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U.S. Department of Justice Federal Bureau of Investigation

Introduction to Forensic Fiber Examination

3.0. Terminology

Known (Sample): A subset of a larger population or sample originating from a verifiable source, collected as representative of that larger grouping; for example, a 2" x 2" section of carpet from a suspect's living room.

Questioned (Sample): Materials collected as or from items of evidence that have a known location but an unknown origin; for example, loose fibers collected from a victim's clothing.

Class Characteristics: Traits that define a group of items collectively.

Class: A group of items that share properties or characteristics.

Individual Characteristics: Traits that define and identify an item as unique and exclusive of all other items.

Individual: A unique item that is identified as itself to the exclusion of all other items.

4.0. Summary of Fiber Analysis Guidelines

The various analytical methods available for fiber analysis yield different kinds of information. It is highly desirable to select a combination of methods and apply them in an order that provides the most exclusionary information first. By doing this, the examiner optimizes accuracy, precision, and production while most effectively using the laboratory's resources.

5.0. Significance and Use

5.1. Microscopy

At a minimum, a fiber examiner must employ a stereomicroscope, a comparison microscope, and a compound light microscope equipped with polarized light capability. The examiner must view questioned and known fibers side by side at the same magnifications in visible light, and alternative lighting, such as polarized light or fluorescent lighting, although not necessary, is recommended if the equipment allows. For some analyses, for example, in testing for solubility, it may be necessary to place questioned and known fibers next to each other on the same slide or in adjacent wells of a spot plate. Extreme caution must be exercised with loose fibers in these circumstances so as not to confuse the source of each fiber.

5.2. Comparison
Typically, fiber examinations involve a comparison of samples from known and questioned sources to determine whether they are consistent with having originated from the same source (e.g., carpet from a suspect's car compared with foreign fibers removed from the victim's clothing). This comparison involves the recognition and evaluation of class characteristics, which associate materials to a group but never to a single source. Conversely, individual characteristics allow the association between two or more items with each other to the exclusion of all other items. For fiber examiners, this most often occurs when pieces of fabric or cordage are physically matched.

5.3. Source Determination
Textile fibers can be exchanged between individuals, between individuals and objects, and between objects. When fibers are associated with a specific source, such as fabric from the victim, suspect, or scene, a value is placed on that association. The probative weight of this value is dependent upon many factors. The following subsections describe those factors.

5.3.1. Fiber type or types found;
5.3.2. Fiber color or colors;
5.3.3. Number of fibers found;
5.3.4. Fiber location or locations;
5.3.5. Fabric type or types;
5.3.6. Multiple fiber associations;
5.3.7. Nature of contact; and
5.3.8.Fiber transfer and persistence.

Whether a fiber is transferred and detected is also dependent on the nature and duration of the contact between the suspect, the victim, or both and the persistence of the fibers after they have been transferred.

5.3.1. Fiber Type or Types. The rarity or commonness of the fiber types found at a crime scene or on a victim or suspect affects their probative value. Cotton fibers are by far the most commonly used plant fibers in textile production. The type of cotton, the fibers' length, and the degree of twist contribute to the diversity found in cotton fibers. Processing techniques, such as mercerization, and color applications also influence the value of cotton fiber identifications. The presence of other less common plant fibers at a crime scene or on the clothing of a victim or suspect increases its significance.

The most common animal fiber used in textile production is wool originating from sheep. The fineness or coarseness of woolen fibers often dictates the end use of wool. The finer woolen fibers are used in the production of clothing, whereas the coarser fibers are found in carpet. The diameter and the degree of scale protrusion of the fibers are other important characteristics. Woolen fibers from other animals may also be found, including camel, alpaca, cashmere, and mohair. The identification of less common animal hairs, fibers, or both at a crime scene or on the clothing of a suspect or victim would have increased significance.

Over half of all fibers used in the production of textile materials are manufactured. Some manufactured fibers originate from natural materials such as cotton or wood, whereas others originate from synthetic materials. All nonnaturally occurring fibers are manufactured, but not all manufactured fibers are synthetic (e.g., rayon). Certain types of manufactured fibers are more common than others. Polyester and nylon fibers are the most commonly encountered manufactured fibers, followed by rayons, acetates, and acrylics. There are also many other less commonly manufactured fibers. The amount of production, the end use, the cross-sectional shape, microscopic characteristics, and other traits of the fiber help to influence the degree of rarity of a particular fiber type.

5.3.2. Fiber Color or Colors. One of the greatest variations seen in textiles is color. Thus, color greatly influences the significance of a fiber comparison. Synthetic dyes and pigments belong to 29 different chemical categories with more than a dozen different application methods (7). Even simple dyes might require between eight and ten processes to convert the raw materials into a finished dye. Given that the total annual production of any particular dye might not amount to more than 10 tons and that small process batches are becoming the rule in the dyeing industry, color becomes a powerful discriminant. Color is particularly significant when the gamut of colors is spread out over the range of garments and carpeting produced in any one year and even more so when multiplied by the number of garments and carpets produced in previous years.

Individual fibers can be colored before being spun into yarn, yarns can be dyed after being spun, or the fabric can be dyed before or after its construction. Color can also be applied to the surface of a fabric by printing. The absorbance of the dye along the fiber length suggests the dyes and dyeing method used. Fading and discoloration may also add increased significance to a fiber association.

5.3.3. Number of Fibers. The number of fibers identified on the clothing of a victim associated to the clothing of a suspect is important in determining actual contact. The greater the number of fibers, the more likely that direct contact occurred between these individuals. The converse is not necessarily true, however, and even one fiber association can have probative and scientific value. Additionally, finding no fibers does not de facto mean that no contact occurred. Each case is different, and the examiner must weigh all of the relevant factors before determining the significance of the evidence.

5.3.4. Fiber Location. Where the fibers are found also affects the probative value of a particular fiber association. The location of fibers on different areas of the body or on specific items at the scene can influence the significance of the fiber association.

5.3.5. Fabric Type. Fabric construction affects the number and types of fibers that may be transferred. Tightly woven or knitted fabrics shed fewer fibers than loosely knit or woven fabrics. Fabrics composed of filament yarns shed less than fabric composed of spun yarns. Certain types of fibers also transfer more readily. The condition and wear of the fabric also affects the degree of fiber transfers: Newer fabrics may have an abundance of loosely adhering fibers on the surface of the fabric, whereas worn fabrics may have damaged areas that easily shed fibers. Damage to a fabric caused during physical contact greatly increases the likelihood of fiber transfer.

5.3.6. Multiple Fiber Associations. If many different fiber types are associated among the suspect, victim, and scene, then the likelihood that contact occurred between these items is greatly increased. Each associated fiber transfer is considered to be an independent event, and multiple associations undermine an argument that the fibers were all deposited by coincidence.

5.3.7. Nature of Contact. The type of physical contact between a suspect and a victim helps to determine the number of fibers transferred and the value placed on their discovery. Violent physical contact of an extended duration may result in many fiber transfers.

5.3.8. Fiber Transfer and Persistence. Textile fibers are transferred to the surface of a fabric either by direct (primary) transfer or indirect (secondary) transfer. The likelihood of transfer depends on the types of fabric involved in the contact and the nature and duration of the contact. Studies have shown that transferred fibers are lost at a geometric rate, depending on the types of fabrics involved and on the movement of the clothing after contact (see endnote 1). For example, the clothing of a homicide victim may retain transferred fibers for a longer time because the victim is not moving. Therefore, under these circumstances it is difficult to predict precisely how many fibers might remain on the clothing of a living individual after a given period, but it is important for investigators to retrieve clothing immediately.

Whenever a fiber is found in relation to a crime scene, victim, or suspect, it has potential significance. Matching dyed fibers, whether manufactured or natural, can be very meaningful, whereas the matching of common fibers such as white cotton or blue denim cotton can would be less significant. In some situations, however, the presence of white cotton or blue denim cotton possibly still has some meaning in resolving the truth of an issue. The discovery of cross transfers (suspect[s] to victim[s] and vice versa) dramatically increases the likelihood that two items came into contact and greatly reduces the likelihood of chance occurrence.

When a fiber examiner associates a questioned fiber to a known textile item, there are ultimately two possible explanations: (a) The questioned fiber originated from the known textile, or (b) the questioned fiber did not originate from the known textile.

To say that the questioned fiber originated from the known textile, it either had to be the only fabric of its type ever produced or now existing, or the transfer of fibers was directly observed. As neither of these situations is likely to occur, fiber examiners must conclude that because the questioned fibers exhibit the same results in all tested properties as the fibers from the known sample, the questioned fibers are consistent with originating from the source textile. Other textile sources that incorporate the same fibers can be ruled out only by context and availability. In order to say that a fiber did not originate from a particular textile is to know the history of the textile or have observed the fiber transfer from another textile.

5.4. Volume of Fiber Production

It could be argued that the large volume of fibers produced reduces the significance of a fiber association discovered in a criminal case. It can never be stated with certainty that a fiber originated from a particular textile because other textiles are produced using the same fiber types and color. The inability to positively associate a fiber to a particular textile to the exclusion of all others, however, does not mean that a fiber association is without value. Considering the volume of textiles produced worldwide each year, the number of textiles produced with any one fiber type and color is extremely small. The likelihood of two or more manufacturers exactly duplicating all of the aspects of the textile is extremely remote (see endnote 2). Beyond the comments made previously about color, shade tolerance differs between dyeing companies. Therefore, color may vary demonstrably from batch to batch. Also, the life span of a particular fabric must be considered. Only so much of a given fabric of a particular color and fiber type is produced, and it will eventually end up being destroyed or dumped in a landfill.

The world produced approximately 80 billion pounds of fabric in 1995, about half of which was cotton (5). The other approximately 44 billion pounds of fiber were manufactured or synthetic. Table 1 provides U.S. fiber production levels.

Table 1.
U.S. Annual Production for Manufactured Fibers: 1995
(millions of pounds)

Fiber	**Product**
Polyester	3,887
Nylon	270
Olefin	521
Rayon/Acetate/Triacetate	498
Acrylic/Modacrylic	432
(Table 1 [6]). All these fibers were used in a variety of applications including but not limited to clothing, household textiles, carpeting, and industrial textiles.	

5.4.1. Significance. As an example, given a yarn-dyed nylon fiber from a knit polo shirt of a specific color, the significance could be described in the following way:

5.4.1.1. Total fiber production;
5.4.1.2. Total nylon (of that type) production;
5.4.1.3. Total nylon production in staple form;
5.4.1.4. Total production of Item 3 in a particular denier, cross-section, optical characteristics, and luster;
5.4.1.5. Total amount of Item 4 used in production of garments;
5.4.1.6. Total garments constructed in the same fashion, including knit specifications, collar, and sleeve incorporating Item 5;
5.4.1.7. Total of Item 6 in a specific color;
5.4.1.8. Total of Item 7 from indistinguishable dye lots;
5.4.1.9. Total of Item 8 available for merchandising;
5.4.1.10. Total of Item 9 sold;
5.4.1.11. Total of Item 10 still in existence;
5.4.1.12. Total of Item 11 available to be connected with a particular criminal offense; and
5.4.1.13. Total of Item 12 actually connected with a particular criminal offense (i.e., found and submitted as evidence).

The fiber examiner is still limited to stating that the questioned fibers are consistent with originating from the evidence garment, with the understanding that all other garments listed under Item 11 (subsection 5.4.1.11) may or may not be distinguishable from the evidence garment by fiber analysis alone. This argument in no way intimates a positive match to the evidence garment to the exclusion of all other garments. Production numbers for textiles may be available for use in interpreting the significance of evidence in a crime, but the examiner must be careful to be conservative in all estimates in order to avoid false inclusions (8). Calculating exact probability statistics for this type of evidence is problematic at best, and professional statisticians must be consulted before any calculations are reported or testified.

5.5. Fiber Source

If questioned fibers are associated with known fibers, the questioned fibers either originated from the known textile or from another fabric source, which not only is composed of fibers of the exact type and color but also from a fabric that had to be available to contribute those fibers through direct or indirect contact. The chance is, therefore, remote to encounter fibers from the environment of a victim that are identical to fibers from the suspects' environment or environments in the absence of contact (9). Put another way, the chance of finding known fibers from a randomly selected suspect source that match the questioned fibers is remote (see endnote 3).

6.0. Sample Handling

Although examiners may be consulted concerning proper sample size, collection, or packaging, this may not happen, and the examiner must optimize the evidence that is submitted. Garfield (1) and others (2) list the following methods of sampling:

6.1. Probability Sampling (So-Called "Random Sampling")

Every unit in the population has a known, nonzero probability of being included in the sample (e.g., collecting about 33 percent of the fibers from a pillbox or by taping and mounting them);

6.2. Nonprobability or Judgment Sampling

Every unit in the population either is or is not included in the sample on the basis of certain characteristics it has in common with other units of interest (e.g., mounting only red trilobal carpet-type fibers from the victims' evidence given the suspect has red carpet as a possible source); and

6.3. Bulk or Lot Sampling

A sampling unit is taken from a larger amount of material that does not consist of discrete and identifiable units. Special considerations are involved with bulk sampling, such as where the sample is taken, how much sample is taken, and if the sample is considered representative of the lot (e.g., cutting a swatch from a garment for fabric and fiber examination).

Samples are adequate for analysis when they are taken in a manner consistent with generally recognized and accepted sampling techniques and practices within the context of the proposed analyses. All of the previously mentioned sampling methods have their place, and one may be more feasible than another, given crime scene or laboratory constraints. The examiner must be able to explain how the samples were taken and why that procedure was used.

Examinations typically should be conducted in the order of increasing magnification, from gross inspection to microscopical analysis. If sample size is limited, nondestructive methods must be exhausted before subjecting the sample to any destructive tests (e.g., pyrolysis).

It is highly desirable that the methods be selected in an order that provides the greatest discrimination between samples. An exclusion precludes further analysis, thereby maximizing the examiner's time and resources.

7.0. Analysis

There are three basic activities involved in an analysis (1): (a) collection of a representative sample; (b) preparation of the sample for analysis; and (c) analysis using appropriate methods.

Although these activities are ostensibly independent of each other, any one can have a significant effect on another. Because error is possible at each step, the examiner must be able to identify these errors and avoid them. Any method of analysis has certain attributes such as accuracy, precision, specificity, sensitivity, dependability, and practicality that must be considered when choosing the most appropriate method to adequately answer the question at hand. Ultimately, it is the examiner's responsibility to evaluate all of the available information and decide the level of uncertainty that is acceptable with a given method on a given set of samples.

7.1. Physical Matches

A physical match occurs when two or more pieces of fabric or cordage are reconstructed to prove they were previously one continuous piece of fabric or cordage. This examination is conducted by describing and documenting any cut, torn, or damaged edges on questioned items and their correlation to like areas on known items. Photography is the recommended method of documentation.

Depending upon sample size, suitability, and exhibited characteristics, it may not be possible to effect a positive physical match. For descriptions of physical construction refer to the fabric and cordage guidelines in Chapter 7 of this document.

7.2. Fiber Examinations

Fiber identifications consist of determining the generic class of fiber type, which generally follows the Federal Trade Commission Guidelines (3). This analysis requires a sufficient number of examinations to unequivocally place the fiber in question into one and only one generic class (see Table 2).

Fiber comparisons consist of determining if a questioned fiber or fibers exhibits the same chemical, microscopic, and optical properties as fiber or fibers comprising part or all of a known sample. A comparison requires an examiner to complete at least two of the analytical techniques listed for each of the following categories: generic class, physical characteristics, and color (see Figure 1). The techniques selected should independently confirm the results obtained. It should be noted that some techniques allow greater discrimination than others between apparently similar samples.

8.0. Report Documentation

Laboratory results should be reported in a uniform and consistent manner. Format, units of measurement, and accepted calculations should all be documented in the laboratory's manuals. The contributor of the evidence must be able to "interpret the results and understand their significance" (1). The International Organization for Standardization (ISO) recommends that reports be clear, accurate, and unambiguous in the presentation of results (4). Refer to the appropriate sections of the SWGMAT Quality Assurance Guidelines for further information.

Microscopy of Textile Fibers

http://www.fbi.gov/hq/lab/fsc/backissu/april1999/houckch2.htm

4.0. Summary of Microscopy Guidelines

Textile fibers are examined microscopically. They are mounted on glass microscope slides in a mounting medium under a cover slip. The fibers are then examined microscopically with a combination of various illumination sources, filters, and instrumentation attached to a microscope to determine their polymer type and record any microscopic characteristics. Known and questioned fibers are then compared to determine if they exhibit the same microscopic characteristics and optical properties.

5.0. Significance and Use

Microscopic examination provides the quickest, most accurate, and least destructive means of determining the microscopic characteristics and polymer type of textile fibers. Additionally, a point-by-point and side-by-side microscopic comparison provides the most discriminating method of determining if two or more fibers are consistent with originating from the same source. These guidelines require specific pieces of instrumentation outlined herein.

6.0. Sample Handling

6.1. Preparing Samples

Items of evidence are visually inspected, and tweezers are used to remove fibers of interest. Simple magnifiers and stereomicroscopes, with a variety of illumination techniques, may also be employed. Other methods such as tape lifting or gentle scraping are usually conducted after a visual examination. Tape lifts should be placed on clear plastic sheets, glass microscope slides, or another uncontaminated substrate that eases the search and removal of selected fibers. Do not overload the tapes. The tape lifts or any material recovered from scraping should be examined with a stereomicroscope, and fibers of interest should be isolated for further analysis. Fibers on tape lifts are removed using tweezers, other microscopic tools, and solvents (1-6). Tape should not be attached to paper or cardboard.

6.2. Avoiding Contamination

Take care to ensure contamination does not occur. This must be accomplished by examining questioned and known items in separate areas, at different times, or both. The work area and tools must be thoroughly cleaned and inspected before examining items that are to be compared.

7.0. Analysis

7.1. Microscopy

Fibers should be first examined with a stereomicroscope. Physical features such as crimp, length, color, relative diameter, luster, apparent cross section, damage, and adhering debris should be noted. Fibers are then tentatively classified into broad groups such as synthetic, natural, or inorganic. If the sample contains yarns, threads, or sections of fabric, construction should be recorded (7-9).

7.1.1. Side-by-Side Comparisons. If all of the characteristics are the same under the stereoscope, the next step is to examine the fibers with a comparison microscope. This side-by-side and point-by-point examination is the best technique to discriminate between fibers, especially those that appear to be similar. The physical characteristics of the fibers (see subsection 7.3) must be compared visually with the comparison microscope to determine if they are the same in the known and questioned samples. Photography is recommended to capture the salient features for later demonstration.

7.1.2. Illumination and Magnification. Comparisons should be made under the same illumination conditions at the same magnifications. For comparison microscopes, this requires color balancing the light sources. This is best achieved with two fibers or fiber samples from the same source mounted on two microscope slides, which are then compared. The visual responses from the two samples must be approximately the same color, brightness, and clarity. A balanced neutral background color is optimal.

7.2. Fiber Mounts
Many suitable media are available as temporary and permanent fiber mounts. The choice of mountant depends on availability, the particular application, and examiner preference. However, the following certain criteria (5, 10-15) must be met:

7.3. Physical Characteristics of Manufactured Fibers

7.3.1. Fiber Diameter. The diameter of circular fibers can be measured using a calibrated eyepiece graticule. Noncircular fibers require special considerations (18). If fiber diameters are not uniform within a sample, a determination of the range of diameters exhibited by the sample is recommended.

7.3.2. Fiber Color. Color can be uniform along the length of a fiber, or it can vary. Variation in color between fibers in a sample should be recorded. The examiner should be able to distinguish between dyed, surface-dyed, and pigmented fibers.

7.3.4. Cross-Sectional Shape. When viewed longitudinally on glass slides in a suitable mountant, the apparent cross-sectional shape of fibers can often be determined by slowly focusing through the fiber (optical sectioning). Actual fiber cross sections provide the best information on cross-sectional shape. (See section 8.1)

7.3.5. Fiber Surface Characteristics. Record fiber surface characteristics such as manufacturing striations, damage, and surface debris (e.g., droplets, blood, or other foreign material). Surface striations are more apparent in a mounting medium of refractive index significantly different from those of the fiber (7).

7.4. Physical Characteristics of Natural Fibers

7.4.1. Physical Features. Color, diameter, and miscellaneous physical features described previously should be noted for natural fibers. The following characteristics should also be noted.

7.4.2. Morphological Features of Animal Hairs. The principal morphological features of animal hairs are the root, medulla, cortex, and cuticle. Shield size and subshield strictures are also useful traits for species identification. Medullary and cortical structures are best observed on hairs mounted on a slide with a suitable mounting medium. Cuticular scales are best observed on replicas cast in a transparent polymer (scale casts). Scale counts (scales per 100 micrometers) can help distinguish specialty fur fibers (19-22). Silk, a protein fiber produced by caterpillars, has morphological features that differ from animal hairs. Some features of silk include crossover marks and a wedge to triangular cross section with rounded corners. In textiles, silk is occasionally seen as paired fibers cemented together, but it is most often found as single fibers (23).

7.4.3. Plant Fibers. Plant fibers can be encountered as the technical fiber (cordage, sacks, and mats) or as individual cells (fabrics and paper). The examination of technical fibers should include a search for epidermal tissue and crystals and the preparation of a cross section. Additionally, a chemical test for lignin may be performed. Technical fibers should be macerated, fabrics teased apart, and paper repulped for the examination of individual cells. Relative thickness of cell walls and lumen, cell length, and the presence, type, and distribution of dislocations should be noted. The direction of twist of the cellulose in the cell wall can also be determined (24). Other characteristic cells should be noted and compared to authentic specimens (25-27).

7.5. Physical Characteristics of Inorganic Fibers

7.5.1 Asbestos Minerals. Mineral fibers are commonly called asbestos, which is a general term for many naturally occurring fibrous hydrated silicate minerals. The asbestos minerals include chrysotile, amosite, crocidolite, fibrous tremolite/actinolite, and fibrous anthophyllite. Chrysotile belongs to the serpentine group of minerals that are layer silicates. The other asbestos minerals are amphiboles and are classified as chain silicates. Asbestos fibers alone or mixed with other components occur in building materials and insulation products. Chrysotile is the only asbestos mineral that would be encountered as a woven fabric, but any of the asbestos minerals are found in pressed sheets such as gaskets. Take care when analyzing asbestos fibers because they are considered a potential health hazard.

All asbestos minerals can be easily identified by their optical properties using polarized light microscopy. Although not considered essential, the dispersion staining technique is extremely helpful (28-29). Scanning electron microscopy with energy dispersive spectrometry can also be used to characterize the asbestos minerals. Nonmicroscopical techniques for asbestos identification include X-ray diffraction and infrared spectroscopy.

Glass fibers are often encountered in building materials and insulation products. Glass fibers are also called manmade vitreous fibers (30). On the basis of the starting materials used to produce glass fibers, they can be placed into three categories: fiberglass (continuous and noncontinuous), mineral wool (rock wool and slag wool), and refractory ceramic fibers (glass ceramic fibers). Single crystal and polycrystalline refractory fibers such as aluminum oxide, silicon carbide, zirconium oxide, and carbon are not included because they are not considered glass fibers.

7.7. Miscellaneous Techniques

7.7.1. Preparing Cross Sections. Physical cross sections from fibers as short as 1 mm can be prepared. Manufactured and vegetable fibers may be sectioned anywhere along their length (54-59). Animal hairs may be sectioned to yield additional identifying characteristics (60-61). When observing manufactured fiber cross sections, the general shape and distribution of delustrant, pigment particles, or both; the presence and size of spherulites or voids; depth of dye penetration; and surface treatments should be recorded when present. The fiber dimensions measured from a cross section can be used for the calculation of birefringence and the determination of the modification ratio of multilobed fibers.

7.7.3. Heat Effects.

[I deleted this section, but just know that fibers can be destructively tested with heat. A simple way is to hold the fiber near a flame to see how it reacts. Does it char, melt, or remain unchanged? Does a melting fiber create balls or burst into flame? All of these reactions can help to determine fiber type.]

8.0. Report Documentation

The examiner's analytical notes should reflect the particular characteristics used in the microscopic comparison, especially any calculated values, descriptions, diagrams, or photographs. A positive association is when the questioned and known fibers exhibit the same microscopic characteristics and optical properties in all tested parameters and are therefore consistent with originating from the same source. A negative association is when the questioned and known fibers are different in some significant aspect and are therefore from separate sources. An inconclusive result indicates that no conclusion could be reached, and some explanation is required as to why a definitive conclusion was not possible.