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Guest Editorial

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Guest Editorial

Guidelines and Resources for Conducting an Environmental Crime Investigation in the United States[1]

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Common environmental crimes in the United States include the illegal disposal of hazardous waste, unpermitted discharges to sewer systems or surface water, discharge of oil by vessels to waters within United States jurisdiction, the misapplication of pesticides, the illegal importation of ozone-depleting substances, data falsification, and laboratory fraud. Federal, state, and sometimes local statutes and regulations are in place to protect the water, air, land, and human health. From a federal perspective, these include the Resource Conservation and Recovery Act (RCRA) for hazardous wastes, the Toxic Substances Control Act (TSCA) for toxic substances, the Clean Air Act (CAA), the Clean Water Act (CWA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for abandoned waste sites, and the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) for pesticides. Each of these laws contains some standard methods for sampling and analyses to prove environmental crimes. The Code of Federal Regulations (CFR) contains the specific requirements of the laws. Within the United States Environmental Protection Agency (USEPA), the Criminal Investigation Division (CID) of the Office of Criminal Enforcement, Forensics and Training (OCEFT) has the responsibility to investigate criminal offenses.

Criminal offenses are more serious in nature than civil violations in the United States. To successfully prosecute an environmental criminal case, the government has to prove, beyond a reasonable doubt, that a corporation or person knowingly violated an environmental statute containing criminal sanctions. The same environmental forensic techniques used to provide scientifically defensible data prevail in both civil and criminal cases; the only distinction between the two types of cases is legal.

Keywords: Computer forensics; environmental crimes; case studies; *Daubert*; chemical fingerprinting; link analysis.

Introduction

The criminal prosecution of environmental crimes in the United States is in its infancy. While a few scattered efforts at environmental crime prosecution occurred during the 1970s, the United States federal government prosecution of environmental crimes substantially increased in the 1980s as environmental laws were promulgated and enhanced from misdemeanor criminal penalties (any crime punishable by less than one year in jail) to felony provisions (any crime punishable by more than one year in jail). Given the seriousness of these crimes, an investigative team must focus on several issues when developing an environmental case that may come before a federal court of law.

Investigative procedures

The first step in an investigation is to understand the alleged crime and the participants. Often multiple government agencies are involved and communication between agencies can be a challenge. In the United States, a leading criminal investigator is commonly referred to as the *case agent*. The case agent develops an understanding of allegations of criminal activities, consults with various witnesses, peers, and experts to decide what evidence can prove the case, and directs the investigative team. Documents prepared for use in environmental investigations include "Environmental Investigations: Standard Operating Procedures and Quality Assurance Manual" and "Conducting Environmental Compliance Inspections". The first manual contains information about different types of investigations, forms and recordkeeping, sampling design, quality assurance (QA), and an extensive listing of field procedures (USEPA R4, 2001). The second manual includes information on site inspection, safety issues, legal considerations, and evidence topics (USEPA R10, 1997).

During the investigative process, a decision is often required about conducting one or more searches for evidence. In the United States, evidence must be gathered in accordance with the Federal Rules of Criminal Procedure and other federal guidelines designed to protect the individual's constitutional rights (KU School of Law, 2002). Methods used to obtain evidence of a crime include the use of consent searches,

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search warrants, and grand jury subpoenas. See *Environmental Crime: Evidence Gathering and Investigative Techniques* for additional details regarding on-site investigations (Drielak, 1998). Sampling conducted on a consensual basis is not recommended because consent can be revoked. If a search warrant is necessary, a description of the probable cause and alleged crime is needed in addition to naming the location requested for the search. The case agent may articulate probable cause through evidence gathered from a variety of sources including witness interviews, surveillance of suspects, use of informants, and sampling of suspected discharges from the targeted facility.

The execution of a search warrant can require extensive planning. Ongoing communication, including face-to-face meetings to discuss goals, problems, and objectives, can enable the team to plan the field objectives and make the best use of the limited time on-site. Generally, warrants are required to be executed during the hours of 6 a.m. to 10 p.m., unless a special situation is involved, such as a chemical release that can only be sampled as the release is occurring. Prior to implementing a search warrant, any manufacturing processes should be evaluated to understand how chemicals are produced and what wastes are generated. Industrial waste treatment and management systems often need detailed examination. For example, waste tanks and all associated piping may require identification to see if there is a connection to a sewer where an alleged release occurred.

The investigator should maintain contact with laboratory personnel to discuss sampling activities, to determine if appropriate analytical techniques are available for use, and to ensure that resources are available to complete the analyses within applicable holding times (established time limitations for sample analysis). Multiple laboratories may be needed. Laboratory personnel should be involved as early as possible in the planning process. The analytical chemist(s) should be familiar with the types of samples being collected, the purpose of each sample in proving the case, and the appropriate analytical methods that could prove the allegations.

Analytical documentation includes laboratory notebooks, bench sheets, instrument printouts, instrument calibration, and confirmatory analysis by alternate methods. Expert opinions may be required regarding chemical compounds and the fate and transport of contaminants.

Evidence preservation is a critical step in prosecuting any case and environmental cases are no exception. As part of the Federal Rules of Evidence, the government has the burden of proof that any evidence presented in court is authentic. Challenges may be made to every step of the investigative process including sampling, transportation, physical and chemical analysis, and sample storage. If care is not taken to properly preserve evidence and maintain chain of custody in every step of the investigative process, then the evidence may be inadmissible at trial.

The investigative file should contain records of interviews, photographs, video recordings, sketches, field project plans, laboratory quality assurance project plans, correspondence, field notes, chain-of-custody records, calibration records, laboratory bench sheets, analytical reports, and any other pertinent records.

Sources of investigative information

Information that may be needed for an environmental crime investigation is available from many sources, several of which are electronically accessible. An example is "Using On-line Searches in Investigations", an article that explores the online research tools available for fact-finding and discusses the merits of commercial database research versus Internet resources (Schmidt *et al.*, 1998). Another publication outlining research resources is *The Investigator's Little Black Book 2*. The book contains information on experts, organizations, and publications with topics ranging from "Accident Reconstruction" to "Zip Code Information" (Scott, 1998). *Sources of Information for Criminal Investigators*, prepared by Anacapa Sciences,

Table 1. Information sources on corporations and individuals

Source	Description
Dun and Bradstreet Services	Provides business histories, operations, public filings and credit ratings with an international scope. The service also provides access to information on more than 58 million global companies (D&B, 2002).
EDGAR	The Electronic Data Gathering, Analysis, and Retrieval system performs automated collection, validation, indexing, acceptance, and forwarding of submissions by companies and others who are required by law to file forms with the US Securities and Exchange Commission (SEC) (US SEC, 1999, 2002; EDGAR Online, Inc., 2002).
Directory of Corporate Affiliations	Business information source offering corporate linkage coverage – a trusted guide to corporate families in the United States and worldwide (Corporate Affiliations, 2002).
Autotrack and CDB Infotek	Database services available from ChoicePoint Company. This is a nationwide provider of organized online public record data and other information services that are used to detect fraudulent activity, locate people and assets, and verify information and identities (ChoicePoint, 2002).
*info*USA	Regarded as a comprehensive and accurate source of business and residential information about nearly 12 million businesses in the United States, 1.1 million Canadian businesses, 125 million US households, and 12 million Canadian households. The company provides information in a variety of formats ranging from CD-ROM and Internet access to printed materials (infoUSAGov, 2001).
GIS	Additional information about the crime scene can be obtained using Geographic Information Systems (GIS) maintained by a local or state agency (US Census Bureau, 2002; USEPA, 2001d; USEPA R2, 2001; USEPA R7, 2001).

Table 2. Manufacturing processes, raw materials, and waste streams

Source	Description
Kirk-Othmer Encyclopedia of Chemical Technology	The latest version of this 27-volume set encyclopedia is now complete and includes Chemical Abstract Service registry numbers and in-depth information on regulations, patents, and licensing. Articles primarily focus on chemical substances and industrial processes (John Wiley & Sons, 1999a).
Ullmann's Encyclopedia of Industrial Chemistry	This encyclopedia has a 40-volume print set covering the basics of theoretical principles and fundamentals of chemical engineering. The encyclopedia presents practical knowledge of unit operations and plant construction with specific company examples. A newer electronic edition is also available (John Wiley & Sons, 1999b).
Development documents for effluent limitations guidelines and standards	In this series, the USEPA Office of Water has published details about many industries. The Landfills Point Source category, the Alkaline Coal Mining subcategory, the Metal Products and the Machinery Point Source category are included in this series. Diagrams and descriptions of industrial processes are provided in the series. These documents are distributed through the National Technical Information Service (NTIS) (USEPA NTIS, 2000a,b,c).
Sector notebooks	The USEPA Office of Compliance has developed a series of profiles containing information on selected major industries. Each notebook includes a comprehensive environmental profile, industrial process information, pollution prevention techniques, contaminant release data, regulatory requirements, contact names, compliance and enforcement history, and bibliographic references (USEPA, 2001c).

describes methods of investigation and criminal analysis (Anacapa Sciences, Inc., 2001a).

Information on many relevant topics used in criminal investigations is available. Investigators can access information about alleged polluters (Table 1), manufacturing processes, raw materials, and waste streams (Table 2), and the toxicology (Wright, 2001; Keita-Ouane *et al.*, 2001; Miller Poore *et al.*, 2001; Brinkhause, 2001), chemistry, and transport model of a contaminant of interest (Table 3). The financial and compliance history of a facility is often available by accessing the sources listed in Table 4. Sources for environmental terms and publications (Table 5) and for international environmental information (Table 6) are available as well.

Field techniques and equipment

A thorough knowledge of the field equipment and its proper use is necessary in a criminal investigation as it is anticipated that any deviation from a standard operating procedure is vulnerable to scientific and legal challenges. General sources of information on commonly used equipment are summarized in Table 7.

A recently published handbook details field analytical tests and includes step-by-step instructions,

Table 3. Chemistry, toxicology, and transport models of contaminants

Source	Description
Global Information Network on Chemicals (GINC)	A global information network for the safe use of chemicals. This site lists useful information sources provided by both international organizations and national institutions collaborating for safe control of chemicals (GINC, 2002).
MSDS-SEARCH	This Internet site is a good starting point for locating manufacturers' material safety data sheets (MSDS). These sheets provide detailed information including references about the hazards of a particular chemical. Links to translation services that provide MSDS in many languages are included on the internet site (MSDS-SEARCH, 2002).
Chemical Abstracts Service (CAS)	CAS is the world's largest and most comprehensive databases of chemical information. The principal databases, Chemical Abstracts (CA) and REGISTRY, include about 16 million document records and more than 30 million substance records, respectively. CAS also produces databases of chemical reactions, commercially available chemicals, listed regulated chemicals, and compounds claimed in patents (CAS, 2002).
Integrated Model Evaluation System (IMES)	IMES is an interactive system for selecting fate models (air, surface water, groundwater and multimedia) most appropriate to the needs of an exposure assessor. It includes information on over 100 models that address items such as the input requirements, level of detail, required user expertise, applications, and validation. IMES is distributed on a CD-ROM that includes many of the fate models and manuals (USEPA NCEA, 2001, 2002; USEPA OWOW, 1997).
Environmental Fate Data Base (EFDB)	The EFDB was developed under the sponsorship of the USEPA to allow rapid access to all available fate data on a chemical and to provide a data source for constructing structure-activity correlations for degradability and transport of chemicals in the environment. The EFDB is a tremendous aid in identifying persistent chemical classes as well as the physical or chemical properties that may correlate to particular behavior in the environment. The EFDB is composed of several interrelated files-DATALOG, CHEMFATE, BIOLOG, and BIODEG. These databases share a CAS number file containing over 20,000 chemicals with preferred name and formula and a bibliographic file containing full references for over 35,000 cited articles (SRC, 2001).
HazDat Database	HazDat, the Hazardous Substance Release/Health Effects Database, is the scientific and administrative database developed by the Agency for Toxic Substances and Disease Registry (ATSDR) to provide access to information on the release of hazardous subtances from Superfund sites or from emergency events. The database also contains information on the effects of hazardous substances on the health of human populations (ATSDR, 2002).

Table 4. Facility financial and compliance history

Source	Description
Financial Crimes Enforcement Network (FinCEN)	FinCEN of the United States Department of Treasury supports law enforcement investigative efforts and fosters interagency and global cooperation against domestic and international financial crimes. FinCEN is a network linked between law enforcement, financial, and regulatory communities. FinCEN strives to work with its domestic and international partners to maximize the information sharing network and find new ways to prevent and detect financial crime (FinCEN, 2002).
Envirofacts Warehouse	The USEPA created the Envirofacts Warehouse to provide the public with direct access to information contained in the Envirofacts databases. The Envirofacts Warehouse enables searches on a company or facility name to retrieve environmental information from across USEPA databases (such as the Toxic Release Inventory, RCRAInfo, and CERCLIS). The USEPA-internal version of Envirofacts allows retrieval of compliance data as well (USEPA, 2001f).
LexisNexis and Westlaw	Two commercial, computerized legal research systems provide access to case decisions and other public records including legal histories of companies and individuals as well as the statutory and regulatory issues. Easily accessed online, these systems also produce traditional print products. Nexis provides many full-text newspapers, journals, financial reports, and news wires from around the world (LexisNexis, 2002; Westlaw, 2002).
DIALOG	A potent information retrieval service providing access to more than 600 databases spanning business, science, and technology. Many of these databases provide the full-text online (Dialog Corporation, 2002).

diagrams, and question-and-answer sections for each analyte (Drum *et al.*, 2000). Another source of information on this subject is the periodical *Field Analytical Chemistry and Technology* (Wiley Interscience, 2002). Recent papers discussing developments or trends in fieldwork are summarized in Table 8.

In the execution of a search warrant, the evidence collected must be authorized by that warrant (Littlefield, 2001). Each person collecting evidence is a potential fact or percipient witness. When established procedures are used to collect evidence, it is easier to defend the scientific reliability and legal acceptability of the procedures. If field conditions necessitate deviation from standard procedures, the rationale must be documented.

Field monitoring and measurement equipment should be maintained, calibrated, and periodically checked to ensure that the equipment is working properly. These actions should be documented. In the United States, a chain of custody is required for any item introduced in legal proceedings. Interviews are recorded along with other field activities such as sampling and environmental measurements. Marking, labeling, preservation (if appropriate) of environmental and waste samples, shipping, and observance of any applicable quarantines (for example, certain soils or vegetation shipped across geographical boundaries) should all be included in the permanent record as documentation of the site visit.

Sampling

Details regarding types of sample containers, preservation techniques, and holding times suggested by the United States Environmental Protection Agency (USEPA) are found with the analytical test methods. Chapters 2–4 within the "Test Methods for Evaluating Solid Waste" (otherwise known as SW-846) contain useful tables with sampling information (USEPA OSW, 2001a).

Environment Canada has two guides for field personnel when site investigation or sampling is

Table 5. Terminology and publication sources

Source	Description
Environmental Forensics: A Glossary of Terms	Morrison's book has a very long list of acronyms and abbreviations as a chapter before the book starts environmental forensics terms (Morrison, 1999).
USEPA Terminology Reference System (TRS)	The Terminology Reference System is a collection of environmental terms used by the USEPA. Terms and the definitions can be found by browsing or by performing a keyword search (USEPA, 2001g).
USEPA National Service Center for Environmental Publications (NSCEP)	Understanding "EPA Speak" has a section on "Terms of the Environment". This has a browse option for terms, abbreviations, and acronyms (USEPA NSCEP, 2002a). The codes used to refer to USEPA reports and publications are deciphered at NSCEP with the USEPA Publication Numbering System. A table to convert code numbers and alpha descriptors is provided (USEPA NSCEP, 2002b).
US Department of Commerce National Technical Information Service (NTIS)	NTIS is a centralized source for scientific, technical, and business related government publications (NTIS, 2002).
US Government Printing Office (GPO)	The US GPO is another publications source for the United States federal community (US GPO, 2002).
USEPA Publications	A list of sources for USEPA publications can be found at the USEPA Publications Internet site (USEPA, 2001h).

Table 6. International environmental resources

Source	Description
UNEP-Infoterra	This is an international environmental referral and research network made up of 177 countries coordinated by the United Nations Environment Programme (UNEP) in Nairobi, Kenya. The US National Focal Point for UNEP-Infoterra is located at the USEPA Headquarters Library and is managed by the Office of Environmental Information. The services offered by UNEP-Infoterra/USA include document delivery, database searching, bibliographic products, purchasing information, and referrals to experts (UNEP-Infoterra, 2001).
Interpol	Interpol, the International Criminal Police Organization, has an Environmental Crimes Committee to combat environmental crime. Member nations fill out "Eco Messages" on international environmental crimes for Interpol. These messages are compiled in a database, analyzed, and circulated to other member nations for the purpose of coordinating international law enforcement in the fight against environmental crime (Interpol, 2002).
European Union Policies – Environment	This Internet site contains an index to information from the European Union on environmental issues (Europa, 2001).
Environmental Agencies of the World	Lists of the agencies primarily responsible for environmental issues at the national level are available here (World Bank Group NIPR, 2000).
NIPR: New Ideas in Pollution Regulation	Information for researchers, government officials, and citizens interested in understanding and improving control of industrial pollution, especially in developing countries. This site focuses on materials produced by the World Bank's Economics of Industrial Pollution Control Research Project (World Bank Group NIPR, 2001).
Regional Environmental Center (REC) for Central and Eastern Europe	This is a non-advocacy, non-profit organization that assists in solving environmental problems in Central and Eastern Europe (REC, 2002).
Environment Canada – CEPA Environmental Registry	The CEPA Environmental Registry is a comprehensive source of public information relating to activities under the Canadian Environmental Protection Act, 1999 (Environment Canada, 2002a).
Joint Research Centre (JRC)	Created by the European Commission, all eight institutes of the Joint Research Centre are listed on this site. The Environment Institute (EI) conducts research in support of European Union policies for the protection of the environment and the citizen (JRC, 2002).
The Air Pollution News – Exchange	"News Directions" appears in Atmospheric Environment, an international journal, as an invited or contributed column reporting on all aspects of the atmospheric sciences. The articles are written in a popular style by experts in their field. A panel of members from the journal's editorial board reviews the articles. The columns are also featured in Atmospheric Environment journal (UEA Norwich, 2001).

necessary. *The Inspector's Safety Guide* provides details on protective equipment, hazardous substances, and potential hazards when inspecting industrial sites (Environment Canada, 1995a). The industrial hazards section includes chemical hazards, safety precautions, emergency response actions, and other extremely valuable information specifically targeted to each industry type listed. *The Inspector's Field Sampling Manual* offers a full guide for sampling from the early planning stages (data quality objectives, equipment and sampling plan checklists, quality assurance and quality control) to on-site actions (sampling protocol for specific media and laboratory tests) to the shipment of samples (Environment Canada, 1995b).

The CLU-IN Internet site, listed in Table 7, also includes a few documents on sampling (USEPA TIO, 2002b). An American Chemical Society (ACS) book on environmental sampling contains chapters on sample design, quality assurance and quality control, and sampling for specific media. The methods mentioned in the book primarily refer to USEPA methods (Keith, 1996a).

Many USEPA publications and Internet sites provide guidance for planning environmental sampling work. Chapters 9 and 10 within SW-846 cover sampling plans and sampling methods (USEPA OSW, 2001a). A USEPA guidance document on "Choosing a Sampling Design for Environmental Data Collection" has been prepared and is available to the public, but it is undergoing peer review (USEPA, 2001k).

A useful reference for soil sampling is the USEPA field pocket guide *Description and Sampling of Contaminated Soils* (USEPA, 2001k). The American Society for Testing Materials (ASTM) has an extensive book of standards on environmental sampling for a variety of media (soil, water, waste, air, and biological) (ASTM, 1997). Standards include terminology, diagrams, material and apparatus lists, calculations, procedures, and numerous references. Also included is a standard on quality assurance and quality control (QA/QC) for sampling activities. Many of these standards are referenced in USEPA regulations.

The purpose of each sample should be considered carefully. Some regulations in the United States require that samples be representative of the waste. The meaning of *representative* is sometimes defined in the regulation. These definitions vary between the different regulations. A sufficient number of samples should be collected from the appropriate areas to ensure that meaningful scientific statements can be made about the sampling target. Statistical calculations may be used to determine sample size and sample quantity needed.

Many statistical references and guides for environmental sampling exist. These cover the QA/QC aspects of sampling, sampling theories, and examples of statistics used in environmental pollution studies (Gy, 1998; Quevauviller, 1995; Gilbert, 1987; Ott, 1995;

Table 7. Field technology and equipment sources

Source	Description
Technology Innovation Office (TIO)	The USEPA TIO homepage contains links to publications that can be viewed, downloaded, or ordered. There is a section for site characterization that includes information on technology, tools, and educational materials. Also available are links to international updates, conferences, newsletters, Internet sites, and to another TIO site that is abbreviated as CLU-IN (USEPA TIO, 2002a).
Hazardous Waste Clean-Up Information (CLU-IN)	The Hazardous Waste Clean-Up Information site, also known as CLU-IN, has documents, reports, videos, and software on various topics related to methods, techniques, and developing technologies. Options of interest to site assessment and site remediation professionals include the opportunity to sign up for e-mail newsletters that highlight new publications and events. Users can also register for live Internet events (online seminars with a web-based slide presentation and options for accessing the audio portion of the presentation). A useful section is the Field Analytic Technologies Encyclopedia (FATE). The training modules in FATE cover geophysical, organic chemical, and inorganic chemical characterization techniques and data interpretation. The modules include information about work plans and data quality objectives. Most modules are presented on-screen as slide-show presentations. Supplemental information and additional sources for information are spread generously throughout the training program. The analytics listing in the technologies section has links to the description, theory of operation, target analytes, performance specifications, limitations, cost data, and vendors of particular technologies. A free seminar on systematic planning and innovative field measurement technologies is available on the CLU-IN site. Users can download the seminar (including the speaker's notes) in one of three different formats (USEPA CLU-IN, 2001a,b, 2002a,b).
USEPA REACH IT	REACH IT (abbreviation for REmediation And CHaracterization Innovative Technologies) has an online searchable database of innovative and conventional technologies for characterizing or treating hazardous waste sites. The search function guides the user through questions regarding the contaminant group of interest, the type of media involved, and the technological scale desired. Details provided on the technology include a description, verification information, uses by media type, technical support needed, and a cost analysis. A vendor database allows the user to search for companies that provide specific technologies and gives links to Internet sites (USEPA, 2001i).
USEPA Environmental Technology Verification (ETV) Program	The ETV was established to verify the performance and help accelerate the use of new environmental technologies. On this site, verified technologies are listed by media and by specific pilot programs. Each technology item includes a verification statement and report. Links to the Internet sites of project partners, USEPA sites, associations, and international sites are also included (USEPA, 2001j).
Federal Remediation Technologies Roundtable (FRTR)	The FRTR Internet site includes two informative field sampling and analytical guides. One guide addresses field sampling and collection techniques with information on tools and extraction methods cross-referenced with analytes, type of sample media, and technology details. The tools and extraction methods have links to basic descriptions, limitations, and any applicable ASTM standards or USEPA methods. The other guide is a matrix that cross-references sample analysis tools (techniques or instrumentation) to analytes, sample media, detection limits, and more. Just like the other matrix, the analysis tools have links to additional information such as the descriptions of techniques or instruments, the applicable uses, the turnaround times, the analysis costs, limitations, and any applicable ASTM standards or USEPA methods (FRTR, 1998a,b, 2001).

Piegorsch *et al.*, 1998; Gemperline, 1999). A current USEPA guidance document on data quality assessment provides an overview of statistical tests (USEPA R3, 2000).

A simple and efficient generic guide to sampling survey designs has been provided by the Energy and Environmental Division of the American Society for Quality. In it, a logical order of steps in a sampling plan is presented along with explanations of key terms, issues, and a summary of responsibilities for each scientific discipline involved. The guide includes information on quality control (QC) measures such as field blanks and equipment blanks and the logic behind taking blanks (Koepp and Luedtke, 2002).

Samples should be locked in a secured, initialed container under the control of the sampler. Each sample container should be marked with a discrete identification number for tracking purposes. This can be done using numbered tags or bar codes. The lid of the container, as well as the container itself, should be marked with the sample location. Preservative should be added to the samples, if appropriate (many waste samples do not require preservation). Samples should be maintained at temperatures appropriate for the type of samples taken and for the analytical techniques that will be used for testing. Wastes generated during the sampling should be properly disposed according to applicable regulations. Decontamination procedures are often performed on sampling equipment to avoid spreading contamination and to allow the equipment to be reused. Split samples are often collected to allow the defense to conduct independent laboratory analyses.

Samples should be shipped as soon as possible within any analytical holding times (CFR, 2000). The samples are required to be packaged for shipment according to applicable regulations and in a manner that protects the containers from breaking or leaking. Samples of waste and contaminated environmental samples should be stored and shipped in separate containers from background samples to avoid cross-contamination. Incompatibility of chemicals in waste samples must also be considered to avoid chemical reactions.

The International Air Transport Association, in the *Dangerous Goods Regulations Manual*, has established restrictions regarding the shipment of dangerous goods (IATA, 2002). Restrictions may differ between

Table 8. Recent papers discussing developments or trends in field work

Category	Description
Field analytical chemistry	Substantial review paper from 1997; topics covered include portable instrumentation, sensors, mass spectrometry, gas chromatography, field methods and applications, and immunochemical techniques (Lopez-Avila and Hill, 1997). Outfield report on work plans and field analysis for hazardous waste site investigations; cost comparisons of traditional and dynamic field investigations; site application examples (Robbat, Jr. *et al.*, 1998). Technology review of trends and advances in field-portable analytical instrumentation; outlines operational characteristics that make a "fieldable analytical instrument"; list of past, present, and future field analytical technologies (Overton *et al.*, 1996).
Aerosol measurement	Review of literature on laser-induced plasma spectroscopy with emphasis on analysis in gaseous and aerosol phases; technique presented as potential next-generation field portable instrument for characterizing metal species (Martin *et al.*, 1999).
Volatile organic compounds (VOCs)	Review of specific recent developments for the analysis of VOCs in ambient air and natural waters; includes applications in the field (DeWulf and Van Langenhove, 1999).
Petroleum hydrocarbons in soils	Technology review on direct-push fluorescence-based sensors for determining subsurface chemical contaminants; different systems and configurations presented (Lieberman, 1998).
Atomic spectroscopy	Review with emphasis on field-portable atomic spectrometry; includes a table of selected applications of laser-induced breakdown spectroscopy (LIBS) with elements, matrices, and limits of detection (Hou and Jones, 2000).
Biosensors	Technology review of biosensors and the potential for use in screening and monitoring; list of analytes and biosensors provided (Rogers and Mascini, 1998).
Field portable X-ray fluorescence (FPXRF) spectrometry	Technology review of FPXRF; evolution and characteristic features of the field-portable XRF analyzer (Piorek, 1997). FPXRF analysis of environmental samples; tables with list of available instrumentation and vendors and a comparison of calibration methods are included (Kalnicky and Singhvi, 2001). Application of FPXRF from soil and sediment metals analysis to filters used in air monitoring (Bernick and Campagna, 1995).
Gas chromatography mass spectrometry (GC MS)	Technology review of advances in field-portable GC-MS; discussion and pictures of vehicle-portable and man-portable systems (Meuzelaar *et al.*, 2000). Outfield report on fast on-site analysis of hazardous emissions from fires and chemical accidents; details on equipment, sampling and sample preparation, and applications; many figures of procedures and techniques are included (Matz *et al.*, 1997). Mini-review on fast field screening of contaminated areas; overview of analytical methods for mobile GC-MS systems (Matz and Schröder, 1996). Outfield report overviewing GC-MS uses; includes sections on environmental analyses by type of sample media (Eckenrode, 1998). Outfield report on a modular laboratory designed for travel; list and diagram of system components (Heyl, 1996).
Infrared (IR) analysis	Portable IR analyzer for low-level hydrocarbon vapors; near real-time distribution data included (Goldthorp and Lambert, 2001).
Ion chromatography (IC)	Schematic layout and detailed discussion on a field-portable capillary ion chromatograph (Boring *et al.*, 1998).
Ion mobility spectrometry (IMS)	Technology review on capabilities and limitations of IMS for field screening uses; includes details on different spectrometers, detection limits for some pollutants, and future developments (Hill and Simpson, 1997).
Mass spectrometry (MS)	Technology review of direct sampling mass spectrometry (DSMS) in analysis of environmental samples; discussion of instrumentation, portability, analytical methods, and environmental applications (Wise *et al.*, 1997).
Ultramicroelectrode arrays (UMEAs)	Review on UMEAs with emphasis on the determination of heavy metals in environmental samples; a table of analytes and media is provided (Feeney and Kounaves, 2000).

airlines and countries for some hazardous items. Additionally, the US Department of Transportation has Hazardous Materials Regulations (49 CFR 100-185) covering all modes of shipping hazardous materials (ground, sea, rail, and air) (US NARA, 2001b).

Chain-of-custody records include a standard form documenting the delivery and the receipt of each sample. Personnel handling the samples are recorded from the initial contact at the crime scene through each sample transfer until the samples are received in the laboratory (ASTM, 2000). Under chain-of-custody procedures, samples are to be under the control of the investigative team at all times. The location of each sample, from the time of sample collection through the time of laboratory analysis, is documented.

Laboratory methods and selection

Methods for testing different sample matrices (air, water, or waste) have been promulgated within the Environmental Protection Agency and are codified in publications such as the Test Methods for Solid Waste (SW-846), Title 40 of the Code of Federal

Regulations (often abbreviated as 40 CFR), and the American Water Works Association (AWWA) Standard Methods for the Examination of Water and Wastewater. Method validation is an important focus of these methods. Wood (1999) discusses the need for laboratories to use fully validated analytical methods. Subramanian (1995) provided a compilation on quality assurance in environmental monitoring and instrumental methods and techniques (for example, solid phase extraction, ICP-OES techniques, and capillary electrophoresis are included). Details about the QA/QC needed for the analysis of airborne particles are presented by Hopke (1999a) and Biegalski (1999).

Berger *et al.* (1996) compiled an impressive reference guide titled *Environmental Laboratory Data Evaluation*. This publication addresses issues regarding scientifically valid data. Eurachem, a network of organizations in Europe, has also published guidelines on laboratory QA/QC procedures that are available in several languages (Eurachem, 2001).

Hazardous and solid wastes

The Test Methods for Solid Waste, or SW-846, is used for environmental crimes involving the illegal disposal of hazardous waste. SW-846 is entirely accessible on the Internet (USEPA OSW, 2001a). The table of contents and chapter titles are provided for easy reference. Copies of SW-846 in print and on CD-ROM are also available (USEPA OSW, 2001b). The CD-ROM version has a helpful analytes-to-method cross-reference table.

Within SW-846 is guidance for using analytical methods. Quality control criteria are provided throughout the methods in SW-846. Many methods in a numerical series (for example, the 3000, 3500, or 7000 series) refer to one primary location for the QC information on that series. Chapter One also provides a quality control overview for both laboratory and field activities. Method-defined QC criteria may be found in the specific methods. If inconsistencies are found between the general QC guidance and method-specific or technique-specific QC, then the latter takes precedence (USEPA OSW, 2001a).

A cautionary note within SW-846 concerns comparing test results from different methods. Even if methods are designed for the same analyte, different methods may produce different results. Analyte recoveries vary between extraction techniques and digestion methods used in metals analysis.

Water and wastewater

Violations of the Clean Water Act (CWA) often involve the illegal discharge of a contaminant to surface water without a permit or in violation of an existing permit. Methods for water and wastewater used by the USEPA in environmental crime investigations include those available for purchase through NTIS and those on the Internet (USEPA OGWDW, 2001, 2002). A collection of analytical methods, including drinking water methods published by the USEPA titled "Methods and Guidance for Analysis of Water", is available on CD-ROM (USEPA OGWDW, 2000a).

Two non-USEPA sources providing analytical procedures for surface water are the American Water Works Association (AWWA) and the American Society for Testing and Materials (ASTM). The AWWA provides water methods in *Standard Methods for the Examination of Water and Wastewater* which is available from the American Public Health Association (APHA) (APHA, 2001). ASTM water methods are described in the *Annual Book of ASTM Standards* (ASTM International, 2002). An online list of non-USEPA analytical methods includes the source of each method (USEPA OGWDW, 2000b,c).

Air

Environmental crimes involving Clean Air Act (CAA) violations are primarily related to the illegal removal and disposal of asbestos and the illegal importation of chlorofluorocarbons (CFCs). Asbestos is regulated under the Toxic Substances Control Act and the Clean Air Act (USEPA OPPT, 2001).

CFCs and other ozone-depleting chemicals are a serious concern since the adoption of the Montreal Protocol on Substances that Deplete the Ozone Layer of 1987. As part of the United States' commitment to implementing the Montreal Protocol, the Clean Air Act was amended by the US Congress to add provisions for the protection of the ozone layer by restricting the domestic production and importation of these chemicals in the United States (USEPA, 2002a). Methods for detection and determination of air pollutants are listed at the Technology Transfer Network (TTN) Internet site through the Emissions Measurement Center (EMC) and the Ambient Monitoring Technology Information Center (AMTIC) (USEPA OAQPS TTN, 2000, 2001). A publicly available compendium that lists and summarizes methods for the determination of toxic organic compounds in air is available online (USEPA AMTIC, 1999, 2002).

Sources of national and international analytical procedures

Pesticides are regulated under two federal statutes: the Federal, Insecticide, Fungicide and Rodenticide Act (FIFRA), and the Federal Food, Drug, and Cosmetic Act (FFDCA). The Food Quality Protection Act of 1996 (FQPA) amended FIFRA and FFDCA to set tougher safety standards for pesticides and uniform requirements regarding foods (USEPA OPP, 2001a). The Office of Pesticide Programs has two indexes of analytical methods for pesticides (USEPA OPP, 2001b,c). The Code of Federal Regulations also contains methods for analysis and can be accessed at two different Internet sites (USEPA, 2001m; US NARA, 2002a).

A nearly all-inclusive list of the USEPA methods, revised December 2001, contains the chemical name or method name cross-referenced with USEPA report numbers, the location of the method in the Code of Federal Regulations (40 CFR), and the publication media used for the method (if an electronic version is available) (USEPA R1, 2001a). Several sites with links to USEPA methods and guidelines are also online

Table 9. Downloadable USEPA methods online

Topic	Methods/information
Environmental analysis	Choosing the correct procedure: Ch. 2*
Sample preparation	Inorganic analytes: Ch. 3.2* Organic analytes: Ch. 4.2*
Atomic absorption (AA)	Method 7000A, Table 1 lists detection elements; 7000 Series Methods*
Gas chromatography (GC)	Methods, analytes listed in Ch. 2, Tables 4–19* 515.3, 515.4, 556, and 556.1† 601 to 604, 606 to 612‡
GC-FTIR	8410 and 8430*
Gas chromatography–mass spectrometry (GC–MS)	Methods and analytes listed in Ch. 2, Tables 20–23;* Method 526;† 613, 624, 625, 1624, and 1625‡
High performance liquid chromatography (HPLC)	Methods and analytes listed in Ch. 2, Tables 24–31;* Method 532;† 605 and 610‡
Infrared (IR) spectrometer	8440*
Ion chromatography (IC)	9056 and 9057,* 300.0, 300.1, 314.0 and 317.0†
ICP-AES	6010B, detection elements in Table 1*
ICP-MS	6020, detection elements in Table 1*
Polarized light microscopy (PLM)	EPA/600/M4-82-020§
X-ray fluorescence (XRF)	9075*

*USEPA OSW, 2001a.
†USEPA OGWDW, 2001.
‡USEPA Office of Water, 2001.
§ US NARA, 2002b.

(USEPA, 2001n,o; USEPA R1, 2001b) including those that may be downloaded (Table 9).

A book by Keith (1996b) provides a short description of USEPA methods listed by analytes. It includes information regarding the analytical methods but only brief details on the sampling method for each. Comparisons between different analytical methods and analyte cross-reference tables are provided in a handy book titled *Guide to Environmental Analytical Methods* (Northeast Analytical, Inc., 1998).

Analytical methods used in countries other than the United States can sometimes be accessed through a nation's environmental protection or analytical standards Internet sites. The Environment Canada Internet site provides a search engine to locate selected environmental protection publications including reference methods and guidance documents. The number and title of the document, the description of the document, and the purchase price are given in the search results (Environment Canada, 2002b). A search by keyword or document number at the Dutch National Institute of Public Health and the Environment (RIVM) Internet site will yield detailed abstracts of available reports and order information for full reports (RIVM, 2000).

Standards Australia has a flexible power search allowing the user to find documents by title, keyword, or standard number. The document number, title, and order information are provided in the search results (Standards Australia, 2002). The Environmental Protection Authority for the state of New South Wales, Australia, has two Internet sites that list approved methods for the sampling and analysis of water and air pollutants (NSW EPA, 1998, 2002). Tables of methods are organized by the analytes of interest.

British Standards Online requires that users register first and then login before beginning any document search. The expanded search feature is impressive and allows wide-ranging search options in order to track down documents. Search results include the document number, title, and purchase price (British Standards Online, 2002).

Analytical instrumentation

A variety of instrumentation is often required for the analysis of environmental samples. *Analytical Chemistry*, a journal published by the American Chemical Society, is a valuable source of information for trends and current developments about instrumentation and analytical techniques. This journal has yearly review issues that alternate between Fundamental Reviews (1996, 1998, and 2000) and Application Reviews (1997, 1999, and 2001). In Fundamental Reviews, techniques such as infrared spectroscopy or gas chromatography are critically evaluated. Updates to the techniques, current research, and applications are included in these reviews. Application Reviews cover areas of chemistry such as environmental analysis, field analytical chemistry, and forensic science. These reviews are often subcategorized by instruments, techniques, or types of samples. Searches of the table of contents for several years of *Analytical Chemistry* issues can be made at the journal's web site (ACS Publications, 2002). The results from a literature search of recent papers and reviews on topics,

Table 10. Instrumentation and techniques

Topic	Description
Environmental analysis	Biennial review; developments in applied environmental analytical chemistry from November 1998 to October 2000; subcategories include SPME applications, air, water, and soil sample analyses (Clement *et al.*, 2001). Biennial review; developments from November 1996 to October 1998; categorized by matrix (air, water, soil, and biological); includes technology cross-reference table (Clement *et al.*, 1999). Biennial review; developments from November 1994 to October 1996; matrix subcategories for analysis applications; quality control and reference materials section (Clement *et al.*, 1997). Trends in environmental analysis; developments in extraction methods, MS, and field-portable instrumentation (Lopez-Avila, 1999a).
Sample preparation	Review; extensive tables on techniques for preparation of solid and liquid samples (Lopez-Avila, 1999b). Proper subsampling from field sample to the laboratory analysis sample; reducing mass and segregation errors (Ramsey and Suggs, 2001). Selection of extraction technique for organic pollutants in environmental matrices; table summaries of analytes extracted by MAE, SFE, and PFE (Dean and Xiong, 2000). Review; solventless sample preparation techniques; covers extraction with a gas stream, membrane extraction, SPE, and SFE (Namieśnik and Wardencki, 2000). Comparison of extraction techniques for environmental solids (Hawthorne *et al.*, 2000). Evaluation of extraction recoveries for certain organometallic compounds in sediment and other matrices (Quevauviller and Morabito, 2000).
Air analysis	Review of research published from 1995 to 1998; air analysis by GC; table of sampling and injection techniques; table of stationary phases and analytes (Helmig, 1999). Biennial review; methods for air pollutant analysis covering literature from January 1997 to December 1998; contents divided as gases and aerosols; applications to a variety of instrumentation (Fox, 1999). Review; analysis of organic compounds in air; tables of analytical methods for volatile organic compounds, aldehydes and ketones, semivolatile organic pollutants, polycyclic aromatic hydrocarbons, halocarbons, and isocyanates and amines (Aragón *et al.*, 2000). Review; sorbents used to trap volatile organic compounds from air (Harper, 2000). Analysis of process gases; overview of instrumentation and techniques, sampling systems, calibration and traceability, and data collection and processing (Cleaver, 2001).
Water analysis	Review covering developments in water analysis from 1999 to 2000 with a few significant 2001 references; contents categorized by pollutants (Richardson, 2001). Review; methods for preconcentrating organic and inorganic compounds (Bruzzoniti *et al.*, 2000).
Atomic spectrometry	Annual review; atomic spectrometry update on analysis of environmental samples; categorized by media (air, water, soils, and geological) (Cave *et al.*, 2001). Annual review; combined atomic absorption and fluorescence with atomic emission spectrometry; covers literature from 1998 and 1999; topics include sample introduction, instrumentation, and coupled techniques (Hill *et al.*, 2000). Annual review; atomic spectrometry analysis for elements in air, water, soil, and geologic materials; includes MS, XRF, AA, ICP-MS, AES, and other instrumentation (Cave *et al.*, 2000). Trace element analysis of airborne particles; overview of methods with comparison between GFAAS, flame AAS, ICP-AES, and ICP-MS (Grohse, 1999). Biennial review; cited papers from 1998 and 1999; developments with instrumentation and operation (Jackson, 2000). Annual review; atomic spectrometry update on environmental analysis; topics categorized by sample media (Dean *et al.*, 1998). Annual review; developments in atomic absorption and fluorescence spectrometry in 1997 and 1998 (Hill *et al.*, 1998). Invited lecture on the future of atomic spectrometry in environmental analysis; discussed sample preparation, instrumentation, detection power, speciation, and field portability; includes nearly 200 references (Sturgeon, 1998). Biennial review; publications from 1996 and 1997 on techniques of analytical atomic absorption; electrothermal atomization, flame atomic absorption and emission, laser techniques, and vapor-phase sample introduction are covered (Jackson and Lu, 1998).
Capillary electrophoresis (CE)	Review; analysis of environmental samples; charts of fresh and salt water, wastewater, and industrial process water matrices; chart for soil, sediment, and biological samples (Valsecchi and Polesello, 1999). Review; status of CE for organic environmental pollutant determination based on papers published from 1997 to early 1999; excludes pesticides and inorganic pollutants from the review (Sovocool *et al.*, 1999). Review; analysis of inorganic pollutants; environmental applications divided by sample media; analyte tables for atmospheric, aquatic, and soil samples (Timerbaev *et al.*, 1999). Review of references published mainly from 1995 to 1997; analysis of environmental samples; tables of sample matrices and ions (Fukushi *et al.*, 1999). Review; separation and analysis of environmental pollutants (Song *et al.*, 1997). Biennial review; covers the period of October 1995 to October 1997; focus on significant developments in theory and practice of CE; advances in performance optimization, instrumental configuration, and detection strategies (Beale, 1998). Review; focused on methods developed since 1994 for the determination of pollutants; divided according to pollutant type; large table of environmental applications and corresponding references (Dabek-Zlotorzynska, 1997). Review; analysis of inorganic pollutants (Timerbaev, 1997). Review; extensive table of anions, sample matrices, and electrolyte system (Kaniansky *et al.*, 1999).
Gas chromatography (GC)	Biennial review; covers fundamental developments in gas chromatography published from 1998 and 1999; topics include adsorbents, phases, theory, and new technology (Eiceman *et al.*, 2000).

Table 10. continued

Topic	Description
	Biennial review; GC developments published in articles from 1996 and 1997 (Eiceman *et al.*, 1998). Review; sample introduction techniques; GC-MS and GC-FTIR applications (Ragunathan *et al.*, 1999). Review; trace analysis of pesticides by GC; discusses differences between detectors and extraction techniques (van der Hoff and van Zoonen, 1999). Overview of sample introduction and sample preparation of volatile organic compounds for GC analysis (Majors, 1999). Automated GC system used by the Taiwan EPA for measuring ambient VOCs (Wang *et al.*, 2000).
Gas chromatography atomic emission detection (GC AED)	Empirical formula study of chlorofluorocarbons using GC coupled to atomic emission detection (Hardas and Uden, 1999).
Gas chromatography mass spectrometry (GC MS)	Analysis of petroleum products within forensic science review (Brettell and Saferstein, 1997).
High performance liquid chromatography (HPLC)	Biennial review; fundamental developments in column liquid chromatography equipment and instrumentation from October 1997 to October 1999; instrumentation, columns, and a variety of detectors are covered (LaCourse, 2000). Biennial review; developments in equipment and instrumentation from October 1995 through October 1997 (LaCourse and Dasenbrock, 1998). Biennial review; theory and methods in liquid chromatography from October 1995 through October 1997; topics include data analysis, biopolymer separations, affinity chromatography, ion chromatography, and preparative LC (Dorsey *et al.*, 1998). Review of literature methods published from 1989 to 1996; chart of anions, stationary and mobile phases, methods (Gennaro and Angelino, 1997). Review; determination of nitrite and nitrate in environmental samples (Matteo and Esposito, 1997). Review; determination of hazardous compounds (PCBs, dioxins, etc.) using reversed-phase HPLC; stationary phases discussed (Buszewski *et al.*, 1999).
Ion chromatography (IC)	Review of articles published from 1997 to 1999 with some classic references; detailed chart of inorganic anions, matrices, columns, detectors; environmental applications (López-Ruiz, 2000). Review; sample preparation and separation techniques for IC and CE; comparison of advantages and disadvantages of IC and CE (Haddad *et al.*, 1999). Elemental analysis of airborne particles; included are tables on separation methods and filter media (Chow and Watson, 1999).
Inductively coupled plasma (ICP)	Review; book selection on advances in ICP-Atomic Emission Spectrometry (ICP-AES) and ICP-Mass Spectrometry (ICP-MS); analytical capabilities and interferences of the two spectrometers; practical applications highlighting soil samples (Soltanpour *et al.*, 1998). USEPA methods and elements list; ICP-Optical Emission Spectrometry (ICP-OES) and ICP-MS technique comparison (Thomas, 1997). Elemental speciation using ICP-MS interfaced to a liquid chromatograph (Donais, 1998).
Infrared (IR) spectrometry	Biennial review; articles published during 1998 and 1999; focus on 2D IR, combinatorial chemistry, and human health (Gillie *et al.*, 2000). Biennial review; covers published literature from November 1995 to October 1997 on aspects of IR spectroscopy relevant to chemical analysis; includes a section on environmental analysis (McKelvy *et al.*, 1998).
Liquid chromatography-mass spectrometry (LC-MS)	Review; general overview of instrumentation; environmental applications (Niessen, 1999). Review; current and future developments in pesticide trace analysis (Hogendoorn and van Zoonen, 2000). Determination of herbicides in water; techniques and applications to herbicide analysis (D'Ascenzo *et al.*, 2000). Analysis of surface and wastewater with atmospheric pressure chemical ionization (Kienhuis and Geerdink, 2000).
Microwave assisted extraction (MAE)	Review; extraction of environmental samples; tables for extraction of PCBs, pesticides, phenols, and organometallics in environmental matrices (Camel, 2000). Review; table comparing extraction techniques; tables for extraction of persistent organic pollutants and pesticides (Eskilsson and Björklund, 2000). Review; extraction of petroleum hydrocarbons from contaminated soils (Punt *et al.*, 1999).
Mass spectrometry (MS)	Annual review; update on developments in instrumentation and methodology with atomic mass spectrometry (Bacon *et al.*, 2000). Annual review; advances in instrumentation, methodology, and in understanding the fundamental phenomena of atomic mass spectrometry (Bacon *et al.*, 1999). Annual review; developments from 1997 and 1998; trends identified in each section (Bacon *et al.*, 1998).
Pressurized fluid extraction (PFE), pressurized liquid extraction (PLE), or accelerated solvent extraction (ASE)	Review; extraction of persistent organic pollutants; tables of conditions found in the literature with matrices of soil, sediment, sewage sludge, dust, clay, fly ash, and biological tissue (Björklund *et al.*, 2000). Extraction of polycyclic aromatic hydrocarbons from soils (Lundstedt *et al.*, 2000). Extraction of PCBs from environmental samples as compared to SFE (Björklund *et al.*, 1999). Extraction of hydrocarbons from soils (Richter, 2000). Recovery of PCBs from organic matrix; comparison to Soxhlet extraction (Abrha and Raghavan, 2000).
Supercritical fluid extraction (SFE)	Review; methods, instrumentation, and applications including environmental (Smith, 1999). Discussion of advantages and limitations of SFE (Luque de Castro and Jiménez-Carmona, 2000).
Solid phase extraction (SPE)	Review; environmental applications, coupling with capillary electrophoresis; table of analytes for SPE-CE (Martínez *et al.*, 2000). Review; includes method development, sorbents, and coupling with liquid chromatography (Hennion, 1999).

Table 10. continued

Topic	Description
	Review; multi-residue analysis of organic contaminants in water (Pichon, 2000). Review; historical to present day technical developments for SPE of organic pollutants in water (Liška, 2000). Review; functionalized cellulose sorbents for preconcentration of trace metals in environmental analysis (Pyrzyńska and Trojanowicz, 1999). Review; recent developments in SPE based on polymer sorbents (Huck and Bonn, 2000). Developments in SPE disks for use in environmental chemistry for analysis of trace organic compounds (Thurman and Snavely, 2000).
Solid phase microextraction (SPME)	Review; extraction modes, fibers, and instrumentation interfaces (Lord and Pawliszyn, 2000). Review; determination of organic pollutants in environmental matrices; tables of published applications in air and liquid samples (Zygmunt *et al.*, 2001). Review; trace element speciation; table of species, sample type, and SPME method (Mester *et al.*, 2001).
Ultra-violet (UV) spectrometry	Biennial review; developments in ultraviolet and visible absorption spectrometry from January 1996 through October 1997; subject matter covered in categories of chemistry, physics, and applications (Howell and Sutton, 1998).
X-ray spectrometry (XRS)	Annual review of X-ray fluorescence spectrometry; developments over the period of 1999 to 2000; details on instrumentation and applications, including environmental (Potts *et al.*, 2000). Analysis of ambient air samples; topics include method comparison, sampling, interferences, and calibration (Watson *et al.*, 1999). Annual review of X-ray fluorescence; covering papers published from 1998 to 1999 (Potts *et al.*, 1999). Biennial review of X-ray spectrometry; literature from late 1998 to October 1999 (Szalóki *et al.*, 2000). Annual review of X-ray fluorescence spectrometry; covers work published from 1997 to 1998; topics include instrumentation and applications (Ellis *et al.*, 1998). Biennial review; covering advances in X-ray spectrometry from November 1995 to the autumn of 1997; contents include categories on excitation, detection, and quantitation (Török *et al.*, 1998).

techniques, and instrumentation are summarized in Table 10.

Dean (1998) presents various extraction methods for environmental analysis in a recent book. Theoretical considerations and methods of analysis are discussed for the extraction techniques and a comparison chart for the techniques is included. Barceló (2000) has compiled a significant book in the "Techniques and Instrumentation in Analytical Chemistry" series. Chapters submitted by various authors fall into these key sections: "Field Sampling Techniques and Sample Preparation", "Quality Assurance, Reference Materials, and Chemometrics", "Application Areas", and "Emerging Techniques".

Laboratory fraud

Laboratory fraud is defined as the deliberate falsification of analytical or quality assurance results, where failed method and contractual requirements are made to appear acceptable during reporting (CMECC CDQ/CR PAT, 1997). Laboratory fraud has also been defined as a deliberate mechanism, concealment, or falsification producing detrimental reliance on analytical results (USEPA OCEFT, 2001). Laboratory fraud has historically been detected either by reports from disgruntled employees or electronic data audits. In both circumstances, the laboratory has already performed fraudulent work and the damage resulting from the fraud has occurred (CMECC CDQ/CR PAT, 1997; Worthington and Brilis, 1999).

Lab fraud cases generally are brought forward by informants, disgruntled employees, or outside audits (CMECC CDQ/CR PAT, 1997). In 1999, the Center for Strategic Environmental Enforcement (CSEE), Criminal Investigation Division (CID), Office of Criminal Enforcement, Forensics and Training performed an extensive review of all USEPA CID lab fraud cases that were investigated from 1983 to 1998. The review identified 63 cases involving data falsification committed by a third party laboratory (USEPA OCEFT, 2001). Third party laboratories are outside labs hired by companies for analytical testing instead of using an in-house company lab for analyses.

The extent of lab fraud cases has grown exponentially recently with 11 new lab fraud cases opened in the United States during the past two years (USEPA OCEFT, 2001). A literature review was conducted to examine the scope of the laboratory fraud problem. In a lab fraud case from 1995, Eureka Laboratories, Inc. was fined $1.8 million and two chemists were convicted of federal fraud charges related to the manipulation of lab results for federal contracts. The convictions came after the federal government suspended Eureka from government contracts because of allegations of fraudulent practices (Simmons, 1997).

In another case, Donald Budd, the former owner of Texas Environmental Services of Beaumont, Texas, was sentenced to six years in federal prison after misrepresenting laboratory methods. The laboratory tested water for cities, refineries, and other companies (Lubbock Online Headlines, 1997).

A slightly different type of laboratory fraud case involved a consulting company located in Portland, Oregon. On December 14, 1996, the USEPA published an account of the fraudulent reporting of data by Robert Cyphers (USEPA, 1996a). According to the USEPA statement, Cyphers, the former president and owner of UST Environmental Services, pled guilty to four felony counts involving the submission of written false statements to the government. As part of the plea agreement, he agreed to serve a recommended 30-month term of incarceration.

Cyphers operated a company with the primary business of removing leaking underground storage tanks and performing subsequent cleanup of contaminated soil and groundwater. He submitted more than 1000 fictitious laboratory analysis reports regarding the extent of soil and groundwater contamination to the Oregon Department of Environmental Quality. These reports were used by regulatory agencies to determine the degree of environmental contamination and cleanup necessary to protect human health and the environment. A few sites affected by Cyphers' lab fraud case have been re-sampled. Analyses have determined that petroleum contamination still exists.

On January 7, 1998, Intertek Testing Services Environmental Services laboratory (ITS) voluntarily disclosed that fraudulent practices were being conducted in their laboratory located in Richardson, Texas (Waldman, 2000). ITS disclosed that employees were improperly manipulating QC data during a time period that was later determined to be 1991–1997. The manipulations included actions of shaving, juicing, and time traveling to make data appear to meet QC requirements. These practices affected hundreds of projects, thousands of clients, and hundreds of thousands of samples.

In another case, the USEPA Central Regional Laboratory was investigated for allegations of altering test results. A criminal investigation regarding these allegations was conducted by the United States Department of Justice. The USEPA alerted federal prosecutors handling pollution cases, as well as informing suspected polluters, that some data used in pollution cases might be tainted. An unpublicized, 28-month investigation of the laboratory organic section found that USEPA supervisors and private contractors had mishandled some time-sensitive test samples by not initiating analyses within required holding times (Nicodemus, 2000a,b; Keoun, 2000).

An internal USEPA memorandum discusses contributing factors for laboratory fraud, including ineffective oversight of laboratory data, shrinking market resulting in focus on production over quality, and a standardized approach to analytical requirements. USEPA officials, prime contractors, and laboratory owners may rationalize or even foster laboratory fraud when these factors exist. Lack of oversight was identified as a problem in prior Office of Inspector General (OIG) and USEPA investigations. The second factor, a shrinking market, cannot be influenced by the USEPA. The final condition, a "one-size-fits-all" approach, can occur in contracts that define specific QA/QC requirements. Although laboratories bidding on contracts are aware of requirements, in specific cases managers or staff may view the requirements as too stringent and may cut corners to save money (USEPA, 2002b).

In addition to reports by a disgruntled current or former employee, investigators may receive reports of lab fraud from data reviewers and data users, auditors and inspectors, and regulators (USEPA OCEFT, 2001). Another indicator of potentially fraudulent data reporting is an anomalously low bid on a contract. Bids 50% lower than every other bid indicate the possibility of lab fraud according to Stephen Remaley, an investigator for the USEPA. Remaley describes the types of laboratory fraud as well as methods for detecting fraudulent practices (Martin, 2000).

Simmons (1997) presented guidelines being developed by the California Military Environmental Coordination Committee for the prevention of laboratory fraud. The techniques being considered to discourage fraud include double-blind proficiency test samples, audits, data validation, and electronic record audits.

According to Worthington, an important step in processing non-authentic data is making and documenting decisions when the problem is first discovered. The timely reporting of potential fraud and the establishment of a reconciliation process is emphasized (Worthington and Brilis, 1999). Resources assisting in the detection of laboratory fraud and the subsequent reconciliation of data include laboratory employees, data users, and inspectors (CMECC CDQ/CR PAT, 1997; USEPA OCEFT, 2001).

Accreditation of environmental forensics laboratories

In the United States, forensic laboratories have received greater scrutiny for analyses and operations (Nicodemus, 2000a,b; Keoun, 2000; LVRJ, 1997; US House of Representatives, Subcommittee on Crime, Committee on the Judiciary, 2002; US DOJ, 1998; Kerr, 1998; CBS News, 2001). "Trustworthiness" and "responsibility" are repeating themes as questions about the quality supporting the scientific data are discussed in the media. Assuring the public that a forensic lab is capable of providing legally defensible analyses has made accreditation the goal of many forensic laboratories at federal and state levels (US DOJ FBI Press Room, 2001; ELWR, 2001; California State Auditor/Bureau of State Audits, 1999; Office.com, 2001).

In the case of the USEPA National Enforcement Investigations Center (NEIC), this facility obtained accredited status for the laboratory asbestos analysis program under the National Voluntary Laboratory Accreditation Program (NVLAP, 2002a,b). Since asbestos analysis accounts for only a portion of the total analyses conducted in the laboratory operations, accreditation in other laboratory functions was desirable.

NEIC investigated accreditation requirements with the National Environmental Laboratory Accreditation Program (NELAP), the American Association for Laboratory Accreditation (A2LA), and the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB) before reaching a viable accreditation standard agreement for center activities (laboratory, field, and courtroom) with the National Forensic Science Technology Center (NFSTC) (ELWR, 2001; NVLAP, 2002a; NELAP, 2001; A2LA, 2002; ASCLD, 2001; NFSTC, 2001). The NEIC accreditation standard used elements of the ASCLD/LAB manual and met the requirements for ISO/IEC Guide 25 and ANSI/ASQC E4.

Writing an accreditation standard for a forensic laboratory and establishing a quality system to maintain the standard is not enough to ensure that quality scientific data is being produced. Members of the facility assume responsibility for their part in the system. Rosecrance (1999) suggests the implementation of an ethics program in the laboratory. In this article, the author covers the kinds of policies and actions that can inform employees about unacceptable and fraudulent behavior. A valuable tool for managers and scientists is the detailed table of unacceptable laboratory practices and the corresponding actions to take to avoid the problems listed in the article.

Articles describing the implementation of quality systems are found in the technical program of the 19th Annual National Conference on Managing Environmental Quality Systems. In one article, McMillan (2000) tells the success story of quality system implementation for a small environmental testing laboratory. Of special note was the decision to hire a dedicated quality staff to document and formalize components of the program.

The USEPA Quality System has guidance documents that take into consideration recent legal developments regarding the admissibility of scientific evidence. A table of these documents and corresponding Internet site locations are provided by Brilis *et al.* (2000). Additionally, the authors have provided a detailed list of criteria to consider in every stage of an environmental investigation to ensure that quality is maintained and is consistent.

Günzler (1996) provides details on different international accreditation systems. Several authors contributed brief descriptions of accreditation systems in different nations. The book contains chapters on quality assurance, traceability, and reference materials. Several sources for reference materials can be found on the Internet (NIST, 2001; NRC, 2001; Particle & Surface Science Pty. Limited, 2001).

The United States environmental testing industry has joined with state regulators to form the National Environmental Laboratory Accrediting Conference (NELAC). NELAC has published a series of standards and has accredited the first group of private laboratories (USEPA NELAC, 2001).

An outstanding "one-stop" Internet site for quality assurance is the ISO 17025 (Guide 25) home page (FASOR Technical Service, Inc., 2002). This site links to hundreds of other sites on quality assurance including accrediting bodies, calibration and testing labs, and measurement testing web sites.

Chemical fingerprinting

A useful forensic technique used in environmental investigations is chemical fingerprinting. Chemical fingerprinting is used to identify an unknown chemical or compound or to trace contaminants back to a particular origin. For example, petroleum contamination can often be traced back to a particular refinery based on additives that are unique to that refinery. A study of metals in areas surrounding a smelter can point back to the smelter effluent as the cause of pollution.

Morrison reviews the use of chemical fingerprinting for petroleum hydrocarbons in recent articles (Morrison, 1997; 2000a). Some items discussed include proprietary additives, alkyl leads, oxygenates, dyes, isotopic analysis, and transport models (Morrison, 2000a). Morrison (2000b) also discusses the chemistry and transport of petroleum hydrocarbons and contaminant transport modeling in a recent book. A similar overview of chlorinated solvents is also included.

Chemical fingerprinting as it relates to oils, gasoline, and diesel fuel is addressed by Bruya (2001). Test methods and analyses used in identifying and matching samples are evaluated. Tables of production specifications with test methods and tables of petroleum compositions with references are provided. Metals analysis is mentioned briefly.

Lead isotope analysis for source identification and age dating is frequently used in studies on the effects of lead-based gasoline on the environment. Residual traces of lead can be found in the environment even after the use of lead-based gasoline has been discontinued (Hurst *et al.*, 1996).

Determining the sources of lead in the environment is of international interest. Lead isotope ratios have been studied in sediments in Scotland by Farmer *et al.* (1996) to determine geochemical origins of lead and relative contributions from industrial and vehicle-exhaust emissions. Gulson *et al.* (1981) detail a study on lead contamination that was centered in the intersection between a rural and an urban area in South Australia. Natural soil lead was considered along with orchard sprays, power stations, smelters, and gasoline additives. Isotopic ratios indicated that while the natural soil lead was the major component for soil below 30 cm, contamination from the tetraethyllead additive in gasoline was determined as the major component in surface samples. Dunlap *et al.* (2000) conducted a study of river waters flowing into San Francisco Bay, California, and traced the lead deposited in the drainage basin. They saw a trend from leaded gasoline to isotopic concentrations similar to inputs that occurred during hydraulic gold mining in 1853.

Elemental ratios can also be used as a means of source identification. Monna *et al.* (1999) used lead isotope data and elemental ratios to study the lead isotope composition in lichens and aerosols. Elemental associations were also used by Rauch *et al.* (2000). Lead and platinum group metals in road sediments were studied using laser ablation-inductively coupled plasma-mass spectrometry.

Particle analysis is also used for contaminant source identification. An article by Linton *et al.* (1980) examines the use of the scanning electron microscope with energy dispersive X-ray analysis, multi-element analysis, and X-ray powder diffraction to identify the sources of lead-containing particles in urban dusts. The techniques used in the lead tracing study are described and the strengths and limitations of the techniques are summarized.

Hopke (1999b) discusses particle source identification for air quality management. A section covering basic principles and natural physical constraints leads into other sections on source composition for airborne particles, chemical mass balance, multivariate calibration methods, and factor analysis methods used for these studies.

Electronic evidence

Computer forensics is an integral component in environmental crime investigations (Devaney *et al.*, 1998). A significant portion of compliance monitoring is being generated by and stored on computers in either a laboratory environment or by computerized environmental monitoring equipment. For example, continuous emissions monitoring (CEM) systems collect measurements of gases or particulate matter. After the computer converts these measurements to the units of the emissions standard, the information is forwarded to the responsible regulatory agency. A similar computerized database and reporting system is encountered in leak detection and repair (LDAR) investigations at refineries. These systems monitor fugitive emissions from the various valves, flanges, and pumps at the plant. While LDAR is primarily evaluated during civil environmental investigations, the job of the computer forensic analyst is the same. The analyst obtains the database or data that is generated during monitoring, analyzes the data, and compares the results to the reports submitted to the regulatory agency.

A developing area of environmental crime investigations is laboratory fraud. Laboratory fraud is the deliberate misrepresentation of analytical results. This misrepresented data is often submitted to government agencies for regulatory determinations. In any laboratory setting, there can be a considerable variety of computers and computerized systems connected to laboratory instrumentation. These systems are capable of producing data ranging from raw data directly from the instrument to reduced data in the form of a report for a specific analysis. For this type of investigation, specialized knowledge of the operating systems and programs can be an invaluable aid in determining if fraud occurred.

The means of acquiring, securing, and analyzing computer evidence varies (Casey, 2000). Guidance for handling electronic evidence is available from the United States Department of Justice (2001, 2002), the literature (Stephenson, 1999; Wilding, 1997; Sammes and Jenkinson, 2000), and the Internet (US DOD, 2002; NIST, 2002; AOL, 1999; RCMP, 2002; ASIS, 2002). Additional problem areas, such as reverse engineering and internal data security issues, should be addressed by computer forensic analysts prior to pursuing an environmental crime investigation (Devaney *et al.*, 1998). Reverse engineering involves understanding the code for a computer program and using that knowledge to determine if the computer system can perform properly for its designed function. This examination can ascertain if reported results are reliable or if the code contains an error that may lead to false results.

An examination of data security issues within a company can be an integral component of the computer forensic investigation, especially in determining if a suspected chemical release was accidental, the deliberate action of a disgruntled employee, or the result of a computer hacker tampering with an automated system. These security questions also apply to automated reporting systems that transfer data directly to a regulatory authority.

Presentation of scientific evidence

Link analysis

Link analysis is a widely accepted tool in traditional criminal investigations and is used to support criminal and civil environmental investigations. Charting techniques include many types of analysis such as Traditional Link Analysis, Association Analysis, Telephone Record Analysis, Event and Activity Flow Analysis, Commodity Flow, Financial Analysis, and Time/Event Analysis (Anacapa Sciences, Inc., 2001b; i2inc, 2002). These chart types and more are available to illustrate how an environmental crime was committed.

Link analysis charts are an effective and successful tool in trial presentations when used to depict a set of events and specific information related to a crime. These charts assist a trier of fact to understand the complex relationships that exist in environmental crime. Environmental crimes are often very difficult to follow, especially if understanding the crime requires keeping track of the activities of many people and the timing of particular events (e.g. when various loads of waste are transported).

Case studies

As a result of a United States Supreme Court case referred to in short as *Daubert*, federal judges now have the responsibility of being the "gatekeeper" of scientific evidence in the courtroom (Findlaw, 2002). The benefit of this ruling is that it prevents so-called "junk science" from being presented and possibly misleading a jury. (Juries composed of US citizens often serve as fact-finders.) In many environmental cases, a federal judge will hold some type of *Daubert* hearing before expert testimony will be heard.

In a *Daubert* hearing, both sides must present their best case regarding the scientific work and be prepared to defend the work as having a sound scientific footing. The opinions presented may be based on standard methods or on a novel application to established science. In addition to questioning by lawyers, judges often delve into the basis for expert opinions in order to find the answers to two key questions (Simmons, 2002).

- *Is the opinion relevant?*

Does the opinion presented deal with the issues in the case? Do the scientific studies or research cited to support the opinion have direct relationship to the issues in the case?

- *Is the science reliable?*

Is the methodology that was used good science? (Was the method validated?) How were all aspects of the measuring process performed (from sampling to the laboratory analysis)? Were all the necessary QC actions taken to ensure the reliability of the data? Were established procedures for each action followed in the field, in the laboratory, and in all the steps in between? (Defensibility of field methods is no different from that of laboratory methods.) (Simmons, 2002).

Two environmental crime cases involving NEIC demonstrate the issues that can occur in determining the reliability of the science involved. One case necessitated that USEPA guidance be challenged and shown to be faulty. In the other case, the prosecuted company challenged their own data to show that it was unreliable and could not be used against them.

In the first case, the owner and operator of a fertilizer manufacturing company knowingly endangered his workers by exposing them to cyanide waste. A criminal investigation by USEPA examined the illegal hazardous waste disposal activities that physically crippled and caused permanent brain damage to an employee. The employee was sent into a 25,000-gallon storage tank to clean out the cyanide sludge inside without the required protective equipment. The employee was not told the tank contained cyanide waste. When rescue workers and medical personnel arrived, they were not told that the storage tank sludge contained cyanide, even though the medical personnel asked direct questions regarding cyanide exposure.

NEIC developed a storage tank model to demonstrate that the waste material in the storage tank was capable of generating toxic gases in harmful levels. Because USEPA guidance on hazardous waste contained a flawed analytical method for measuring cyanide, other methods were employed to prove that the waste was hazardous. The *Daubert* challenge from the defense attacked the tank model and the waste sample collected from the storage tank on the premise that neither was representative of the actual circumstances.

An NEIC expert testified during the *Daubert* hearing and was able to satisfy the judge that his opinion was based on reliable data and corroborating evidence. At trial, he presented his opinion that the waste was hazardous and explained how the evidence (witness testimony, NEIC sample analyses, and medical records) supported his opinion. The defendant was sentenced to a 17-year prison term, the longest sentence ever imposed for an environmental crime, and was ordered to pay \$6 million in restitution to the injured employee (USEPA, 2000).

In the second case, the challenge raised by the defendant during the *Daubert* hearing was directed against the expert for the prosecution and the defendant's own chemist and data. A meat processing company and several company managers were charged with felony counts of conspiracy, illegal dumping of pollutants, and filing of false reports in violation of the federal Clean Water Act (USEPA, 1996b,c). The company's discharge monitoring reports were falsified to indicate compliance with the discharge permit provided to the wastewater treatment plant that treated waste from the company's slaughterhouse operation. Measurements taken to monitor discharges were recorded by the company chemist in two sets of books. One set contained the real numbers from testing and the other set contained the numbers fabricated for reporting to the USEPA.

The methodology used to obtain the test results was not challenged in the *Daubert* hearing. The company challenged how their own chemist conducted the method and claimed that the numbers were unreliable. The company also argued that the chemist used no quality control and was incompetent and unreliable. An NEIC expert examined the company's data and offered the opinion that the data was of sufficient quality to prove permit violations. The court accepted the company data for use in the trial.

A guidebook for legal professionals and scientists providing expert testimony is the *Scientific Evidence and Experts Handbook* (Brown, 1999). It is a compilation of eight chapters on topics such as "Pretrial Preparation in Scientific Cases", "Finding, Hiring, and Supporting Scientific Experts in Complex Scientific Evidence Cases", and "Scientific Evidence in Criminal Cases," and is written by litigators with years of experience in the courtroom. A year 2000 update to this handbook is also available (Brown, 2000).

With the responsibility of being a gatekeeper for scientific and technical testimony in the courtroom, district court judges must perform inquiries into technical matters and evaluate scientific evidence. Several resources to assist judges will be tested for usefulness and legal reliability in the coming years (Stroup and Meiners, 2000). The *Reference Manual on Scientific Evidence* produced by the Federal Judicial Center is a readily available source for help in evaluating scientific evidence. Both editions of the manual are available from the Federal Judicial Center Internet site in whole or in separate sections (Federal Judicial Center, 2002).

Another aid to judges is the Court Appointed Scientific Experts (CASE) project developed by the American Association for the Advancement of Science (AAAS, 2002). Many trial lawyers question the legal viability of this project because of concerns that a court-appointed expert might not be fully impartial or that such expert testimony could tip the balances in the legal system. The Federal Judicial Center has indicated support for the CASE project and will evaluate the usefulness of the project after five years (Kaiser, 1999). An international perspective on environmental law and regulatory issues is available from libraries on the Internet (EHS Internet Library, 2001; Monash University Library, 2002).

Conclusions

Key points relevant to environmental forensics investigations are summarized.

- Information systems for the environmental forensic investigator are booming. Databases are increasing daily with information about chemicals, fate models, and financial or corporate connections. Two encyclopedias provide details on industrial processes. The Kirk-Othmer Encyclopedia of Chemical Technology and the Ullmann's Encyclopedia of Industrial Chemistry contain information on engineering fundamentals, plant processes, and industrial chemicals.
- Many Internet sites hosted by the USEPA provide extensive details about environmental crime scene investigations. Information available for investigators in the field include references to standards and methods, documentation and report examples, sampling techniques, and guides on field measurements. Several other Internet sites include details on laboratory analysis and methods available for download. The environmental protection agencies of many countries provide Internet sites with search

engines useful for locating reference methods and guidance documents.

- Case agents for environmental criminal investigations face new challenges because of the increasing expansion of computer systems and software. Including computer forensic analysts as part of an investigative team is one approach to using electronic evidence in an investigation. An alternate approach, training the case agent in computer forensics, may be time-consuming and may not be adequate for the agent to follow rapid changes in computer technology.
- In the United States, laboratory fraud is an increasing part of environmental crime investigations. Conditions that may encourage laboratory fraud to occur are the ineffective oversight of laboratory data, a shrinking consumer market, and inappropriate QA/QC actions. Fraud hotlines and techniques such as double-blind proficiency testing, data validation, and electronic record audits may be useful in the prevention of laboratory fraud.
- Accreditation is a key focus of environmental forensic laboratories. Important considerations for achieving accredited status include sufficient funding to support elements of accreditation (e.g. proficiency testing, facility improvement, and management information systems) and sufficient time resources to develop documentation and support changes in the organizational and functional structure.
- For environmental forensic organizations encompassing more than just a laboratory, elements of the investigative process that are outside the lab should be included in an accreditation standard. Elements of field sampling, evidence custody and preservation, and proper documentation can affect the prosecution of a criminal case and should be included in the quality management provided by a properly designed accreditation standard.

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