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

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

Background

Paints and polymers examinations are typically considered to be trace evidence examinations, as a result of how paints and polymers evidence is created and transferred and the types of questions their analysis attempts to answer. Trace evidence analysis became possible once the microscope was developed near the end of the 17th century. Since that time, microscopists have been using various light microscopes to view tiny (trace) objects. The modern trace evidence examiner has access to an arsenal of advanced instrumental techniques. As a result, trace evidence analysis requires strong foundations in the physical sciences, such as chemistry, mathematics, and physics.

Trace evidence was formally discussed by Edmond Locard as early as 1930,[1] and Paul Kirk devoted a chapter to paint examinations in "Crime Investigation" originally published in 1953.[2] Additional works have been published over the years in which chapters have been devoted to forensic paint examinations.[3] Though forensic tape and polymer analyses appear less frequently in the scientific literature, many of the same chemical starting materials are used in their manufacture, and many of the same analytical techniques are applicable for their analysis. Further, the paint, tape, and polymer manufacturing industries have extensive experience in analyzing these manufactured products, and therefore industry representatives are frequently contacted by examiners for their expertise on specific products.

Principles of Forensic Paints and Polymers Examinations

When conducting paints and polymers (e.g., pressure sensitive adhesive tapes, adhesives, glues, plastics) comparisons, an examiner assesses whether the observed features and collected analytical data are in agreement or disagreement between two evidence items in order to form an

[1] Locard, Am.J.Pol.Soc. (1930) 1(3), 276-298.

[2] Kirk, P.L., Crime Investigation, Thornton, J.I., ed., 2nd ed., John Wiley & Sons, New York, NY, 1974; reprint edition, Robert E. Krieger Publishing Company, Inc., Malabar, FL, 1985.

[3] Ryland, S.G. in Practical Guide to Infrared Spectroscopy, Vol.19, Humecki, H.J., ed., 1995. Caddy, B., in Forensic Examination of Glass and Paint: Analysis and Interpretation, 2001.

opinion. The conclusion the examiner reaches upon completion of the testing procedures depends upon the amount and condition of specimens available, the techniques performed, and the results of those examinations. Such conclusions for comparative requests include physical matches, associations (with varying degrees of significance), inconclusive results, or eliminations.

Examiners must not overstate or understate the weight of their conclusions. As such, examiners need to be aware of the limitations associated with paint and polymer examinations. Since most polymeric materials are mass produced, the examiner must consider the possibility that a given paint could be applied to multiple objects, that a given roll of tape could be one of many with the same characteristics, and that a particular polymer has many possible applications for use. These main limitations of paint and polymer comparisons are described in the report through the conclusions scale.

Theory of Paints and Polymers Examinations

The examiner attempts to differentiate items and thereby eliminate the possibility that they could have originated from the same source. If the items cannot be differentiated, then the examiner concludes that they may share a common origin (*e.g.*, tape roll, paint can, vehicle, assembly plant) and attempts to assess the significance of that association. Other analyses include determining the potential source of a material when an exemplar has not been located. These types of analyses involve comparisons to reference collections and databases.

Reference collections and their corresponding databases are critical in the forensic analysis of paints and polymers, because they provide the data that allows forensic examiners to demonstrate that differentiation of products and classes of materials is possible using a variety of laboratory techniques. Numerous studies using reference collections have demonstrated the forensic capabilities regarding analysis of automotive paint,[4] architectural and spray paints,[5] duct tapes,[6] electrical tapes,[7] and packaging tapes.[8]

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[4] Buckle, J.L., MacDougall, D.A., and Grant, R.R. PDQ – Paint Data Queries: The history and technology behind the development of the Royal Canadian Mounted Police Forensic laboratory services automotive paint database. *Canadian Society of Forensic Science Journal* (1997) 30(4):199-212; Cousins, D.R., Platoni, C.R., and Russell, L.W. The variation in the colour of paint on individual vehicles, *Forensic Science International* (1984) 24(3):197-208; Edmondstone, G., Hellman, J., Legate, K., Vardy, G.L., and Lindsay, E. An assessment of the evidential value of automotive paint comparisons. *Canadian Society of Forensic Science Journal* (2004) 37(3):147-153; Fukuda, K. The Pyrolysis gas chromatographic examination of Japanese car paint flakes, *Forensic Science International* (1985) 29:227-236; Ryland, S.G., Kopec, R.J., and Sommerville, P.N. The evidential value of automobile paint. Part II: The frequency of occurrence of topcoat colors, *Journal of Forensic Science* (1981) 26(1):64-75; Ryland, S.G., et. al. Discrimination of 1990s original automotive paint systems: A collaborative study of black nonmetallic base coat/clear coat finishes using infrared spectroscopy, *Journal of Forensic Science* (2001) 46(1):31-45; Wampler, T., Bishea, G., and Simonsick, W.J. Recent changes in automotive paint formulation using pyrolosis-gas chromotography/mass spectrometry for identification, *Journal of Analytical and Applied Pyrolysis* (1997) 40-41:79-89.

[5] Bell, S., Fido, L.A., Speers, S.J., Armstrong, W.J, and Spratt, S. Forensic analysis of architectural finishes using Fourier Transform infrared and Raman spectroscopy, Part I: The resin bases, *Applied Spectroscopy* (2005) 59(11):1333-1339; Bell, S., Fido, L.A., Speers, S.J., Armstrong, W.J, and Spratt, S. Forensic analysis of architectural finishes using Fourier Transform infrared and Raman spectroscopy, Part II: White paint, *Applied Spectroscopy* (2005) 59(11):1340-1346; Buzzini, P., and Massonnet, G. A market study of green spray paints by

Further, Interpol has a triennial meeting where forensic managers from Interpol Member States convene to discuss the current status of various forensic disciplines. As part of this meeting, review articles are published in the various disciplines. The Interpol review covering late 2007 to early 2010, for instance, included 378 references on paint developments and analysis that had occurred during that timeframe.[9] Another thorough review paper on paint analysis covers a wider timeframe and provides the scientific foundation of forensic paint analysis.[10]

More recently, the Department has conducted a number of studies to expand on this foundation and to explore the discrimination power possible using a combination of techniques for the comparison of paints and tapes.

Two of the most recent studies involved the analysis of architectural paint samples. In the first,[11] a very high level of discrimination (99.998%) was achieved for 964 random samples (464,166 comparison pairs). The indistinguishable pairs of samples each originated from the

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Fourier transform infrared (FTIR) and Raman spectroscopy, *Science and Justice* (2004) 44(3):123-131; Tippett, C.F., Emerson, V.J., Fereday, M.J., Lawton, F., Richardson, A, Jones, L.T., and Lampert, S.M. The evidential value of the comparison of paint flakes from sources other than vehicles, *Journal of the Forensic Science Society* (1968) 8(2):61-65; Wright, D.M., Bradley, M.J., Mehltretter, A.H. Analysis and discrimination of architectural paint samples via a population study, *Forensic Sci. Int.* 2011, 209(1-3):86-95; Wright, D.M., Bradley, M.J., Mehltretter, A.H. Analysis and discrimination of single-layer white architectural paint samples. *J Forensic Sci.* 2013, 58(2):358-364; Muehlethaler, C., et.al., Survey on batch-to-bath variation in spray paints: a collaboratorive study, *Forensic Sci. Int.* 2013, 229(1-3):80-91.

[6] Hobbs, A., Gauntt, J., Keagy, R., Lowe, PC., and Ward, D. A new approach for the analysis of duct tape backings. *Forensic Science Communications*, 2007; 9(1); Mehltretter, A.H., Bradley, M.J. Forensic analysis and discrimination of duct tapes, *Journal of the American Society of Trace Evidence Examiners*, 2012, 3(1): 2-20; Smith, J. The forensic value of duct tape comparisons. *Midwestern Association of Forensic Scientists, Inc. Newsletter*, 27(1), January 1998, 28-33; D.M. Wright, A.H. Mehltretter. Forensic duct tape sourcing examinations: Developing investigative leads using multiple resources, Journal of the American Society of Trace Evidence Examiners, 2013, 4(1): 13-28.

[7] Goodpaster JV, Sturdevant AB, Andrews KL, Brun-Conti L. Identification and comparison of electrical tapes using instrumental and statistical techniques: I. Microscopic surface texture and elemental composition. *J Forensic Sci* 2007;52:610-29; Kee, T.G. The characterization of PVC adhesive tape. *Proceedings of the International Symposium on the Analysis and Identification of Polymers*, FBI Academy, Quantico, VA, July 31- August 2, 1984, 77-85; Keto, R.O. Forensic characterization of black polyvinyl chloride electrical tape. *Proceedings of the International Symposium on the Analysis and Identification of Polymers*, FBI Academy, Quantico, VA, July 31-August 2, 1984, 77-85; Mehltretter, A.H., Bradley, M.J,. Wright, D.M. Analysis and discrimination of electrical tapes: Part I. Adhesives, *J Forensic Sci.*, 2011, 56(1): 82-94; Mehltretter, A.H., Bradley, M.J., Wright, D.M. Analysis and discrimination of electrical tapes: Part II. Backings, *J Forensic Sci.*, 2011; 56(6): 1493-1504.

[8] Maynard, P., et al. Adhesive tape analysis: establishing the evidential value of specific techniques. *J. Forensic Sci.* 2001; 46(2): 280-287; Smith, J., and Weaver, R. PLM examinations of clear polymeric films: identification of monoaxial and biaxial orientation and other observations. *Microscope*, 2004; 52(3/4): 112-118.

[9] M.J. Bradley, A.H. Mehltretter, and D.M. Wright. Examination of Paint, Review: 2007-2010, in *Review Papers*, 16th Interpol International Forensic Science Symposium, Lyon, France, October 5-8, 2010: 113-181.

[10] Ryland, S.G., Jergovich, T.A., and Kirkbride, K.P. Current Trends in Forensic Paint Examination, *Forensic Sci Rev* (2006), 18:97.

[11] Wright, D.M., Bradley, M.J., Mehltretter, A.H. Analysis and discrimination of architectural paint samples via a population study, *Forensic Sci. Int.* 2011, 209(1-3):86-95;

same source and were therefore not false inclusions. Further, in the follow-up study regarding only white architectural paints,[12] no random pairs of samples remained indistinguishable.

A similar study was conducted on the discrimination power of the techniques for duct tape samples.[13] A very high level of discrimination (99.8%) was achieved for 82 samples (3321 comparison pairs); including 99.6% by stereomicroscopy alone. Only seven pairs (five groups) of samples were unable to be discriminated, and based on their labels/brand names, the samples that remained indistinguishable likely share a common manufacturing source.

A roll of duct tape is manufactured from a master ("jumbo") roll that is cut to the desired length and width to produce many smaller rolls for individual or bulk sale. Based on this knowledge of the manufacturing process, a follow-up study was designed and undertaken to evaluate the within-roll and within-jumbo roll variation of duct tapes.[14] The results indicated that most of the examined features varied to a limited extent along the length of an individual roll of tape. Further, aside from width, minimal variation in these characteristics also occurs between different rolls cut from the same jumbo roll. Statistical analysis of a portion of the data indicated that some statistically significant differences are observed, but these differences are minor and would not likely have resulted in an exclusion/elimination in a forensic comparison case.

For electrical tapes, two additional studies evaluated discrimination power using standard techniques. The first publication[15] addressed adhesive analysis and the second[16] discussed the backings and the tape as a whole. These studies were evaluating the relative abilities of the different analytical techniques to discriminate tapes. Despite the knowledge that many replicate rolls were included in the sample set, a very high level of discrimination (95.76%) was achieved for 90 tapes (4005 comparison pairs). Most of these were known to be replicate rolls of the same product. This study also demonstrated the wide range of chemical compositions available for electrical tape products.

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[12] Wright, D.M., Bradley, M.J., Mehltretter, A.H. Analysis and discrimination of single-layer white architectural paint samples. *J Forensic Sci.* 2013, 58(2):358-364.

[13] Mehltretter, A. and Bradley, M. (2012) "Forensic analysis and discrimination of duct tapes," *Journal of the American Society of Trace Evidence Examiners*, 3(1): 2-20.

[14] Mehltretter, A.H., Wright, D.M., Dettman, J.R., and Smith, M.A. (2015). "Intra-Roll and Intra-Jumbo Roll Variation of Duct Tapes," *Journal of the American Society of Trace Evidence Examiners*, 6(1): 21-41.

[15] Mehltretter, A.H., Bradley, M.J,. Wright, D.M. Analysis and discrimination of electrical tapes: Part I. Adhesives, *J Forensic Sci.*, 2011, 56(1):82-94.

[16] Mehltretter, A., Bradley, M., and Wright, D. (2011) "Analysis and discrimination of electrical tapes: Part II. Backings," *Journal of Forensic Sciences*, 56(6): 1493-1504.

Paints and Polymers Process

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

Department paints and polymers examinations focus on the analysis of paints, tapes, and other polymeric materials. Most often the request for these examinations is to determine whether two items could share a common source (e.g., whether paint found on a hit-and-run victim's clothing could have originated from a suspect vehicle). The sequence of examinations is dictated by Department laboratory standard operating procedures (SOPs), the quality and quantity of the material to be analyzed, and professional judgment. Additionally, ASTM International and the Scientific Working Group for Materials Analysis (SWGMAT) have established minimum recommendations for the analysis of these materials.[17] These recommendations are based upon the use of an analytical scheme which incorporates multiple orthogonal[18] techniques.

Paints and polymers examinations begin with visual observations, with the unaided eye and/or a stereomicroscope. The purpose of these techniques is to evaluate the physical characteristics of the specimens. If two items did not originate from the same source, differences are frequently observed in the physical characteristics (e.g., different colors or layer structures). If no differences are observed, instrumental analyses and comparisons of the chemical properties are warranted and would be conducted next.

The selection of the technique(s) utilized will depend upon the case request, the material being analyzed, and the quality and quantity of available specimens. As a general matter of scientific principle, the comparison of materials requires (whenever possible) the use of two or more orthogonal techniques. The combination of techniques is chosen to achieve the maximum potential for sample discrimination.

Chemical/instrumental techniques utilized in the Paints and Polymers Subunit examinations include, but are not limited to, Fourier transform infrared spectroscopy, (FTIR), pyrolysis - gas chromatography / mass spectrometry (Py-GC/MS), scanning electron microscopy with energy dispersive spectroscopy (SEM/EDS), and X-Ray diffraction (XRD). Each of the techniques is routinely used in laboratories around the world: forensic laboratories as well as academic, environmental, other government and industrial laboratories.

[17] ASTM International and the Scientific Working Group for Materials Analysis (SWGMAT) are long-standing guidance groups and are not regulatory groups. More recently, the Organization for Scientific Area Committees (OSAC) was established by the National Institute of Standards and Technology (NIST) to, according to its website, "support the development and promulgation of forensic science consensus documentary standards and guidelines." The OSAC includes a subcommittee on Materials (Trace) analysis, and this group is further evaluating the ASTM and SWGMAT guides to decide whether or not to recommend them to the OSAC Registry of approved documents.

[18] Orthogonal techniques assess items' chemical properties using fundamentally different chemical principles (e.g., light versus mass).

FTIR[19] is a technique in which infrared light is transmitted through or reflected off a sample. The functional groups (e.g., C=O, C=C, C-N) present in the chemical components of the sample interact with the light in patterns that are indicative of those functional groups. FTIR is a straightforward and non-destructive technique to obtain information about both the organic (e.g., C=O) and inorganic (e.g., TiO_2) constituents of the materials analyzed.

Py-GC/MS[20] is used to obtain more detailed information about the organic constituents of the materials analyzed. The pyrolysis (Py) step involves the heating of a solid polymer sample in an inert atmosphere, which breaks the polymer down into smaller units. These chemical fragments are separated through the gas chromatography (GC) step, and then are detected by the mass spectrometer (MS). The separation aspect of this technique and improved detection limits over FTIR frequently result in an improved discrimination power for paint, tape, and polymer examinations.

SEM/EDS[21] is a technique in which a high powered electron microscope (i.e., electrons are used for imaging rather than light) is used to evaluate elements (e.g., aluminum, titanium,

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[19] Selected references include: ASTM E2937, Standard Guide for Using Infrared Spectroscopy in Forensic Paint Examinations. ASTM International, West Conshohocken, PA; Goodpaster, J.V., Sturvdevant, A.B., Andrews, K.L., Briley, E.M., and Brun-Conti, L. Identification and comparison of electrical tapes using instrumental and statistical techniques: II. Organic composition of the tape backings and adhesives. *J Forensic Sci*., 2009; 54(2):328-38; Hobbs, A., Gauntt, J., Keagy, R., Lowe, PC., and Ward, D. A new approach for the analysis of duct tape backings. *Forensic Science Communications*, 2007; 9(1); Ryland, S.G. Infrared microspectroscopy of forensic paint evidence. Chapter 6 in *Practical Guide to Infrared Microspectroscopy*. (ed. H.J. Humecki) NY: Marcel Dekker, Inc., 1995; Ryland, S.G. and Suzuki, E.M. Analysis of paint evidence. Chapter 5 in *Forensic Chemistry Handbook*. (ed. L.F. Kobilinsky) NJ: John Wiley and Sons, Inc. 2012; SWGMAT, "Guideline for Using Fourier Transform Infrared Spectroscopy in Forensic Tape Examinations," Online at http://www.swgmat.org; McNorton, S.C., Nutter, G.W., Siegel, J.A. The characterization of automotive body fillers, *J. Forensic Sci.* 2008, 53(1):116-124.

[20] Selected references include: Blackledge, R.D. Application of pyrolysis gas chromatography in forensic science. *For. Sci. Rev.* 1992; 4(1): 1-16; Challinor, J.M. Pyrolysis techniques for the characterization and discrimination of paint. In: *Forensic Examination of Glass and Paint; Analysis and Interpretation*, B. Caddy, ed., Taylor & Francis, London, England, 2001; Phair, M., Wampler, T.P. Analysis of rubber material by pyrolysis GC. *Rubber World* Feb. 1997: 30-34; SWGMAT, "Standard Guide for Using Pyrolysis Gas Chromatography and Pyrolysis Gas Chromatography-Mass Spectrometry in Forensic Paint Examinations," Online at http://www.swgmat.org; SWGMAT, "Standard Guide for Using Pyrolysis Gas Chromatography and Pyrolysis Gas Chromatography-Mass Spectrometry in Forensic Tape Examinations," Online at http://www.swgmat.org; Wampler, T.P. *Applied Pyrolysis Handbook.* 2nd ed. Boca Raton, FL: CRC Press, 2007; Wampler, T.P., Bishea, G.A., Simonsick, W.J. Recent changes in automotive paint formulation using pyrolysis-gas chromatography/mass spectrometry for identification. *J. Anal. Applied Pyrolysis* 1997; 40-41: 79-89; Wampler T.P., Zawodny C.P. Analysis of polymer packing products using pyrolysis-gas chromatography-mass spectrometry. *Am. Lab. News Ed.* 1999; 31(19): 30-32; Williams, E.R., Munson, T.O. The comparison of black polyvinylchloride (PVC) tapes by pyrolysis gas chromatography. *J. For. Sci.* 1988; 33(5): 1163-1170; Plage, B., Berg, A., and Luhn, S. The discrimination of automotive clear coats by pyrolysis-gas chromatography/mass spectrometry and comparison of samples by a chromatogram library software, *Forensic Sci. Int.* 2008, 117:146-152.

[21] Selected references include: ASTM E2809, Standard Guide for Using Scanning Electron Microscopy/X-Ray Spectrometry in Forensic Paint Examinations, ASTM International, West Conshohocken, PA; Goldstein, J.I., *Scanning Electron Microscopy and X-ray Microanalysis*, 2nd ed., 1992, Plenum Press, New York; Goodpaster JV, Sturdevant AB, Andrews KL, Brun-Conti L. Identification and comparison of electrical tapes using instrumental and statistical techniques: I. Microscopic surface texture and elemental composition. *J Forensic Sci* 2007;52:610-29; Lee, R.E., *Scanning Electron Microscopy and X-Ray Microanalysis*, 1993, Englewood Cliffs, NJ; SWGMAT, "Guideline for Using Scanning Electron Microscopy/Energy Dispersive X-ray Spectroscopy in Forensic Tape

calcium) present in the materials and/or to provide images of the samples based on elemental content.

XRD[22] supplements the inorganic information available from FTIR and SEM/EDS by providing information on the crystalline forms present in the sample. For instance, XRD can distinguish the rutile and anatase forms of titanium dioxide (TiO_2), either of which can be present within a paint or tape. Other techniques can detect the presence of TiO_2 but cannot distinguish between its crystalline forms.

When conducting paints and polymers comparisons, an examiner assesses whether the observed features and collected analytical data at each step in the process are in agreement or disagreement between two or more evidentiary items in order to form an opinion. If significant differences are observed between samples at the completion of any step in the analytical scheme, the examiner will stop conducting examinations and report an **Elimination**. If no significant differences are found upon the completion of all testing procedures, then the possibility that the items came from the same source cannot be eliminated. Depending upon the amount and condition of specimens available, the techniques performed, and the results of those examinations, the examiner will, at a minimum, add a statement to aid the reader of the report in understanding the significance of the conclusion reached.

The results of the examinations and the assigned conclusion for each comparison are included in the report. A statement addressing the rationale as to why that conclusion was assigned and the conclusions scale in its entirety may also be included in order for the reader of the report to understand how the assigned conclusion relates to the range of possible conclusions.

Policy Considerations

In 2006, Congress authorized the National Academy of Sciences to conduct a study on forensic science, which culminated in a 2009 report.[23] While the NAS committee determined that the scientific methodologies supporting paint examinations (neither tape nor general polymers were specifically addressed) are "based on a solid foundation of chemistry to enable class identification," the committee raised one criticism pertaining to the practice of Paints and Polymers analysis.[24]

A general criticism in the publication was the lack of guidance for report writing as well as the absence of set criteria for determining a conclusion.[25] This criticism was due to the relevant

Examinations," Online at http://www.swgmat.org; Vaughan, D., Ed., *Energy Dispersive X-ray Microanalysis: An Introduction*, 1989, Kevex Instruments Inc., San Carlos, CA.

[22] Selected references include: Buhrke, V.E., et al., editors. *A Practical Guide for the Preparation of Specimens for X-Ray Fluorescence and X-Ray Diffraction Analysis*, Wiley-VCH, New York, 1998; Cullity, B.D. *Elements of X-Ray Diffraction*, 2d ed., Addison-Wesley, Reading, MA, 1978; Mehltretter, A.H., Bradley, M.J. Forensic analysis and discrimination of duct tapes, *Journal of the American Society of Trace Evidence Examiners*, 2012, 3(1): 2-20.

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

[24] *Id.* at 170.

[25] *Id.* at 169.

forensic science community not defining "precise criteria for determining whether two samples come from a common source class."[26]

[26] *Id.* at 170.