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**Best Practice Manual**

**for the EUROPEAN PAINT, GLASS AND TAGGANTS EXPERT WORKING GROUP**

**ENFSI-XXX-BPM-XX**

**Version XX – Month Year**

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**European Union’s Internal Security Fund — Police**

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**Official language**

The English language version remains the definitive version.

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| **BEST PRACTICE MANUAL FOR THE FORENSIC IDENTIFICATION AND COMPARISON OF GLASS** |
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1. **AIMS**

This Best Practice Manual (BPM) provides a framework for procedures, quality principles, and approaches to the forensic examination of glass. Member laboratories of the European Network of Forensic Science Institutes (ENFSI) and other forensic science laboratories can use this manual to establish and maintain working practices in the field of forensic identification and comparison of glass. Following the recommendations in the manual will deliver reliable results, maximize the quality of the information obtained and produce robust evidence. The use of consistent methodology and the production of more comparable results will facilitate interchange of data between laboratories.

This BPM is aimed at experts in the field of forensic glass investigation, and therefore assumes prior knowledge in this discipline. It is not a standard operating procedure and addresses the requirements of the judicial systems in general terms only.

This BPM provides the means to choose between the methods that are currently accepted by the European Paint and Glass expert working-group (EPG) forensic glass analysis. community.

The scope of this manual includes the procedures, personnel, equipment and facilities involved in the forensic process, from reception of samples at the forensic laboratory to presentation of evidence in a report.

The term BPM is used to reflect the scientifically accepted practices at the time of creating. The term BPM does not imply that the practices laid out in this manual are the only good practices used in the forensic field.

This BPM is independent of any ISO standard or ASTM standards, but it is written to agree with ISO 17025 and ASTM-standards that are relevant for forensic comparison and analysis of glass1.

1. **SCOPE**

This manual applies to identification and comparison of glass by analysis of physical and chemical characteristics of the samples.

The activity of forensic glass examination is of complex nature. This BPM and its Guidelines will cover methods that are normative and suitable in the field so that practitioners and reporting scientists will be able to choose the most suitable route according to her or his needs and available equipment.

This BPM does not cover detailed description of Scene of Crime (SOC) investigation and recovery of evidence from the crime scene.

This manual covers the following methods/analytical techniques;

*Table 1 Topics covered in this Best Practice Manual (see Guidelines).*

|  |  |  |
| --- | --- | --- |
|   | Topic  |   |
| Guideline 1  | Forensic examination of the Visual Characteristics of Control and Recovered samples of glass   |   |
| Guideline 2  | Recovery of glass   |   |
| Guideline 3  | Micro X-ray Fluorescence Spectroscopy of Glass Samples in Forensic Science   |   |
| Guideline 4  | Quantitative elemental analysis of glass samples using LA-ICP-MS   |   |
| Guideline 5  | Scanning Electron Microscopy and Energy Dispersive Spectroscopy of Glass Samples in Forensic Science   |   |
| Guideline 6  | Determination of refractive indices of glass fragments   |   |

This Best Practice Manual and the associated Guidelines are not specific to any of commercial instruments on the market. It is expected that an individual laboratory will be aware of instrument specific functions and limitations.

This manual will present relevant and recommended methods accompanied by a short summary of their limitations and strengths (see chapter 5 and 6). For details, please refer to the specific guidelines attached to this BPM.

1. **TERMS AND DEFINITIONS**

For an extensive reference on glass terminology, please see ASTM C162-05(2015) Standard Terminology of Glass and Glass Products (ASTM, 2015). 2

Table 1 Definitions and Terminology relevant in for the content in Best Practice Manual. The definitions/terms are not covered in ASTM C162-05(2015)

|  |  |
| --- | --- |
|  | *Definition* |
| Calibration  | Operation that, under specified conditions, in a first step, establishes a relationship between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties (of the calibrated instrument or secondary standard) and, in a second step, uses this information to establish a relationship for obtaining a measurement result from an indication |
| *Class* | See “Group” |
| *Coating:*  | functional and/or decorative layer applied to a glass surface. |
| *Collaborative exercise* |  A situation in which two or more groups of practitioners perform a test against pre-established criteria |
| Control sample: | a sample of known origin, e.g. a sample from a broken sheet of glass at the scene of crime  |
| *Density:* | Mass per unit volume |
| *Discriminate*  | to distinguish between two samples; to differentiate. |
| *Discriminating power :*  | the ability of an analytical procedure to distinguish between two items of different origin. |
| *Glass:* | an inorganic product of fusion that has cooled to a rigid condition without crystallizing. |
| *Group* | a group or class of items that share properties or characteristics within a given uncertainty, often given as categorical data |
| *Group characteristics:* | properties that define a group of items collectively. |
| *Practitioner* | A person trained to perform testing. |
| *Proficiency Test*  | Proficiency testing is the evaluation of the performance of a practitioner against pre-established criteria. |
| *Questioned sample* | Material of an unknown source/origin collected from a known location either as, or from, items of evidence (e.g., fragments recovered from a suspect's clothing) |
| *Raw data:* | The actual, unprocessed results from an analysis or measurement |
| Recovered sample: | Material recovered from an object (such as glass collected from the surface of a piece of clothing) |
| *Refractive index*  | the ratio of the speed of light in one media compared to another, usually expressed as n=v1/v2 (n=refractive index, v1 =speed of light in medium 1 and v2 = speed of light in medium 2). |
| *Validation*  | A process that aims to demonstrate that the method of choice is appropriate for the application intended |

1. **RESOURCES**

## 4.1 Personnel

*Reporting Scientist:* the forensic scientist responsible in a particular case for directing the examination of the items submitted, interpreting the findings, writing the report and providing evidence of fact and opinion for the court.

*Peer reviewer*: a forensic scientist with a similar level of competence as the Reporting Scientist. The peer reviewer should assist the reporting scientist in formulating a correct, consistent and understandable report (see chapter 5.1).

*Analyst/Assistant:* an individual carrying out general casework examinations or analytical tests under the supervision of a Reporting Scientist and who can provide information to assist with the interpretation of the tests.

All personnel must have undergone proper, documented training in accordance with the institution’s requirements.

An individual may be responsible for more than one of the defined roles.

## 4.2 Equipment

In this BPM, it is assumed that the institute provide laboratories that are adequate to collect, isolate, prepare and analyse evidence. In addition, the facilities should be designed in such a way to minimize the risk of contamination of evidence.

It is also assumed that basic equipment such as glassware, balances, proper light etc are available.

It is strongly recommended to have stereomicroscopes as a general-purpose apparatus.

In order to identify glass, the object should be observed in transmitted cross-polarized light, preferably under a microscope.

To compare glass, it is considered as minimum to meet the requirement in this BPM to have access to at least one of the following:

-equipment to measure refractive index by means of oil immersion method (Guideline 3)

-equipment to perform elemental analysis

-SEM/EDS (Guideline 4)

-(micro-) XRF (Guideline 5)

-LA-ICP-MS (Guideline 6)

Equipment for performing compound microscopy and interference microscopy will also be relevant when comparing glass. These methods will not be covered in this manual.

## 4.3 Reference materials

See individual guidelines for specific reference materials. In general, it is recommended to use certified reference material or material that have been broadly tested by laboratories. Example: Schott/BKA-K5 glass for measurement of refractive index.

## 4.4 Facilities & Environmental Conditions

Facilities etc should conform to ISO17025 standards

## 4.5 Risk-Based Thinking

It is recommended that each institute have written protocols for risk-assessment, see chapter 7 for more details.

## Materials and 4.2 Reagents

Materials and reagents shall be of such quality (purity/grade) that they meet the expected requirements of the method. It is recommended that product data is available/documented.

1. **METHODS**

The European Paint and Glass expert working-group only recommends the use of methods that are published in peer-reviewed scientific journals and aimed at forensic science. The guidelines in this BPM present what is normative and generally accepted methods for visual characteristics of control and recovered samples and comparison of glass.

The following tables will provide general information of the methods listed in Table 1.

Table 1

|  |  |
| --- | --- |
| **Method** | **Recovery of glass from items** |
| **Description** | Description of recovery, collection, handling and seizure of glass. |
| **Input** | Items submitted. |
| **Output** | Debris, fragments or pieces of glass. |
| **Discriminating power** | Not applicable. |
| **Consequences for subsequent analyses**  | When executed properly, debris inherently containing fragments of glass and/or fragments/pieces of glass are provided for subsequent analyses.  |
| **Strengths** | Fast and efficient when executed properly. |
| **Limitations** | Other evidence material may suffer physical damage or loss. |
| **Equipment, facilities**  | Proper tools, reasonable large paper-sheets, environment free of possible sources of contamination. |
| **Other remarks** | See also ASTM E14923 |
| **Guideline** | EPG-guideline 1:  *Recovery of Glass in Forensic Identification and Comparison of Glass .* |

|  |  |
| --- | --- |
| **Method** | **Visual Characteristics of Control and Recovered samples of glass** |
| **Description** | Description of visual inspection of glass (fragments, pieces).  |
| **Input** | Samples of recovered and glasses. |
| **Output** | Metric and visual characteristics of glass (thickness, surface, bulk colour, coatings, description of surface by interferometry). |
| **Discriminating power** | Elimination of glass from different sources can be achieved by e.g., colour, thickness, low to intermediate discrimination power for determination of thickness whereas for interferometry the discrimination power is not known. |
| **Consequences for subsequent analyses**  | If deemed different, further analysis is not needed.  |
| **Strengths** | Fast and efficient when, non-destructive. |
| **Limitations** | Size of recovered fragments or insufficient control representative of broken glass object |
| **Equipment, facilities** | Proper source of light, stereo microscope, metric measurement tools with adequate resolution and sensitivity, interferometer system. |
| **Other remarks** | None |
| **Guideline** | EPG-guideline 2: *Forensic Examination of Visual Characteristics of Control and Recovered Samples of Glass*  |

|  |  |
| --- | --- |
| **Method** | **Determination of refractive index of glass fragments.** |
| **Description** | Measurement of refractive index of glass fragments by oil-immersion method. |
| **Input** | Glass samples (control and questioned glass). |
| **Output** | Refractive index. |
| **Discriminating power** | Fairly good discrimination of glass samples from different sources depending on quality of sample (i.e. size, presence of dirt at samples etc). |
| **Consequences for subsequent analyses**  | If deemed different, further analysis is not needed. If deemed indistinguishable further analysis such as elemental analysis and reannealing can be performed to establish similarities or discrimination. |
| **Strengths** | Suitable for sub-millimetre samples, samples can be subjected to further analysis, good discrimination, well documented and mature method. |
| **Limitations** | Sensitive to contamination. |
| **Equipment, facilities** | A system suitable for measurement of RI consisting of a phase-contrast microscope, hot-stage, camera, control-unit for collection of images/video and control temperature and suitable software. For calibration a set glass samples with known refractive indices are required together with (Silicon) Oils with specified refractive index range. One or more samples of glass with known refractive index to be used on a daily basis to control the system, |
| **Other remarks** | *See also ASTM E19674* |
| **Guideline** | EPG-guideline 3: *Determination of Refractive Indices of Glass Fragments* |

|  |  |
| --- | --- |
| **Method** | **Determination of elemental composition by Scanning Electron Microscopy and Energy Dispersive Spectroscopy.** |
| **Description** | Determination of elemental composition of glass fragments on main- and minor level (>1 g/kg). |
| **Input** | Samples of recovered glass (control and questioned glass). |
| **Output** | Elemental composition. |
| **Discriminating power** | Very high discrimination of glass samples from different sources, depending on quality of sample (i.e., size, presence of dirt at samples etc). |
| **Consequences for subsequent analyses**  | It is recommended that SEM/EDS is used in combination with other methods, preferably determination of refractive index or determination of trace element concentration by ICP-MS.If deemed different, further analysis is not needed. If deemed indistinguishable or associated within the uncertainty of the method, the association should be confirmed by at least one supplementary method.  |
| **Strengths** | Fast and reliable method, well documented, for qualitative analysis little sample preparation needed, hence non-destructive.  |
| **Limitations** | Somewhat low discrimination for main elements. If quantitative analysis is performed, sample preparation is required, and samples then may be inaccessible for other methods. |
| **Equipment, facilities** | Scanning electron microscope with low vacuum system if no carbon coater is available, energy dispersive spectrometer, carbon coater, suitable sample holders, embedding material. |
| **Other remarks** | None |
| **Guideline** | EPG-guideline 4: *Scanning Electron Microscopy and Energy Dispersive Spectroscopy of Glass Samples in Forensic Science*. |

|  |  |
| --- | --- |
| **Method** | **Determination of elemental composition by X-ray fluorescence (XRF)** |
| **Description** | elemental composition of glass fragments on trace/minor and major element level. |
| **Input** | Samples of recovered glass (control and questioned glass). |
| **Output** | Elemental composition. |
| **Discriminating power** | Elimination of glass from different sources can be achieved, high to intermediate discrimination depending on quality of sample (i.e. size, presence of dirt at samples etc). |
| **Consequences for subsequent analyses**  | It is recommended that XRF is used in combination with other methods, preferably determination of refractive index or determination of trace element concentration by ICP-MS.If deemed different by use of XRF, further analysis is not needed. If deemed indistinguishable or associated within the uncertainty of the method, the association should be confirmed by at least one supplementary method.  |
| **Strengths** | Fast, well documented and reliable method with little to none sample preparation, non-destructive, more sensitive for elements with Z>20 (Ca) than SEM-EDS. |
| **Limitations** | Determination of trace elements only down to approx. 0.5 g/kg (depending on the element); when a collimator optic is used spot size of minimum 1 mm, with polycapillary spot size of ≥ 20 µm possible.  |
| **Equipment, facilities** | Micro-XRF unit (x-ray tube, detector, polycapillary or collimator optics, data acquisition and evaluation software), vacuum system (optionally helium supply).   |
| **Other remarks** | None. |
| **Guideline** | EPG-guideline 5: *Micro X-ray Fluorescence Spectroscopy of Glass Samples in Forensic Science* |

|  |  |
| --- | --- |
| **Method** | **Quantitative elemental analysis of glass samples using LA-ICP-MS** |
| **Description** | Determination of the concentrations of main, minor and trace elements in glass (approximately 100 µg/kg to 500 g/kg |
| **Input** | Glass samples (control and questioned glass). |
| **Output** | Quantitative data for typically 15-20 chemical elements. |
| **Discriminating power** | Very high discrimination of glass samples from different sources. |
| **Consequences for subsequent analyses**  | If deemed different, further analysis is not needed. If deemed indistinguishable or associated within the uncertainty of the method, the association may be confirmed by Refractive Index measurement.  |
| **Strengths** | Fast and reliable, well documented method for the qualitative analysis of glass samples. Little sample preparation needed; Surface contamination is not critical. Irregularly formed glass particles can be examined.  |
| **Limitations** | Fragments of approximately 0.4 mm x 0.2 mm x 0.1 mm are typically needed for full analysis with six replicates and 600 laser pulses. Smaller fragments can be examined with reduced numbers of replicates or reduced ablation time. Some level of education and training is necessary to operate the instruments appropriately. Somewhat expensive in purchase and maintenance. |
| **Equipment, facilities** | Laser Ablation and ICP-MS units, data reduction software, high purity He and Ar gas supply, sufficient air exhaust, stable temperature and humidity.  |
| **Other remarks** | *See also ASTM E29275* |
| **Guideline** | Guideline 6: *Quantitative* Elemental Analysis of Glass Samples Ssing LA-ICP-MS |

## 5.1 Case review

It is recommended that a case review is independently carried out by a competent peer, see 4.1. The aim of a review will be to control and confirm that appropriate methods and steps have been taken to achieve robust and reliable results with suitable interpretation of the findings. Critical findings should be documented in the case file and approved by the peer, see chapter 7.3.

1. **VALIDATION AND ESTIMATION OF UNCERTAINTY OF MEASUREMENT**

## 6.1 Validation

In this Best practice manual, validation is defined as specific steps taken to demonstrate that a given method is suitable for its intended use.

In order to refer to use of this best practice manual and the guidelines herein, the methods used shall be validated.

Each analytical method should be validated according to the institute's internal quality assurance policy.

Prior to validation of a new method, a validation plan for the actual method should be written. It is recommended that the plan describe minimum requirement for considering the method validated. For an elucidation of factors that should be taken into consideration, see *Guidelines for the single laboratory Validation of Instrumental and Human Based Methods in Forensic Science.6*

## 6.2 Estimation of uncertainty of measurement

In this Best Practice Manual, estimation of uncertainty is limited to the representation of measured values of the same parameters for quantitative analysis for that sample by use of calibration curves, limits of detection and instrumental sensitivity. These topics are covered in the *GUM: Guide to expression of Uncertainty in measurement* and in *IUPAC Gold Book.* 7 8

An institute should keep a record of documents that cover the following topics, if relevant

1. How to determine and present measurement uncertainties,
2. How to establish calibration curves for the method and how to determine the uncertainty of the calibration curves,
3. Determination of limits of detection for a method or the working range (e.g. upper and lower limits of detection/quantification etc.) of the method.

It is recommended that laboratories hold documents that describes the use of graphical as well as tabular representation of uncertainties.

1. **QUALITY ASSURANCE**

## 7.1 Proficiency Testing / Collaborative Exercises

Proficiency tests should be used to test and confirm the quality of forensic comparison and identification of glass. Laboratories performing forensic glass analysis should on a regular basis, participate in collaborative exercises and/or proficiency tests. The test should, if possible, cover the various analytical techniques used at the laboratory.

## 7.2 Performance Controls

It is imperative to monitor performance of analytical equipment periodically. The purpose is to assure stability and follow trends. The laboratory should consider making a suitable system for documentation and safe keeping of recorded measurements. Whenever appropriate it is recommended to establish control cards/charts to follow trends in analytical performance. Limits, defining points where action must be taken should be established for each analytical method/equipment where possible. Suitable reference material for testing analytical performance stability should be used

## 7.3 Verification / Peer Review

It is recommended that a case review is independently carried out by a competent peer, as described in 5.1.

The peer should be in agreement with the conclusion in the report, which is supported by the analytical results etc.

A peer should also read the final report in order to check formal details such as dates, names, internal and external case-file numbers, identification of seizures, finalizing of seizures etc. Further, a peer should confirm that the report answers the question raised in the request, that internal procedures/the policy of the institute are met (such as scale of conclusion) and ensure that the language used is clear, concise and unambiguous.

1. **HANDLING ITEMS**

This Best Practice Manual does not cover Scene of Crime activities related to forensic glass comparison in a separate guideline. Nevertheless, to ensure that relevant samples are properly collected, a limited set of the most important recommendations are given in 8.1.

## 8.1 At the scene

Glass from broken windows or broken glass of known origin should be collected and marked as *Control glass*. If possible, glass from the actual broken window, still in its frame/attached to the car body or at any original place holder, is preferred. Be aware of double or triple glazing. Collect each layer of glass in a separate container and mark unambiguously. If needed, mark what is the outside and inside of the window, car glass etc.

Do not mix glass collected from place holder and glass collected from the ground.

Glass from the ground should be placed in separate containers.

Glass associated with a suspect or glass of unknown origin should be marked as recovered glass. Awareness should be taken to avoid cross contamination, especially of glass from the scene of crime and the suspect.

Small, but visible fragments may be collected separately and attached to gelatine foil or similar material. Try not to attach small fragments to adhesive tape, as glue may attach to/contaminate the fragment.

Parts of tools containing glass should be covered, preferably by a non-static material such as paper/cardboard or similar. Try to avoid plastic bags as the glass fragments can penetrate the plastic and also tend to stick to the surface of the bag.

Garments from individuals should be packaged separately in paper-bags or similar. Avoid using plastic bags. If the garments are wet, it may be expedient to let them dry before shipment to the laboratory. Dry horizontally on paper. Send the paper together with the garments to the laboratory, as it may contain glass fragments.

Treat the garments gently to avoid losing glass fragments.

## 8.2 At the laboratory

See Guideline 1: *Recovery of glass in forensic identification and comparison of glass.*

1. **INITIAL ASSESSMENT**

Based on the request from the client and preliminary examination (often visual inspection) of the received items, an assessment as to whether the laboratory can conduct the examination/analysis should be undertaken. An assessment should be made to establish if such examination/analysis will assist in the investigation.

If issues are discovered, (whether the preliminary examination revealed that the packaging was damaged, deadlines cannot be met etc.) the client should be contacted, and an agreement on further actions should be made.

For a more elaborate introduction, see Guideline EPG-guideline 2 *Forensic examination of visual characteristics of control and recovered samples of glass*

1. **PRIORITISATION AND SEQUENCE OF EXAMINATIONS**

After preliminary examination of the items, a plan/strategy for the recovery of glass and sequence of analytical procedures should be outlined. The different steps will depend on the case, the items received, the request/questions asked by the client and the equipment available at the laboratory.

It is recommended that an outline of the procedure is documented in the case file. Deviations from the procedure should be documented. Deviations from the preliminary plan/strategy may occur as a natural cause of the examination.

It is the responsibility of the Reporting Scientist (expert) to set the plan for the analytical procedures to be used, to determine the analytical sequence and to make sure that the necessary corrective steps are taken if deviations from the original plan occur.

1. **RECONSTRUCTION**

Fractography and determination of physical matches of glass are not a part of this Best Practice Manual. Other aspects of reconstruction at the scene of crime are not within the scope of this Best Practice Manual.

1. **ASSESSMENT OF RESULTS AND INTERPRETATIO**

## 12.1 Introduction

Data obtained from analytical processes as described in this Best Practice Manual will only on rare occasions exhibit equal results. Differences in the results occur due to real physical and chemical differences between samples (between-sample variability) and within-sample variability (due to e.g., inhomogeneity, surface effects, tension), random measurement errors and systematic measurement errors. Potential sources of random and systematic measurement errors are discussed in each guideline, where applicable.

## 12.2 Data treatment

Preliminarily treatment of data can be done by graphical representation of data, summarizing statistics in tables or testing hypothesis by use of statistical models. These will provide information such as median or mean values, spread of data, or whether a statistical test supports or rejects the hypothesis that two (or more) compared values share the same properties.

One or several of the following methods of data evaluation may be applied at this stage:

1. Test for outliers (Grubbs test)
2. Grouping of measurements such as Evett Lambert Modification 1 & 2, Scott-Knott Modification 2 9
3. Comparison of (mean) values (univariate and multivariate data)[[1]](#footnote-1) by
	1. visual representation of data 10, 11
	2. n-sigma tests, 12, 13
	3. Range overlap criteria (ASTM E1967)
	4. hypothesis tests (such as t-test, Tukey´s test, Hotelling´s T2-test) 11, 12, 14.9
4. Classification (e.g., by pre-defined numerical criteria, Principal Component Analysis, Linear Discriminant Analysis)

The statistical methods and tests listed above are the most predominant in the field glass comparison. Other methods exist and may be applied.

It is recommended that whenever a statistical method or test is applied, an in-house validation/verification should be performed in advance.

If no further evaluation, such as to the evidential strength of the findings is to be performed, the results of such calculations may be communicated in *technical reports*.

Another branch of data treatment is the evaluative interpretation of the findings. An

evaluative interpretation will provide information about *evidential strength*. In forensic science, this is often defined as the probability of obtaining a set of observations if one hypothesis is true held against the probability of obtaining the same sets of observations given that the alternative hypothesis is true15.

*Evaluative/interpretative* assessment of the data aim to provide information of the strength of the evidence (i.e., the observations) under two competing hypotheses15, 16. Note: hypotheses may be referred to as propositions in some texts.

The question from the client should be used to form the hypothesis of the prosecutor (**Hp**). In order to be balanced, an alternative hypothesis should be introduced, (**Hd**)[[2]](#footnote-2). For example, information provided by the suspect should be used to form the alternative. Hp and Hd must be mutually exclusive.

The observations (the data from the analysis) are denoted **E.**

When the hypothesis and the evidence have been established, the probability of the observations if (given) the hypothesis of the prosecutor is true can be assigned. In addition, the probability of the observations if (given) the hypothesis of the defence is true should be assigned. Often, to assign this probability, some sort of background information should be available.

The ratio between those two probabilities is referred to as the likelihood ratio (LR).

The likelihood ratio is defined as

«...the ratio of the probability of the evidence if the prosecution’s proposition is true, to the probability of the evidence if the defence proposition is true (i.e. ***the likelihood ratio***);» 17

In order to evaluate the likelihood ratio (LR) for any given proposition (Hp, Hd), the following should be taken into consideration:

* level of proposition or hypothesis (*source, activity*)
* available, relevant case related information
* available background data (databases)
* excepted variability (within and between source variation)

## 12.3 Databases

To perform an evaluation of evidential strength, background information should be available (such as population studies). Such databases can, for example, provide information about the probability of random matches. Relevant databases are (but not limited to)

* databases on frequencies of occurrence of features
	+ Refractive Index,
	+ Elemental Composition
	+ Thickness
* Sales numbers (market share)
* Transfer and persistence of glass on garments, tools
* Information on background levels of glass.

Laboratories should be aware that regional differences concerning frequencies, background levels etc may occur.

1. **PRESENTATION OF RESULTS**

It is recommended that results are presented in a written report. The report should be concise when answering the requests/questions asked by the client. The language should be simple and easy to understand for the members of the court, the prosecutor, defence and public opinion.

It is recommended that the report is independently reviewed by a peer before release.

The content of the written report should include Information give in the ISO 170251.

Presentation of the results might also be given orally, normally in court. It is recommended that oral presentations are given in a clear and concise form using simple language. Technical terms should be avoided or defined in plain words.

1. **HEALTH AND SAFETY**

This document does not address safety concerns, if any, associated with its use. The institute referring to this manual must decide which measures must be taken to conduct the examinations safely and in accordance current regulations.

1. **REFERENCES**

(1) Standardization, I. O. f. *General requirements for the competence of testing and calibration laboratories*; ISO/IEC, 2017.

(2) ASTM. Standard Terminology of Glass and Glass Products. *Book of Standards* **2015**, *15.02*, 16. DOI: 10.1520/C0162-05R15.

(3) ASTM. Stadard Practice for Recieving, Documenting, Storing, and Retrieving Evidence in Forensic Science Laboratory. *Book of Standards* **2022**, *14.02*, 3. DOI: 10.1520/E1492-11R17.

(4) ASTM. Determination of Refractive Index of Glass Samples Using Oil Immersion Method and Phase Contrast Microscopy. *Book of Standards* **2022**, *14.02* (4). DOI: 10.1520/E1967-19.

(5) ASTM. Standard Test Method for Determination of Trace Elements in Soda-Lime Glass Samples Using Laser Ablation Inductively Coupled Plasma Mass Spectrometry for Forensic Comparison. **2022**, *E2927-16e1*.

(6) ENFSI. Validation of Instrumental and Human Based Methods in Forensic Science, . **2014**, *QCC-VAL-002*

(7) Meures, B. I. d. P. e. Evaluation of measurement data — Guide to the expression of

uncertainty in measurement **2008**.

(8) IUPAC. Compendium of Chemical Tetrminology. **2022**.

(9) Evett, I. W.; Lambert, J. A. The interpretation of refractive index measurements. III. *Forensic Science International* **1982**, *20* (3), 237-245. DOI: [https://doi.org/10.1016/0379-0738(82)90123-2](https://doi.org/10.1016/0379-0738%2882%2990123-2). Scott, A. J.; Knott, M. A cluster analysis method for grouping means in the analysis of variance. *Biometrics* **1974**, 507-512.

(10) Crawley, M. J. *The R book*; John Wiley & Sons, 2012.

(11) Nelson, P. R.; Wludyka, P. S.; Copeland, K. A. F. *The Analysis of Means*; Society for Industrial and Applied Mathematics, 2005. DOI: 10.1137/1.9780898718362.

(12) Curran, J. M.; Champod, T. N. H.; Buckleton, J. S. *Forensic interpretation of glass evidence*; CRC Press, 2000. Koons, R. D.; Buscaglia, J. Interpretation of glass composition measurements: the effects of match criteria on discrimination capability. *Journal of Forensic Science* **2001**, *47* (3), 505-512.

(13) Lountain, O.; Tuke, J.; Brown, H.; Redman, K.; Wilczek, S.; Humphries, M. A. A multivariate extension to the standard 4σ criterion for comparison of forensic glass evidence. *Forensic Science International* **2022**, *338*, 111386. DOI: <https://doi.org/10.1016/j.forsciint.2022.111386>.

(14) Tukey, J. Multiple comparisons. *Journal of the American Statistical Association* **1953**, *48* (263), 624-625. Dodds, A. J.; Pollock, E.; Land, D. P. Forensic Glass Analysis by LA-ICP-MS: Assessing the Feasibility of Correlating Windshield Composition and Supplier. *Director* **2010**.

(15) ENFSI. ENFSI Guideline for Evaluative Reporting In Forensic Science. **2010**.

(16) Lucy, D. *Introduction to statistics for forensic scientists*; John Wiley & Sons, 2013. Aitken, C.; Taroni, F. *Statistics and the evaluation of evidence for forensic scientists*; John Wiley & Sons, 2004. Aitken, C.; Roberts, P.; Jackson, G. Fundamentals of probability and statistical evidence in criminal proceedings (Practitioner Guide No. 1). *Guidance for Judges, Lawyers, Forensic Scientists and Expert Witnesses, Royal Statistical Society’s Working Group on Statistics and the Law* **2010**, *42*. Roberts, P.; Aitken, C. The logic of forensic proof: inferential reasoning in criminal evidence and forensic science. *Guidance for Judges, Lawyers, Forensic Scientists and Expert Witnesses, Practitioner Guide* **2014**, *3*.

(17) Aitken, C.; Roberts, P.; Jackson, G. *Fundamentals of probability and statistical evidence in criminal proceedings: guidance for judges, lawyers, forensic scientists and expert witnesses*; 2010.

1. **AMENDMENTS TO PREVIOUS VERSION**

This Best Practice Manual is a complete rewrite of the first edition of the European Paint and Glass Group Best Practice Manual of Forensic Glass Examination. No references to amendments to previous versions is given in this paragraph of the current BPM.

1. This can typically be done by presenting a hypothesis saying that the two compared quantities are indistinguishable (H0). Next, the validity of this hypothesis(H0) will be tested against the hypothesis that the two quantitates are different (H1) [↑](#footnote-ref-1)
2. **d** refers to defence. [↑](#footnote-ref-2)