnel responsible for training forensic science practitioners who will perform examinations and comparisons of glass.

1.2 The trainees and training program shall meet or exceed the minimum training requirements set forth in Practice E2917.

1.3 This practice outlines the tasks, goals, and objectives that allow the trainee to acquire the foundational knowledge and basic practical skills necessary to become a qualified forensic glass practitioner.

1.4 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2 Referenced Documents

2.1 ASTM Standards:

E2917 Practice for Forensic Science Practitioner Training, Continuing Education, and Professional Development Programs

C162 Terminology of Glass and Glass Products

C1036 Specification for Flat Glass

C1256 Practice for Interpreting Fracture Features

E456 Terminology Relating to Quality and Statistics

E1459 Guide for Physical Evidence Labeling and Related Documentation

E1492 Practice for Receiving, Documenting, Storing, and Retrieving Evidence in a Forensic Science Laboratory

WK72932 Guide for the Collection, Analysis and Comparison of Forensic Glass Samples

E1732 Terminology Relating to Forensic Science

E1967 Test Method for the Automated Determination of Refractive Index of Glass Samples Using the Oil Immersion Method and a Phase Contrast Microscope

E2926 Test Method for the Forensic Comparison of Glass Using Micro X-ray Fluorescence (µ-XRF) Spectrometry

E2927 Test Method for Determination of Trace Elements in Soda-Lime Glass Samples Using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) for Forensic Comparisons

E2330 Test Method for Determination of Concentrations of Elements in Glass Samples Using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for Forensic Comparisons

E620 Practice for Reporting Opinions of Scientific or Technical Experts

2.2 Other Documents:

2.2.1 Association of Analytical Chemists (AOAC) Method: 973.65 Emmons Double Variation

2.2.2 ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories

2.2.3 ANSI ANAB AR3125

2.2.4 OSAC 2022-S-0029, Standard Guide for Interpretation and Reporting in Forensic Comparisons of Trace Materials

2.2.5 OSAC 2022-S-0015, Standard Guide for Physical Fit Examination

3 Significance and Use

3.1 This training program will provide the trainee with a broad understanding of both the capabilities and limitations associated with the examination and interpretation of glass.

3.2 A glass analysis training program includes all the standard test methods and techniques used in the forensic examination of glass. This can include techniques beyond those that are covered by the FSSP's procedures.

3.2.1 Additional training could be required for a particular method or instrument referred to herein. The application of analytical techniques to glass analysis assumes the trainee is already competent in the use of each particular analytical technique or instrumental method.

3.3 Additional glass analysis training beyond that which is listed here should be made available to the trainee. Such training could include off-site courses, tours of manufacturing plants, and specialized training by experienced practitioners or subject matter experts.

3.4 Continuing education and training is recommended. Additional training provides a forensic glass practitioner with the opportunity to remain current in the field.

3.5 This practice is in a modular format for easy adaptation to an individual FSSP's training program. Recommendations as to lessons, practical exercises, progress monitoring, and trainee evaluations are included. Reading assignments are listed in each subsequent section of this practice; full citations are available in the References section.

4 Responsibilities

4.1 Each trainee is trained by and works under the guidance of one or more trainers (see 4.2).

4.1.1 The trainee shall meet or exceed the minimum training criteria set forth in Practice E2917 and the objectives set forth in the training program.

4.2 A trainer shall be technically qualified in forensic glass examination and comparison or associated techniques. Other members of the laboratory are encouraged to offer relevant information regarding their specialty to the trainee. The trainer(s) is responsible for:

4.2.1 Introducing the trainee to the relevant scientific literature, appropriate procedures, training material, and reference collections.

4.2.2 Discussing readings and theory with the trainee.

4.2.3 Teaching basic microscopy and instrumental methods for the analysis and comparison of glass evidence.

4.2.4 Teaching case management.

4.2.5 Fostering ethical professional conduct.

4.2.6 Discussing ways in which bias can influence glass examinations.

4.2.7 Teaching appropriate quality assurance and quality control procedures.

4.2.8 Reviewing tests, practical exercises, and casework samples with the trainee.

4.2.9 Teaching expert testimony skills through moot court and observation.

4.2.10 Monitoring the trainee's progress.

4.3 Each laboratory maintains:

4.3.1 An up-to-date training program which is reviewed and assessed for efficacy and relevance as described in Practice E2917.

4.3.2 Documentation of training according to Practice E2917.

4.3.3 Documentation of competency tests proficiency tests and criteria for acceptance.

5 Syllabus

5.1 A glass analysis training program provides the trainee theoretical knowledge and practical skills in examining, interpreting, reporting, testifying, and reviewing forensic glass cases. This is accomplished through a combination of the following training methods:

5.1.1 Reading of relevant literature:

5.1.1.1 The reading assignments listed are suggestions. Newer versions can be used. Other relevant literature can be used or added.

5.1.1.2 Where specific page numbers are not listed, it is the trainer's discretion to specify the appropriate sections.

5.1.2 Instruction and observation of forensic glass practitioners:

5.1.2.1 Lectures and discussions

5.1.2.2 Practical demonstration of basic skills

5.1.2.3 Casework

5.1.2.4 Report writing

5.1.2.5 Court testimony

5.1.3 Practical skills:

5.1.3.1 Practical exercises that include analysis of reference materials and known samples.

5.1.4 Final competency evaluations:

5.1.4.1 Written or oral tests,

5.1.4.2 Practical laboratory tests,

5.1.4.3 Mock cases

5.1.4.4 Moot court or oral exam.

5.1.5 Performing supervised casework.

5.2 The projected training period is between three to six months, full time, for a forensic practitioner that has been previously trained and is competent in the analytical techniques utilized in the analysis of glass evidence. For new practitioners with no previous training in microscopical or instrumental techniques, the projected training period is between nine to twelve months.

5.3 Successful completion of each milestone in the training program will be recorded using the guidance set forth in Practice E2917.

6 Objectives

6.1 Encountering Glass Evidence:

6.1.1 This section introduces the trainee to the types of cases and the various conditions in which glass is encountered as physical evidence.

6.1.2 Types of glass that could be encountered as evidence include automotive glass, architectural glass, container glass, and other specialty glasses.

6.1.3 Reading Assignments:

6.1.3.1 De Forest, "What is Trace Evidence?," pp. 17-19 (1).

6.1.3.2 Curran, et al., "Forensic Interpretation of Glass Evidence," pp. 1-10 (2).

6.1.3.3 Koons, et al., "Forensic glass comparisons," pp. 169-173 (3).

6.1.3.4 Curran, et al., "Interpretation of Glass Evidence," pp. 377-420 (4).

6.1.3.5 Almirall and Trejos, "Analysis of Glass Evidence," pp 228-272 (5).

6.1.3.6 Trejos, et al., "Scientific Foundations and Current State of Trace Evidence—a Review," pp 12-13 (6).

6.1.3.7 Bottrell, "Forensic Glass Comparison: Background Information Used in Data Interpretation," pp. 1-21 (7).

6.1.4 *Practical Exercises:*

6.1.4.1 Demonstrate knowledge of the types of cases and the various conditions in which glass is encountered as physical evidence through an oral or written exercise.

6.1.5 The methods of instruction for this unit are reading and research by the trainee and discussions with the trainer(s).

6.1.6 The method of evaluation for this unit is a review of the trainee's completed exercise by the trainer.

6.2 Glass Terminology:

6.2.1 This section introduces the trainee to frequently encountered terminology. Additional terminology will be encountered throughout the reading assignments.

6.2.1.1 annealing

6.2.1.2 blown glass

6.2.1.3 borosilicate glass

6.2.1.4 cast glass

6.2.1.5 concentric fractures

6.2.1.6 conchoidal fracture

6.2.1.7 cullet

6.2.1.8 dispersion

6.2.1.9 drawn glass

6.2.1.10 fiberglass

6.2.1.11 flat glass

6.2.1.12 float glass

6.2.1.13 frit

6.2.1.14 glass

6.2.1.15 hackle

6.2.1.16 hertzian cone

6.2.1.17 hinge fracture

6.2.1.18 laminated glass

6.2.1.19 mirror

6.2.1.20 mist hackle

6.2.1.21 plate glass

6.2.1.22 radial fractures

6.2.1.23 ream

6.2.1.24 refractive index

6.2.1.25 soda-lime glass

6.2.1.26 tempering

6.2.1.27 Wallner line

6.2.2 Reading Assignments:

6.2.2.1 C162 Standard Terminology of Glass and Glass Products

6.2.2.2 Practice C1256

6.2.2.3 Guide WK72932, sections 3, 5, and 8

6.2.2.4 OSAC Lexicon, https://lexicon.forensicosac.org/

6.2.3 Practical Exercises:

6.2.3.1 Define the terms listed in this section.

6.2.4 The methods of instruction for this unit are reading and research by the trainee.

6.2.5 The method of evaluation for this unit is an oral or written examination.

6.3 The Use and Composition of Glass:

6.3.1 This section introduces the trainee to the uses and compositions of different types of glass to include the following:

6.3.1.1 The significance of main components used for making glass, such as formers, modifiers, colorants, decolorants, and refining agents.

6.3.1.2 Classification of glass by chemical composition (e.g., soda lime, borosilicate, leaded glass)

6.3.1.3 End-use applications of various types of glass (e.g., containers, tempered glass, laminated glass, coated glass, glass fibers, specialty glass)

6.3.2 Reading Assignments:

6.3.2.1 Koons, et al., “Forensic glass comparisons,” pp. 169–173 (3).

6.3.2.2 Almirall and Trejos, “Analysis of Glass Evidence,” pp 228-272 (5).

6.3.3 Practical Exercise:

6.3.3.1 Explain the uses and differences of the glass components listed in this section.

6.3.4 The methods of instruction for this unit are reading and research by the trainee.

6.3.5 The method of evaluation for this unit is an oral or written examination.

6.4 Manufacturing Processes:

6.4.1 This section introduces the trainee to glass manufacturing and application processes to include the following:

6.4.1.1 Fundamentals of glass chemistry

6.4.1.2 How raw materials are acquired, stored, and mixed.

6.4.1.3 How flat glass is produced

6.4.1.4 How flat glass is modified (shaping, coating, toughening, laminating)

6.4.1.5 How container glass is produced

6.4.1.6 How different sorts of specialty glass are produced (e.g. portable electronic device glass, borosilicate glass, optical glass, glass ceramics and light bulb glass)

6.4.1.7 Glass manufacturer's quality control process

6.4.1.8 Variation of glass properties during production times within a single plant and between different plants

6.4.1.9 How glass is distributed in the market

6.4.1.10 Current trends in glass industry and distribution

6.4.2 *Reading Assignments:*

6.4.2.1 Pfaender, "Schott Guide to Glass" (8).

6.4.2.2 Charnock, "The float glass process," pp. 153–156 (9).

6.4.2.3 Seyfang, et al., "Glass fragments from portable electronic devices: Implications for forensic examinations," pp. 442-452 (10).

6.4.2.4 "The World of Glass," https://www.worldglassmap.com (accessed 09 March 2022) (11).

6.4.2.5 Copley, "The composition and manufacture of glass and its domestic and industrial applications," pp. 27-46 (12).

6.4.2.6 Gläser, "Low-emissive coatings on the outer surface of heat insulating glasses - a challenge to the flat glass industry," pp. 12-19 (13).

6.4.2.7 Koons, et al., "Forensic glass comparisons," pp. 163–169 (3).

6.4.3 Practical Exercises:

6.4.3.1 Explain the manufacturing and application processes of glass.

6.4.3.2 Visit glass manufacturing facilities when practical and view manufacturing videos.

6.4.4 The method of instruction for this unit is reading and watching videos and other training resources by the trainee.

6.4.5 The method of evaluation for this unit is an oral or written examination.

6.5 Overview of Forensic Glass Examinations:

6.5.1 This section introduces the trainee to the basic steps in forensic glass examinations and how these steps are used to characterize the glass. This section also introduces the trainee to the current guides for the forensic examination of glass.

6.5.2 Reading Assignments:

6.5.2.1 Laboratory specific glass analysis procedure(s)

6.5.2.2 Scientific Working Group for Materials Analysis (SWGMAT), "Trace Evidence Recovery Guidelines" (14).

6.5.2.3 Guide WK72932

6.5.2.4 Trejos, et al., "Scientific Foundations and Current State of Trace Evidence—a Review," pp. 13-16 (6).

6.5.3 *Practical Exercises* - None.

6.5.4 The methods of instruction for this unit are reading by the trainee and lecture from the trainer.

6.5.5 The method of evaluation for this unit is an oral or written examination.

6.6 Search, Collection, and Preservation Techniques for Glass Evidence:

6.6.1 This section introduces the trainee to methods for locating, collecting, and preserving all types of glass evidence. The trainee is exposed to evidence handling issues such as transfer, persistence, and loss of trace evidence. Topics include the following:

6.6.1.1 The recognition of glass fragments.

6.6.1.2 The use of visual examinations and low power magnification.

6.6.1.3 The use of the particle picking, taping, and scraping methods to collect loose debris.

6.6.1.4 Understanding the persistence, transfer, and loss of glass evidence.

6.6.1.5 Preservation techniques appropriate for various types of glass evidence.

6.6.2 Reading Assignments:

6.6.2.1 Guide E1459

6.6.2.2 Practice E1492

6.6.2.3 Guide WK72932

6.6.2.4 Palenik, “Microscopy and Microchemistry of Physical Evidence,” pp. 164-171 (15).

6.6.2.5 Pearson, et al., "Glass and Paint Fragments Found in Men's Outer Clothing - Report of a Survey," pp. 283–300 (16).

6.6.2.6 Scientific Working Group for Materials Analysis (SWGMAT), “Trace Evidence Recovery Guidelines,” pp. 1-7 (14).

6.6.2.7 Scientific Working Group for Materials Analysis (SWGMAT), “Trace Evidence Quality Assurance Guidelines,” pp. 1-9, 15-17 (17)

6.6.2.8 Buzzini and Yu, “General Principles and Techniques of Trace Evidence Collection,” pp. 75-97 (18)

6.6.2.9 Curran, et al., “Forensic Interpretation of Glass Evidence,” pp. 87-131 (2).

6.6.2.10 Allen and Scranage, “The transfer of glass - part 1 - Transfer of glass to individuals at different distances,” pp. 167-174 (19).

6.6.2.11 Allen, et al., “The transfer of glass - part 2 - A study of the transfer of glass to a person by various methods,” pp. 175-193 (20).

6.6.2.12 Allen, et al., “The transfer of glass - part 3 - the transfer of glass from a contaminated person to another uncontaminated person during a ride in a car,” pp. 195-200 (21).

6.6.2.13 Allen, et al., “The transfer of glass - part 4 - the transfer of glass fragments from the surface of an item to the person carrying it,” pp. 201-208 (22).

6.6.2.14 Curran, et al., “Assessing transfer probabilities in a Bayesian interpretation of forensic glass evidence,” pp. 15-21 (23).

6.6.2.15 Harrison, et al., “A survey of glass fragments recovered from clothing of persons suspected of involvement in crime,” pp. 171-187 (24).

6.6.2.16 Lambert, et al, “A survey of glass fragments recovered from clothing of persons suspected of involvement in crime,” pp. 273-281 (25).

6.6.2.17 Lau, et al., ”The frequency of occurrence of paint and glass on the clothing of high school students,” pp. 233-240 (26).

6.6.2.18 Locke and Unikowski, “Breaking of flat glass - Part 1: Size and distribution of particles from plain glass windows,” pp. 251-262 (27).

6.6.2.19 Locke and Unikowski, “Breaking of flat glass - Part 2: Effect of pane parameters on particle distribution,” pp. 95-106 (28).

6.6.2.20 Locke and Scrange, “Breaking of flat glass - Part 3: Surface particles from windows and windscreens,” pp. 73-80 (29).

6.6.2.21 Allen, et al., “Breaking of flat glass - Part 4: Size and distribution of fragments from vehicle windscreens,” pp. 209-218 (30).

6.6.2.22 Petterd, et al., “Glass particles in the clothing of members of the public in south-eastern Australia - a survey,” pp. 193-198. (31).

6.6.2.23 Roux, et al., “Glass particles in footwear of members of the public in south-eastern Australia - a survey,” pp. 149-156 (32).

6.6.3 Practical Exercises:

6.6.3.1 Perform collections of glass fragments of different sizes from a variety of materials utilizing the methods learned above.

6.6.3.2 Demonstrate appropriate packaging techniques for debris collected and items of evidence, including known and questioned samples.

6.6.3.3 Demonstrate appropriate sampling strategies at the crime scene and at the laboratory to collect representative samples and prevent cross contamination

6.6.4 The methods of instruction for this unit are reading by the trainee and practical instruction from the trainer.

6.6.5 The method of evaluation for this unit is an evaluation of the practical exercises.

6.7 Fractography & Physical Fit of Glass

6.7.1 This section introduces the trainee to the evaluation of broken glass objects for characterization and reassembly. Topics include:

6.7.1.1 Determining the cause (e.g., type of fracture, origin, relative velocity) and direction of the breaking force.

6.7.1.2 Determining the sequence of multiple impacts.

6.7.1.3 Realigning two or more fragments to determine if they were at one time a single unit.

6.7.2 Reading assignments:

6.7.2.1 Practice C1256

6.7.2.2 Guide WK72932, Section 7.

6.7.2.3 OSAC 2022-S-0015

6.7.2.4 Quinn, “Fractography of Ceramics and Glasses” (33).

6.7.2.5 Thornton, “Interpretation of physical aspects of glass evidence,” pp. 97-119 (34).

6.7.2.6 Thornton and Cashman, “Glass Fracture Mechanism – A Rethinking,” pp. 818-824 (35).

6.7.2.7 Welch, et al., “The observation of banding in glass fragments and its forensic significance,” pp. 5-13 (36).

6.7.2.8 Lentini, “Behavior of Glass at Elevated Temperatures,” pp. 1358-1362 (37).

6.7.2.9 Michalshke and Bunker, “The Fracturing of Glass,” pp. 122-129 (38).

6.7.2.10 Katterwe, “Fracture Matching and Repetitive Experiments: A Contribution of Validation,” pp. 229-241 (39).

6.7.2.11 Koons, “Forensic Glass Comparisons,” pp. 173-177 (3).

6.7.3 Practical Exercise:

6.7.3.1 Reconstruct various broken glass objects.

6.7.3.2 Determine the cause and origin of fractures.

6.7.3.3 Determine the sequence of multiple impacts

6.7.3.4 Determine the direction of the breaking force.

6.7.4 The methods of instruction for this unit are reading by the trainee and practical instruction from the trainer.

6.7.5 The method of evaluation for this unit is an evaluation of the practical exercise.

6.8 Physical and Microscopical Characteristics of Glass

6.8.1 This section introduces the trainee to the recognition, description, and categorization of glass. Topics include:

6.8.1.1Macroscopical and microscopical properties of glass and glass fragments

6.8.1.2Microscopical techniques including stereomicroscopy and polarized light microscopy

6.8.1.3Categories of glass distinguishable by these techniques

6.8.2 Reading assignments:

6.8.2.1 Delly, et al. “Polarized Light Microscopy,” pp. 1-64, 125-188 (40).

6.8.2.2 DeForest, “Foundations of Forensic Microscopy,” pp. 216-319 (41).

6.8.2.3 Hamer, "Microscopic techniques for glass examination," pp. 47-64. (42).

6.8.2.4 Elliott et al., “The Microscopic Examination of Glass Surfaces,” pp. 459-471 (43).

6.8.2.5 Curran, et al., “Forensic Interpretation of Glass Evidence,” pp. 10-11, 15-17 (2).

6.8.2.6 Locke, "New Developments in the Forensic Examination of Glass," pp. 1-11 (44).

6.8.2.7 Danielzik, et al., "Overview - Thin Films on Glass: an Established Technology," pp 1-7 (45).

6.8.2.8 Guide WK72932, Sections 8 - 10.

6.8.3 Practical Exercise:

6.8.3.1 Describe and categorize a set of glass samples. Samples should consist of a variety of glass samples including float, non-float, flat, curved, tempered, untempered, colored, fiberglass, cast glass, laminated glass, glass of various thicknesses, and glass fragments of various sizes.

6.8.3.2 View online manufacturer demonstrations of various microscope techniques and configurations.

6.8.4 The methods of instruction for this unit are reading by the trainee and practical instruction from the trainer.

6.8.5 The method of evaluation for this unit is an evaluation of the practical exercise.

6.9 Statistical analysis overview

6.9.1 This section introduces the trainee to some basic concepts of statistics and chemometrics that are helpful in the evaluation of analytical data during forensic glass examinations. Topics include the following:

6.9.1.1 Types of data (e.g., continuous, discrete, nominal, univariate, multivariate)

6.9.1.2 Descriptive statistics (e.g., mean and median values, standard deviation, variance, bias)

6.9.1.3 Calibration methods in instrumental analysis in glass examinations (e.g., external calibration, internal standardization, matrix matched standards, linear regression)

6.9.1.4 Measurement uncertainty, propagation of errors, and reporting significant figures

6.9.1.5 Types of errors in quantitative analysis

6.9.1.6 Precision, bias, and accuracy

6.9.1.7 Handling of systematic errors and testing for outliers

6.9.1.8 The distribution of repeated measurements and confidence limits

6.9.1.9 Comparison criteria used in the examination of glass

6.9.1.10 Estimating and reporting of figures of merit (signal to noise ratio, limit of detection, limit of quantification, linear dynamic range, selectivity, bias, precision)

6.9.1.11 Evaluation of performance measures in glass examinations (error or misclassification rates, discrimination power, selectivity, sensitivity, accuracy)

6.9.1.12 Introduction to quality control methods for glass measurements

6.9.1.13 Introduction to frequency and probability

6.9.1.14 Introduction to the two-stage approach, hypothesis testing, and likelihood ratios approach for the comparison of data from glass examinations

6.9.2 *Reading assignments:*

6.9.2.1 Miller and Miller, “Statistics and Chemometrics for Analytical Chemistry” (46).

6.9.2.2 Zadora, et al., “Statistical Analysis in Forensic Science: Evidential Value of Multivariate Physicochemical Data” (47).

6.9.2.3 Curran, et al., “Interpretation of Glass Evidence,” pp. 377-420 (4).

6.9.2.4 Curran, et al., “Forensic Interpretation of Glass Evidence,” pp. 1-178 (2).

6.9.2.5 Evett, “Bayesian Inference and Forensic Science: Problems and Perspectives,” pp. 99-105 (48).

6.9.3 Practical Exercise:

6.9.3.1 Practical exercises for statistical calculations using spreadsheet software with mock case data or available literature data, such as refractive index and elemental analysis data.

6.9.4 The methods of instruction for this unit are reading by the trainee and practical instruction from the trainer.

6.9.5 The method of evaluation for this unit is an evaluation of the practical exercise

6.10 Refractive Index:

6.10.1 This section introduces the trainee to automated determination of refractive index of glass samples using the oil immersion method and a phase contrast microscope. Topics include:

6.10.1.1 Fundamentals of refractive index and refractive index determinations

6.10.1.2 Fundamentals of phase contrast microscopy

6.10.1.3 Preparation of glass samples for the measurements

6.10.1.4 Instrument set-up and calibration, quality control check

6.10.1.5 Measurement procedure and measurement parameters

6.10.1.6 General preventive maintenance requirements of the instrument

6.10.1.7 Laboratory annealing

6.10.1.8 Databases, population studies, and discrimination by refractive index

6.10.1.9 Measurement uncertainty, comparison criteria

6.10.2 Reading assignments:

6.10.2.1 Test Method E1967

6.10.2.2 Guide WK72932, Sections 12 - 14.

6.10.2.3 Dabbs and Pearson, "The Variation in Refractive Index and Density Across Two Sheets of Window Glass," pp. 139-148 (49).

6.10.2.4 Locke and Hayes, "Refractive index variations across glass objects and the influence of annealing," pp. 147-157 (50).

6.10.2.5 Zoro, et al., "An investigation of refractive index anomalies at the surface of glass objects and windows," pp. 127-141 (51).

6.10.2.6 Bennett et al., "Spatial variation of refractive index in a pane of float glass," pp. 71-76 (52).

6.10.2.7 Munger, et al, "Determining the refractive index variation within panes of vehicular windshield glass," pp. 1351-1357 (53).

6.10.2.8 Cassista and Sandercock, "Precision of Glass Refractive Index Measurements: Temperature Variation and Double Variation Methods, and the Value of Dispersion," pp. 203-208 (54).

6.10.2.9 Davies, et al., "An investigation of bulk and surface refractive indices for flat window glasses, patterned window glasses and windscreen glasses," pp. 125-137 (55).

6.10.2.10 Koons and Buscaglia, "Distribution of Refractive Index Values in Sheet Glasses," pp. 1-3 (56).

6.10.2.11 Koons and Buscaglia, "Forensic Significance of Glass Composition and Refractive Index Measurements," pp. 496-503 (57).

6.10.2.12 Locke, "GRIM: A semi-automatic device for measuring the refractive index of glass particles," pp. 169-178 (58).

6.10.2.13 Locke and Underhill, "Automatic refractive index measurements of glass particles," pp. 247-260 (59).

6.10.2.14 Underhill, "Multiple refractive index in float glass," pp. 169-176 (60).

6.10.2.15 Koons, et al., "Forensic Glass Comparisons," pp. 186-202 (3).

6.10.2.16 Sandercock, "Sample Size Considerations for Control Glass in Casework," pp. 173-185 (61).

6.10.2.17 Garvin and Koons, "Evaluation of match criteria used for the comparison of refractive index of glass fragments," pp. 491-500 (62).

6.10.2.18 Alamilla, et al., "Validation of an analytical method for the refractive index measurement of glass fragments. Application to a hit-and-run incident," pp. 1178-1184 (63).

6.10.2.19 Locke, et al., "The identification of toughened glass by annealing," pp. 295-301 (64).

6.10.2.20 Locke, et al., "The design of equipment and thermal routines for annealing glass particles," pp. 139-146 (65).

6.10.2.21 Locke and Rockett, "The application of annealing to improve the discrimination between glasses," pp. 237-245 (66).

6.10.2.22 Locke, et al., "A comparison of long and short schedules for the annealing of glass particles," pp. 247-258 (67).

6.10.2.23 Newton and Buckleton, "An investigation into the relationship between edge counts and the variability of the refractive index of glass. Part I: Edge morphology," pp. 24-31 (68).

6.10.2.24 Marcouiller, J.M., "A revised glass annealing method to distinguish glass types," pp. 554-559 (69).

6.10.2.25 Manufacturer manuals and tutorials.

6.10.3 Practical Exercise:

6.10.3.1 Practical exercises include sample and standards preparation, proper handling of chemicals, performing a calibration curve, measuring samples with known refractive index, before and after annealing, to test method performance, precision and bias.

6.10.3.2 Diagram and describe the components of a RI instrument.

6.10.4 The methods of instruction for this unit are reading by the trainee and practical instruction from the trainer.

6.10.5 The method of evaluation for this unit is an evaluation of the practical exercise.

6.11 Introduction to elemental analysis of glass

6.11.1 This section introduces the trainee to the fundamentals of the elemental analysis of glass. The following topics are included:

6.11.1.1 Introduction to the purpose and scope of elemental analysis in forensic science

6.11.1.2 Premises and bases for the application of elemental analysis in the forensic comparison of glass

6.11.1.3 Identification of instrumental method's requirements for the forensic elemental analysis of glass

6.11.1.4 Sources of variability in the elemental composition of glass

6.11.1.5 Overview of standard test methods for the elemental comparison of glass

6.11.1.6 Comparison of capabilities and limitations of instrumental methods for the elemental analysis of glass

6.11.2 *Reading assignments:*

6.11.2.1 Koons, et al., "Forensic Glass Comparisons," pp. 169-173 (3).

6.11.2.2 Guide WK72932, Section 15.

6.11.2.3 Trejos, et al., "Scientific Foundations and Current State of Trace Evidence—a Review," pp. 12-13. (6).

6.11.2.4 Almirall and Trejos, "Analysis of Glass Evidence," pp. 228-272 (5).

6.11.3 The methods of instruction for this unit are reading by the trainee and discussions with the trainer

6.11.4 The method of evaluation for this unit is a written examination.

6.12 Micro-X-ray Fluorescence (μ-XRF) Spectrometry:

6.12.1 This section introduces the trainee to the examination and comparison of a variety of glasses based on elemental analysis using *μ*-XRF. Topics include:

6.12.1.1 Fundamentals of *μ*-XRF, including:

Primary and secondary X-rays
Characteristic and non-characteristic X-ray emissions
Nomenclature for the identification of characteristic X-ray emission lines
Instrumental configurations and measurement parameters
Detector types
Analysis depth (i.e., Critical depth effects)
Spectral artifacts
Signal to Noise (S/N) ratios

6.12.1.2 Relevant elements in glass examinations and their respective characteristic X-ray lines

6.12.1.3 Sample preparation for analysis by *μ*-XRF

6.12.1.4 Data collection

6.12.1.5 Comparison of samples based upon their elemental components

6.12.1.6 General preventive maintenance requirements of the instrument

6.12.1.7 Quality control checks

6.12.1.8 Strengths and limitations of the technique

6.12.2 Reading Assignments:

6.12.2.1 Goldstein, et al., “Scanning Electron Microscopy and X-Ray Microanalysis” (70).

6.12.2.2 Brouwer, “Theory of XRF,” pp. 1-57. (71).

6.12.2.3 Test Method E2926

6.12.2.4 Buscaglia, “Elemental analysis of small glass fragments in forensic science,” pp. 17-24 (72).

6.12.2.5 Trejos, 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,” pp. 5393-5409 (73).

6.12.2.6 Trejos, et al., “Forensic analysis of glass by μ-XRF, SN-ICP-MS, LA-ICP-MS, and LA-ICP-OES: evaluation of the performance of difference criteria for comparing elemental composition,” pp. 1270-1282 (74).

6.12.2.7 Naes, et al., “A comparison of laser ablation inductively coupled mass spectrometry, micro X-ray fluorescence spectroscopy, and laser induced breakdown spectroscopy for the discrimination of automotive glass,” pp. 1145-1150 (75).

6.12.2.8 Ryland, “Discrimination of Flat (Sheet) Glass Specimens Having Similar Refractive Indices Using Micro X-Ray Fluorescence Spectrometry,” pp. 2-12 (76).

6.12.2.9 Ernst, et al., “Signal-to noise ratios in forensic glass analysis by micro X-Ray fluorescence spectrometry,” pp. 13-21 (77).

6.12.2.10 Corzo and Steel, “Improving signal-to-noise ratio for the forensic analysis of glass using micro X-Ray fluorescence spectrometry,” pp. 679-689 (78).

6.12.2.11 Corzo, et al., “An interlaboratory study evaluating the interpretation of forensic glass evidence using refractive index measurements and elemental composition,” pp. 1-10 (79).

6.12.2.12 Buhrke, et al., “A Practical Guide for the Preparation of Specimens for X-ray Fluorescence and X-ray Diffraction Analysis” (80).

6.12.2.13 Ernst, et al., “Forensic Examination of Ceramic Frit on Automotive Glass,” pp 22-44 (81).

6.12.2.14 Manufacturer manuals and tutorials.

6.12.3 Practical Exercises:

6.12.3.1 Practical exercises include sample and standards preparation, instrument calibrations, performance checks and calibration checks.

6.12.3.2 Diagram and describe the components of a *μ*-XRF instrument.

6.12.3.3 Compare the elemental characteristics of a variety of glass types using *μ*-XRF.

6.12.3.4 Demonstrate the effects of analysis depth in glass samples.

6.12.3.5 Demonstrate techniques to improve data quality (e.g., sample preparation, instrument parameters)

6.12.3.6 Compare glass samples according to Test Method E2926.

6.12.4 The methods of instruction for this unit are reading by the trainee and lecture from the trainer.

6.12.5 The method of evaluation for this unit is a review of the practical exercise.

6.13 Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS):

6.13.1 This section introduces the trainee to the comparison of glass samples based on elemental analysis of major, minor and trace elements by laser ablation - inductively coupled plasma - mass spectrometry (LA-ICP-MS).

6.13.1.1 Include the following points of instruction:

6.13.1.2 Basic principles of ICP-MS analysis

6.13.1.3 Different mass analyzers

6.13.1.4 Spectral interferences and possibilities to avoid them

6.13.1.5 Non-spectral interferences

6.13.1.6 Basic principles of laser ablation

6.13.1.7 Laser types

6.13.1.8 Elemental fractionation and factors affecting them

6.13.1.9 Common instrumental configuration and parameters for glass

6.13.1.10 Instrument setup and calibrations

6.13.1.11 Quality control check, data evaluation and criteria for comparison of samples

6.13.1.12 General preventive maintenance requirements of the instrument

6.13.1.13 Data processing fundamentals

6.13.2 Reading Assignments:

6.13.2.1 Test Method E2927

6.13.2.2 Thomas, "Practical guide to ICP-MS" (82).

6.13.2.3 Longerich, et al., "Laser Ablation Inductively Coupled Mass Spectrometric Transient Signal Data Acquisition and Analyte Concentration Calculation," pp. 899-904 (83).

6.13.2.4 Latkoczy, et al., "Development and evaluation of a standard method for the quantitative determination of elements in float glass samples by LA-ICP-MS," pp. 1327-1341 (84).

6.13.2.5 Berends-Montero, et al., "Forensic analysis of float glass using laser ablation inductively coupled mass spectrometry (LA-ICP-MS): validation of a method," pp. 1185-1193 (85).

6.13.2.6 Weis, et al., "Establishing a match criterion in forensic comparison analysis of float glass using laser ablation inductively coupled mass spectrometry," pp. 1273-1284 (86).

6.13.2.7 Trejos, 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," pp. 5393-5409 (73).

6.13.2.8 Trejos, et al., "Forensic analysis of glass by μ-XRF, SN-ICP-MS, LA-ICP-MS, and LA-ICP-OES: evaluation of the performance of difference criteria for comparing elemental composition," pp. 1270-1282 (74).

6.13.2.9 Dorn, et al., "Discrimination of float glass by LA-ICP-MS: assessment of exclusion criteria using casework samples," pp. 85-96 (87).

6.13.2.10 Corzo, et al., "The use of LA-ICP-MS databases to calculate likelihood ratios for the forensic analysis of glass evidence," pp 655-661 (88).

6.13.2.11 Hoffman, et al., "An inter-laboratory evaluation of LA-ICP-MS Analysis of Glass and the Use of a Database for the Interpretation of Glass Evidence," pp. 65-76 (89).

6.13.2.12 van Es, et al., "Implementation and assessment of a likelihood ratio approach for the evaluation of LA-ICP-MS evidence in forensic glass analysis," pp. 181-192 (90).

6.13.2.13 Becker, et al., "Forensic float glass fragment analysis using single-pulse laser ablation inductively coupled plasma time of flight mass spectrometry," pp. 2248-2254 (91).

6.13.2.14 Miller and Denton, "The quadrupole mass filter: basic operating concepts," pp. 617-622 (92).

6.13.2.15 Gray, "Solid sample introduction by laser ablation for inductively coupled plasma source mass spectrometry," pp. 551-556 (93).

6.13.2.16 Guillong, et al., ”A comparison of 266 nm, 213 nm, and 193 nm produced from a single solid state Nd: YAG laser for laser ablation ICP-MS,” pp. 1224-1230 (94).

6.13.2.17 Gonzalez, et al., “Comparison of 193, 213, and 266 nm laser ablation ICP-MS,” pp. 1108-1113 (95).

6.13.2.18 Horn and Gunther, “The influence of ablation carrier gasses Ar, He, and Ne on the particle size distribution and transport efficiencies of laser ablation-induced aerosols: implications for LA-ICP-MS," pp. 144-157 (96).

6.13.2.19 Sylvester, “Laser-ablation-ICPMS in the Earth Sciences: Principles and Applications,” pp. 35-51, pp. 79-88, pp. 312-314.(97).

6.13.2.20 Houk, et al., “Inductively coupled argon plasma as an ion source for mass spectrometric determination of trace elements,” pp. 2283-2289 (98).

6.13.2.21 Miller and Denton, “The quadrupole mass filter: basic operating concepts,” pp. 617-622 (92).

6.13.2.22 Heydon, et al., “Elemental heterogeneity observations in float glass samples via LA-ICP-MS thickness profiling,” pp. 103-107 (99).

6.13.2.23 Manufacturer manuals and tutorials.

6.13.3 Practical Exercises:

6.13.3.1 Practical exercises include performing a complete analysis of several standard materials (e.g. NIST 612, NIST SRM 614, NIST SRM 1831, Schott/BKA FGS 1) applying ASTM E2927 and your laboratory SOPs, including sample preparation, instrument setup with tuning and calibrations, programming and running the sample sequence, and data evaluation. Compare results with reference values and discuss performance, precision and bias.

6.13.3.2 Practical exercises include sample and standards preparation, performing a calibration, measuring samples with known elemental composition to test method performance, precision and bias. (see 6.13.3.1)

6.13.3.3 Diagram and describe the components of a laser ablation unit

6.13.3.4 Diagram and describe the components of an ICP-MS instrument

6.13.3.5 Describe the different options of dealing with spectral interferences

6.13.3.6 Describe mechanisms and parameters that can influence elemental fractionation

6.13.3.7 Describe advantages and disadvantages of the different mass analysers

6.13.3.8 Describe advantages and disadvantages of different laser types (wavelengths, pulse durations, fluence)

6.13.3.9 If possible, take part in a specialized LA-ICP-MS training

6.13.4 The methods of instruction for this unit are reading by the trainee and lecture from the trainer.

6.13.5 The method of evaluation for this unit is a review of the practical exercise.

6.14 Other Analytical Techniques:

6.14.1 This section introduces the trainee to additional analytical techniques that can be used but are not currently in frequent use in forensic glass analysis.

6.14.1.1 If any of these techniques are used for glass analysis in the trainee's laboratory, additional training for that technique shall be conducted as specified by the laboratory's protocols and should be in accordance with the level of training specified for the techniques listed in this document.

6.14.1.2 Include the following points of instruction:

6.14.1.3 Basic understanding of SEM/EDS and its application to glass analysis

6.14.1.4 Basic understanding of ICP-MS and its application to glass analysis

6.14.1.5 Basic understanding of ICP-OES and its application to glass analysis

6.14.1.6 Basic understanding of LIBS and its application to glass analysis

6.14.1.7 Understanding of how each technique can be used to compare samples based upon their elemental components.

6.14.1.8 Strengths and limitations of the techniques for glass analysis.

6.14.2 Reading Assignments

6.14.2.1 Goldstein, et al., "Scanning Electron Microscopy and X-Ray Microanalysis" (70).

6.14.2.2 Flegler, et al., "Scanning and Transmission Electron Microscopy: An Introduction" (100).

6.14.2.3 Test Method E2330

6.14.2.4 Guide WK72932, Section 15

6.14.2.5 Naes, et al., "A comparison of laser ablation inductively coupled mass spectrometry, micro X-ray fluorescence spectroscopy, and laser induced breakdown spectroscopy for the discrimination of automotive glass," pp. 1145-1150 (75).

6.14.2.6 Sigman, "Application of Laser-Induced Breakdown Spectroscopy to Forensic Science: Analysis of Paint and Glass Samples," pp. 1-43 (101).

6.14.2.7 Gottfried, et al., "Laser-Induced Breakdown Spectroscopy: Capabilities and Applications," pp. 1-13 (102).

6.14.3 Practical Exercise:

6.14.3.1 Diagram the components of each technique.

6.14.3.2 Describe why each technique is not currently in frequent use in forensic glass analysis.

6.14.4 The methods of instruction for this unit are reading by the trainee and lecture from the trainer.

6.14.5 The method of evaluation for this unit is a review of the practical exercise.

6.15 Comparison and Interpretation:

6.15.1 This section introduces the trainee to the comparison of a variety of glasses based on their physical and chemical characteristics.

6.15.2 Include the following points of instruction:

6.15.2.1 Assessing the comparison results and attaching significance to those results.

6.15.2.2 Discussing the comparative stage, evaluative stage and combined approaches.

6.15.2.3 Defining and recognizing exclusionary differences.

6.15.2.4 Explaining the discrimination power of the analytical protocol used.

6.15.2.5 Understanding the use of databases to assign a significance to evidence

6.15.3 Reading Assignments:

6.15.3.1 Hoffman, et al., "An inter-laboratory evaluation of LA-ICP-MS Analysis of Glass and the Use of a Database for the Interpretation of Glass Evidence," pp. 65-76 (89).

6.15.3.2 Guide WK72932, Section 17.

6.15.3.3 Corzo, et al., "The use of LA-ICP-MS databases to calculate likelihood ratios for the forensic analysis of glass evidence," pp 655-661 (88).

6.15.3.4 Akmeemana, et al., "Interpretation of chemical data from glass analysis for forensic purposes," pp. 1-14 (103).

6.15.3.5 Gupta, et al., "Dimensionality reduction of multielement glass evidence to calculate likelihood ratios," pp. 1-16 (104).

6.15.4 Practical Exercise

6.15.4.1 Complete comparisons and summarize the completed practical exercise sets utilized in previous instruction.

6.15.5 The methods of instruction for this unit are reading by the trainee and lecture from the trainer.

6.15.6 The method of evaluation for this unit is a review of the practical exercise.

6.16 Report Writing:

6.16.1 This section introduces the trainee to writing technically and administratively accurate reports for forensic glass examinations.

6.16.2 Include the following points of instruction:

6.16.2.1 Recognizing and addressing biases

6.16.2.2 Ethical considerations

6.16.2.3 Truthfulness, candor, objectivity

6.16.3 Reading Assignments:

6.16.3.1 Laboratory specific procedure(s) on reporting applicable to glass analyses.

6.16.3.2 OSAC 2022-S-0029

6.16.3.3 ISO/IEC 17025:2017 and Accreditation Requirements (AR) 3125 - Sections that refer to report writing.

6.16.3.4 Practice E620

6.16.3.5 Dror, "Cognitive and Human Factors in Expert Decision Making: Six Fallacies and the Eight Sources of Bias," pp. 7998-8004 (105).

6.16.4 Practical Exercise:

6.16.4.1 Write reports for the previously completed practical exercises using the range of opinions that may be reached during glass examinations.

6.16.5 The methods of instruction for this unit are reading completed technically reviewed reports and lectures from the trainer.

6.16.6 The method of evaluation for this unit is a review of the reports written by the trainee.

6.17 Testimony:

6.17.1 This section introduces the trainee to testimony in forensic glass analysis.

6.17.2 Include the following points of instruction:

6.17.2.1 Role of an expert witness

6.17.2.2 Recognizing and addressing biases

6.17.2.3 Ethical considerations

6.17.2.4 Truthfulness, candor, objectivity

6.17.2.5 Expressing interpretations, opinions, and results of technical material to the trier-of-fact

6.17.3 Reading Assignments:

6.17.3.1 Daubert v. Merrell Dow Pharmaceuticals (92-102), 509 U.S. 579 (1993).

6.17.3.2 Frye v. United States 293 F. 1013 (D.C. Cir. 1923).

6.17.3.3 Kumho Tire Co. v. Carmichael 526 US 137 (1999).

6.17.3.4 Melendez-Diaz v. Massachusetts 557 US 305 (2009).

6.17.3.5 Bullcoming v. New Mexico 564 US 647 (2011).

6.17.3.6 Dror, "The ambition to be scientific: Human expert performance and objectivity," pp. 81-82 (106).

6.17.4 Practical Exercise:

6.17.4.1 Prepare a list of suggested qualifying and predicate questions and answers for testimony.

6.17.4.2 Review relevant materials for an admissibility hearing.

6.17.5 The methods of instruction for this unit are lectures from the trainer and viewing court testimony (if possible).

6.17.6 The method of evaluation for this unit is a review of the court documents prepared by the trainee.

6.18 Final Training Evaluations:

6.18.1 This section evaluates the knowledge, skills, and abilities of the trainee through the following methods:

6.18.1.1 Completing a final, comprehensive, written or oral examination on forensic glass examinations.

6.18.1.2 Conducting mock case(s) for competency evaluation.

6.18.1.3 Participating in a mock trial using one of the mock cases completed during training. If the trainee has previous mock trial or court experience, an oral review may replace the mock trial.

6.18.2 The method of evaluation for this unit is a passing grade on the written examination, successful completion of the competency evaluation, and successful completion of the mock trial or oral review.

6.19 Supervised Casework and Peer Reviews:

6.19.1 This section introduces the trainee to performing independent casework as well as technical and administrative peer reviews.

6.19.2 Practical Exercise:

6.19.2.1 Observe an experienced glass practitioner perform casework.

6.19.2.2 Perform actual casework under the supervision of a qualified glass practitioner before performing independent casework.

6.19.2.3 Complete mock technical and administrative review exercises.

6.19.3 The methods of instruction for this unit are: demonstration by the trainer and discussion with the trainee.

6.19.4 The methods of evaluation for this unit are evaluation of the casework with no technical errors and minimal administrative errors and evaluation of the peer reviews completed by the trainee.

7 Keywords

7.1 forensic science; training; materials; glass; glass analysis

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