An Overview of Measurement Method Tools Available to Communities for Conducting Exposure and Cumulative Risk Assessments

MYRIAM MEDINA-VERA[a], JEANETTE M.VAN EMON[b], LISA J. MELNYK[c], KAREN D. BRADHAM[a], SHARON L. HARPER[a], JEFFREY N. MORGAN[c]

[a]National Exposure Research Laboratory, US EPA, MD-D205-05, Research Triangle Park, NC 27711 USA
[b]National Exposure Research Laboratory, US EPA, 944 East Harmon, Las Vegas, NV 89119
[c]National Exposure Research Laboratory, US EPA 26 West Martin Luther King Drive, MC 564, Cincinnati, OH 45268

Abstract

Community based programs for assessing and mitigating environmental risks represent a challenge to participants because each brings a different level of understanding of the issues affecting the community. These programs often require the collaboration of several community sectors such as community leaders, local governments and researchers. Once the primary concerns, community vulnerabilities and assets are identified, participants plan on how to address immediate actions, rank known risks, collect information to support decision making, set priorities, and determine an evaluation process to assess the success of the actions taken. The evaluation process allows the community to develop new action plans based on the results obtained from previous actions. Tracking the success of the community actions may be as simple as a visual/tangible result (e.g. cleaning a park) or complex as the collection of specific measurements to track the reduction of toxic pollutants or to determine the presence of a specific contaminant. Recognizing that communities may need to perform measurements to meet their goals, this paper provides an overview of available measurement methods for several chemicals and biologicals in relevant environmental samples to a community setting. The measurement methods are organized into several categories according to their level of complexity, estimated cost, and sources. Community project technical advisors are encouraged to examine the objective(s) of the community to be addressed by a measurement collection effort and the level of confidence that is needed for the data to make appropriate decisions. The tables provide a starting point for determining which measurement method may be appropriate for the specific community need.

Keywords: measurement methods, screening, community, analytes, quantitative methods, databases, analyses, exposure.

Introduction

A community based cumulative risk assessment (Callahan and Sexton, 2007, Sexton and Hattis, 2007) requires an understanding of the interactions of multiple stressors, aggregate exposures, and impacts to the particular population in a defined community (e.g. specific geographical boundaries, age group, gender, ethnicity, etc). The necessity to obtain information on particular stressors or target analytes within potentially different time frames, pathways, and routes of exposures may pose difficulties in the process of quantifying the potential exposure and cumulative risk. Community programs often undertake a simplified cumulative risk assessment process by first, identifying and prioritizing their major concerns, then performing a screening level evaluation of their risks, and finally selecting specific areas where an action can provide a measureable reduction on a particular exposure and the risk associated with it. To aid community programs in this process, the United States Environmental Protection Agency (EPA) provides guidance and assistance to communities in the performance of risk assessments, measurement methods, predictive models, and hazard identification (USEPA 1976,

USEPA, 1986, USEPA, 1989, USEPA 1990, USEPA 1992, USEPA 1997, USEPA 2000, USEPA 2002a, USEPA 2002b, USEPA 2003, USEPA 2007a). EPA also provides opportunities to obtain funding (e.g. grants, cooperative agreements) and technical assistance through several partnership programs (Clayton et.al., 2003; NACCHO, 2000; USEPA 2005, USEPA 2008a, USEPA 2008b; Zartarian and Schultz, submitted). Specifically EPA's Community Action for a Renewed Environment (CARE) program provides assistance to communities that want to reduce their levels of toxic pollution (www.epa.gov/CARE). The program offers a roadmap for communities to get organized and mobilized to take actions that would reduce their environmental health risks. EPA's National Center for Environmental Research provides grants for community–based participatory research (http://cfpub.epa.gov/ncer_abstracts/index.cfm/). Many community programs often design projects whose objective is to reduce exposure risks to a specific stressor or analyte. In the early stages, these projects may require screening measurements to determine if an analyte is present in order to make decisions on potential actions. They also may require the quantification of the hazard, stressor or analyte of interest to track the project success in reducing the exposure and therefore the potential risk. In many circumstances, this particular need will translate into the measurement of a specific chemical or biological agent in a targeted environmental media such as air or water.

The focus of this paper is to identify and summarize available tools for the measurement of several chemicals and biological agents in environmental samples relevant to a community setting (Barzyk et al, submitted). It is intended to be an overview of measurement methods having different levels of complexity, technical skill, and costs. The methods chosen for inclusion resulted from conversations with researchers involved in community programs who expressed the need for a summary of measurement methods appropriate for community applications. Currently these measurement methods are scattered across various websites, literature, and databases. These methods could be used to screen for the presence of a suspect stressor (e.g. chemical), develop exposure profiles in a specific locality and to demonstrate the success of a community project in reducing or mitigating exposure to a specific analyte. The paper is intended as a reference for technical staff providing guidance to community groups on how to perform measurements for specific community projects. To reach community project participants without extensive technical expertise, EPA is also planning to make the information available in a "lay-person-friendly" format through EPA's CARE program and community lay publications.

The decision to select a specific measurement method depends on several factors including the needed accuracy, the intended use of the data, the time and resources available to support data collection, and the quality of available or existing data. Spatial and temporal sampling issues must also be addressed in the sampling design. The number of measurements needed, the sampling sites, collection times, and necessary sensitivity also influence the selection of the most appropriate method(s). The methods summary tables presented here should aid the technical advisors participating in community projects in selecting a measurement method and understanding the level of effort necessary for collecting the desired measurements by providing a general description of how the measurement is performed. Options are provided for short-term, low budget efforts for preliminary screening of a specific analyte as well as methodologies for more extensive studies. The tables are organized by the level of method complexity ranging from requiring no technical background yielding data with a relative high uncertainty to more refined methods that produce data with reduced uncertainty. The measurement methods tables were designed to complement the other tools found in the Summary of EPA Exposure Tools Available to Communities for Conducting Cumulative Risk and Exposure Assessment (Barzyk et.al. submitted). The user should consider how the objective(s) of the community may be addressed by a measurement collection effort, determine the rationale for selecting a specific method, the level of confidence desired to make appropriate decisions, the measurements to be collected, and the overall analysis plan (USEPA 1997). The options available to collect data are as varied and different as the issues they seek to address. The selection of the proper measurement method is the first step in a measurement data collection.

Approach

A systematic approach was used to identify and prioritize the available methods relevant to community research. First, environmental concerns identified by communities (Barzyk et.al. submitted) were consolidated into measurable parameters (i.e. chemical, biological, physical). The information was gathered by the EPA's Office of Research and Development in 2007 by surveying the project officers working in the Community Action for a Renewed Environment (CARE) program. The survey results showed that most issues could be categorized into specific areas including air quality (e.g. fine particulate), children's health (e.g. residential mold), and drinking water (e.g. ground water and discharges to surface waters). Within these specific areas, the majority of the observed impacts on the community were categorized into measureable parameters, mainly chemical or biological (Barzyk et. al., submitted). Second, the focus was placed on chemical and biological analytes of concern. The most common routes of human exposure for the identified analytes were inhalation and ingestion. For inhalation, three distinctive environmental samples were indentified: outdoor air, indoor air, and particles either in the form of particulate matter in air (such as $PM_{2.5}$) or residential dust. The analytes of concern for these samples varied from radon to pesticides to allergens. The ingestion pathway focused on two relevant areas: water and food. Water quality perception of residents was dependent on the source (i.e., from a public delivery system or a well) and the plumbing (both inside and outside the residence). The analytes were varied and the methodologies available could be broken down into methods for fresh water systems, well water, and drinking/tap water. Food contamination was another important issue recognized by some communities but, generally, the importance seemed to be localized. Measuring specific chemicals in foods is not an easy task and often requires extensive technical knowledge to perform the measurement and interpret the results. Existing databases on levels of contaminants in food may provide communities some insights on potential dietary exposures (Office of Pesticide Program's Pesticide Data Program, http://www.ams.usda.gov/science/pdp/ or FDA's Total Diet Study, http://www.cfsan.fda.gov/~comm/tds-toc.html).

After reviewing the survey information provided by the community, the third step consisted of determining the chemicals, environmental samples and methods useful to community groups. As a fourth step, the potential users of the methods and participants in the measurement collection were identified. This allowed the summary tables to be more focused. Based on the existing methods, the following measurement categories were identified: Existing Measurement Data, Screening, Quantitative Screening, and Refined Quantitative. The existing measurement data category relates to measurement databases and is discussed in detail by Barzyk et.al. For the other categories, specific information on the applicability of the method is provided to the user. The four categories require different technical skill and, accordingly, each one provides data of varying uncertainty related to the measurement procedure used. For the purpose of this paper, the result of a measurement is defined as an approximation or estimate of the true value of the specific quantity being measured as described by the National Institute of Standards and Technology in their "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" (http://physics.nist.gov/Pubs/guidelines/cover.html). The term uncertainty is defined as the several components of the measurement that may influence the result making it closer or farther from its true value. Some components that may introduce uncertainty to the result include sample collection, sample handling, and analyte detection. The level of confidence is therefore defined as the extent to which the measured result is expected to be true usually expressed as a percentage. Accuracy is defined as the degree to which the measured value is close to its real or true value. Precision is defined as the repeatability of the results obtained by the performed measurements.

The fifth step consisted in tabulating available measurement methods according to categories and environmental media. Representative measurement methods that are available commercially and official EPA methods are included in categorized tables. For a method to be included, information on the applicability, accuracy, and uses of the resulting data needed to be available. The information in the tables is intended as an informational tool on where to find basic methodologies for a project. The web addresses and price ranges may vary from the time of submission to the publication date of this paper.

Results

Existing Measurement Data

A question that is often raised after discussing uncertainty associated with selected measures and analyses is: do we use data that are already available or collect a new measurement? There are several sources of existing measurement data. Barzyk et. al. provide examples of databases that have useful measurement data including toxic chemical releases, lead hazards, Superfund sites, smog and particulates, hazardous pollutants, Clean Water Act activities, watershed indicators, animal waste, and other parameters. The primary question that arises with searching existing databases is how useful are they for the purpose of the specific project. The user needs to know the "data about the data" or metadata information. Metadata usually provide details that help the user understand the intended use of the database, how the data were acquired, and possible data limitations. It is recommended that only databases with documented information be used. Understanding the intended use of the data allows the user to decide if the database will meet the data quality needs of their specific project objectives.

Measurement databases are commonly maintained by local or state government as well as organizations that provide services to a community. An example of this type of information is drinking water databases (http://www.nmenv.state.nm.us/) kept by local governments or organizations providing the service. Municipalities and agencies responsible for drinking water delivery systems monitor regulated drinking water analytes and provide the data to the consumers (http://www.epa.gov/enviro/html/sdwis/sdwis_query.html). It is worth noting that self contained ground water systems, such as wells, must be monitored by the users or independent entities to assure the water quality. Databases providing data quality information for ground systems are scarce.

Screening Measurement Methods

A community project may require specific measurement collection to meet its needs and answer questions related to the issue of concern. A good starting point is screening methods. For this article, screening measurement methods are defined as methods used to rapidly identify analytes or biologicals of interest informing whether a more thorough assessment is advisable. These methods have the advantage of being cost effective, relatively quick, and usually having a simple sample collection protocol. However, their simplicity frequently allows the user to introduce a higher level of uncertainty to the final results by not defining what a representative sample may be (Harper and Gutkencht, 2001 et. al., 2001). The detection of the analyte may also provide another source of uncertainty, for example, colorimetric results are dependent on interpretation of a specific color. The color perception could be influenced by the light in the area where the results are read and the user's eyesight (e.g. not distinguishing tonal differences in color). Screening methods are most useful in determining potential contaminants in a particular area or identifying "hot spots". Commercial test kits for multiple environmental samples such as air, surfaces, and water are available as screening methods. The ranges of analytes that can be detected by these kits include mold, ozone, radon, asbestos, metals, various pesticides, and disinfection byproducts among others. Table I provides examples of commercially available test kits by environmental media, analytes, information, and estimated cost. The environmental media and analytes on the table are representative of those identified as important by communities participating in the 2007 survey. Table I provides a general description of the screening method to provide user tools that could inform the method selection process.

Test kits may provide useful information by identifying areas of concern within a community where potential actions may be needed. The users have to consider that most responses provided by the kits are visual and often provide a wide margin of interpretation. Some require a colorimetric comparison with standards or titration of the sample with solutions of known value while others provide "present" or "not present" answers. The technical knowledge necessary to use these kits is minimal. Users may include adults as well as children in school. As with any analysis, the results of the kits are dependent on how the sample was taken, the environmental media, and experience of the user. For example, when testing for lead in paint, sample collection can be influenced by the painted surface composition (e.g. thick, thin, brittle, rubbery, or a combination of two different kinds of paint) (Harper and Gutkencht, 2001 et. al., 2001). The underlying substrates on which the paint has been placed may also influence the ease or difficulty of removing it. Examples of these substrates include wood, dry wall or plaster, and metal. To add to the complexity, where to sample on a surface may also be an issue. The screening method results may or may not be totally representative of the actual concentration of the analyte of interest but screening methods provide a good starting point. Interpretation of screening measurement results may also prove to be challenging depending on the response for the analyte. For example, when measuring mold (Figure 1), yeast or fungus in indoor air, media designed for mold growth is exposed to the air allowing for colonies to develop. The user has to determine roughly how many colonies are present to know the quality of the air and its potential impact on the residents of the house or building. The time elapsed between sample collection to results varies depending on the kit from 24 hrs to 7 days. The user has to follow the instructions provided by the vendor to make sure that the sample was collected appropriately, no potential cross contaminants are present, and that the results are read at the appropriate time. If a more sophisticated approach is needed for mold determination, additional information is available on an environmental relative moldiness index (Vesper et.al., 2007a) as well as quantitative determination (Vesper et.al., 2007b).

Another example of a commercially available kit is the screening method designed for testing carbon dioxide (CO_2), carbon monoxide (CO), indoor formaldehyde (HCHO), and nitrogen dioxide (NO_2). These test kits use dosimeter tubes that undergo a color change after the air sample has been collected and the reaction time within the dosimeter has expired (around 10 hrs). Figure 2 shows an example of a visual chart included with the screening kit allowing the user to qualitatively determine the air quality.

Reading color from a reference chart is dependant on the user, the type of light available and general perception of the color observed. Some charts have very subtle color changes which may make it difficult for the user to decide between the colors shown. An example is the detection of total nitrate/nitrite in water (Figure 3). The user may have to use their best judgment to determine which color best represents the results of the test. The EPA recommended maximum level for nitrate in water is 10 parts per million (ppm) and 1 ppm for nitrite (http://www.epa.gov/OGWDW/contaminants/dw_contamfs/nitrates.html). Based on this guideline the user may only be able to determine if the water sample is within or above the recommendation.

Some test kits have been successfully used by communities and school systems to monitor air and water. The kits provide a fast, practical, and reliable way to check certain parameters of air and water quality. An example is the determination of ground-level ozone by middle and high school students (http://artofteachingscience.org/ozone/ground-level_ozone.html, http://www2.gsu.edu/~mstjrh/ozone.html, http://www.dnr.state.wi.us/org/caer/ce/eek/earth/field/milkweed/index.htm) The data are collected by the students and shared with the community through the internet. Kits have also been used by schools for water quality monitoring (http://edtech.mcc.edu/amen/wetnet.htm, http://www.lamotte.com/pages/edu/homelist.html). The students compile and analyze the information which can be mapped to provide the community with an idea of the water quality in the area and sometimes in residences (http://www.studentwatermonitoringnetwork.org/).

Quantitative Screening Measurement Methods

The need for more accurate results is answered by another set of tools that combine the "ease of use" of the screening methods with laboratory analysis or an electronic aid. Usually the kits discussed in the previous section are upgraded with an electronic reading device that provides an accurate read out of the results or laboratory analyses with related fees included in the kit price. General technical skills are needed to use these methods. Table II provides examples of the commercially available test kits that include laboratory analyses in their purchase price. The primary source of uncertainty for this particular group of measurement methods is sample collection. Like the previous set of measurement methods- how the sample is collected, collection location, and sample preservation represent potential sources of variability. The advantage of this particular set of methods is that a more precise concentration of the analyte is provided thus reducing measurement uncertainty.

The primary source of uncertainty for this particular group of measuring methods is in the sample collection step. Like the previous set of measurement methods, how the sample is collected, where it is collected, and how the sample is preserved prior to analyses represent potential sources of variability. The advantage of this particular set of methods is that a more precise concentration of the analyte is provided. This reduces the uncertainty due to user interpretation.

Quantitative screening methods may be developed for specific applications and may be in a developmental research state therefore providing users with limited access. These methods often require technical knowledge for data interpretation and can be costly depending on the particular application. Immunochemical, biomarker, and bioavailability methods are within this category. Immunochemical methods in particular have been used to quantitate pesticides and their metabolites, dioxins, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and microbial products in several samples including soil, sediment, water, milk, beef, potatoes, urine, and serum (Van Emon et.al., 1986, 1986; Johnson J.C. and Van Emon, J.M., 1996; William et.al., 1996 K.J., 1996; Barceló, D. et.al., 1998; Dankwardt, A. and Hock, 1997; Van Emon, 2001; Nichkova, M. et. al., 2002, Nichkova, M. et. al., 2004; Brena, B. M. et. al., 2005; Watanabe, H. et.al., 2006; Van Emon, J.M., 2006; Chuang, J.C. et. al., 2008). These methods use selective antibody or antibodies to bind the specific chemical of interest. They are commonly used in the biological sciences and as clinical diagnostics. Few companies sell these assays for environmental monitoring and many can be found under the trademark of RaPID Assay® (PAHS analyses sold by Strategic Diagnostics, Inc. www.sdix.com) or pesticides RaPID Assay ™ Kit (Aldicarb kit sold by Mallinckrodt Baker, Inc.). Many universities have immunoassay development programs and are often looking for real-world samples to test their methods. Mutually beneficial partnerships can be formed between a community and a university with the community supplying samples and the university providing measurement results back to the community.

A common immunoassay format is the enzyme-linked immunosorbent assay (ELISA) that gives a colored end point and can be read visually or by a spectrophotometer. ELISA testing kits for environmental contaminants typically contain antibody-coated test tubes, standards, reagents and plasticware necessary to perform the analysis (Van Emon 2006). These "lab in a kit" procedures can be tailored to provide yes/no, qualitative, semi-quantitative or even highly quantitative results. Prices vary depending on the analyte, the number of analyses (bulk pricing), and the required precision and accuracy of the method. Many tests can be performed for under $300.00 and ELISA is significantly cheaper than instrumental methods. Immunoassay testing kits have been used by community members to monitor their tap water for pesticides and by local watch groups to look for pesticide residues on produce (Van Emon 2001). School projects checking for pesticides in community water sources have also relied on immunoassay testing kits. Simple extraction procedures can be coupled with immunoassay detection to analyze other samples of interest such as soil, dust, and air (Chuang et al 2008). ELISA methods can also be modified and used for monitoring biomarkers in urine and other biological samples.

Biomarker methods measure a chemical or its metabolites in the body providing information about exposures and potential outcomes or diseases. They have been used to assess human exposures to chemicals in the environment and to inform cumulative risk assessments (Ryan, P.B. et. al. 2007) but interpretation of results often requires a comprehensive understanding of exposure issues, dose and body functions (Pleil et. al. 2007). Biomarker methods require the collection of samples such as serum, blood, urine, or exhaled breath (Pleil et. al., 2005). The metabolites, adducts or by-products of interest are measured in those samples by using ELISA methods or sophisticated analytical instrumentation (Nichkova, M., Galve, R., Marco, M.P. 2002, Nichkova M., et.al. 2004). The sample collection may be performed by community members in some instances but the analysis and interpretation of the results require that someone with appropriate expertise analyzes the samples and provides technical knowledge on the interpretation of the results within the context of the sample collection. Most biomarker methods are characterized as quantitative screening methods because they often provide an idea of the total exposures an individual incurred without providing specific information on the duration, frequency, location, and time of the exposure. Results from biomarker methods may be used to provide insight on potential exposures in a community, potential health effects, and to aid in identifying high risk/highly exposed individuals within a group. EPA is working on developing exposure reconstruction pathways from biomarker data (Pleil et. al. 2007). Once these tools become available, the results of biomarker measurements could be interpreted with better accuracy. The cost of using biomarkers in a community study depends on the media to be collected, number of samples, biomarker to be analyzed, and duration of the collection phase which could be extended throughout several weeks to provide statistically significant data.

EPA is committed to researching new measurement methods for communities to apply in their exposure assessment efforts and understanding underlying risks related to the exposures. One development area is bioavailability research. Bioavailability measurements determine how much of a chemical present in a specific contaminated media (e.g. soil, dust) will be absorbed by an organism following exposure. The human health oral bioavailability is defined as "the fraction of an ingested dose that crosses the gastrointestinal epithelium and becomes available for distribution to internal target tissues and organs" (USEPA 2007b). The importance of the method resides in the fact that in most cases, the actual exposures (e.g. toxic metals) related to specific environmental samples are much less than predicted by traditional methods such as determination of toxic metal total concentration (Bradham et. al., 2006, Dayton et. al., 2006). New bioavailability methods based on human physiology are being developed. These quick, inexpensive, cost effective methods estimate bioavailability for use in estimating exposure for health risk assessments. The estimated cost per sample is approximately $150 (Kelley et al., 2002). However, many of these methods have not been validated or they may only be validated for specific types of media, a specific analyte or a specific concentration range. Therefore, methods used to assess bioavailability are usually complemented by models that help predict the risk of a specific analyte to an individual. Most risk assessment applications employing bioavailability data have been done using toxic metals (USEPA 2007b, 2007c, 2007d). As with biomarker measurements, the drawback of bioavailability measurements are the difficulties in data interpretation and the need to perform a risk assessment (e.g. risk calculation) with the data produced. It is considered a quantitative screening technique because it allows the determination of potential risk and risk mitigation actions once the data are used in a health risk assessment. However, at this time, research is on-going to accurately interpret bioavailability results and build up the necessary technical knowledge to interpret the data and understand its underlying impact.

Refined Quantitative Measurement & Analytical Methods

This last category of available methods is the most familiar to individuals in a laboratory setting. The methods provide quantitative/numerical results for the analytes of interest. They require advance technical knowledge and instrumentation. This category includes detailed procedures for sample collection, sample preparation, and analysis. Methods are available for most relevant environmental samples and analytes of interest. The costs are dependent on the type and number of samples, desired analysis, detection limits, and reporting requirements. Table III shows some of the EPA methods available on line. Many of these methods are used by local governments, federal agencies, and industry to measure regulated analytes. They are also used for pilot studies that need to gather baseline information about environmental exposures.

Communities that may be interested in using this level of methodology may partner with their local government, universities, industry or other organizations that have the capability to acquire and prepare samples and perform the analysis. A practical way to implement a community effort that requires high end instrumentation would be to utilize a relative easy procedure for sample collection. One example testing this concept of a "simple" sampling technique paired up with high end analytical instrumentation in a community setting was launched by EPA in 1998. A partnership was established between EPA, the private sector, and residents of 16 counties in the Dallas/Fort Worth (DWF) area. The project was called the Passive Ozone Network in Dallas (POND) project (Sather et.al., 2001, Varns et. al., 2001). The project began after EPA announced the eight hour ozone National Ambient Air Quality Standard (NAAQS) in 1997 (http://www.epa.gov/air/ozonepollution/fs20080317.html).

The POND project's goal was to gather data that would provide a better understanding of ozone exposures and allow localities to identify non-attainment areas in a cost effective way. It used a passive sampler device (PSD) (Figure 4) network to measure ozone (O_3) in the Dallas/Fort Worth area. EPA scientists joined efforts with concerned citizens in the Dallas/Fort Worth area. A passive network of 30 sites was established within 16 counties. Daily PSD ozone data were collected during 8 weeks. The sites operators included EPA employees EPA, members of organizations such 4-H Club and Master Gardeners, and farm retirees recommended by the county agricultural extension service agents. EPA prepared a tutorial video (Varns et.al., 1998) explaining the sample collection and mailing process. Once the samples were received at EPA, they were extracted and analyzed by gas chromatography/mass spectrometry (GC/MS). The data were reported back to the community. The feasibility of deploying a passive sampling network in a community-based participatory research project was tested in this effort. The passive network results showed an excellent correlation (95-97%) with the continuous monitoring sites. The project success was due to a clear objective, easy to follow procedures, and the trust and commitment of all participants. The project showed that with the right partnerships, a community can successfully acquire monitoring data that are meaningful to their locality. The selection of an appropriate sampling method and clear procedures on sample handling and shipment to the laboratory along with tutorial visual aids made this effort successful.

Sometimes a simple sample collection method is not appropriate to answer the particular question the community may have. It may be necessary to utilize complex sampling equipment with highly technical protocols. The cost and technical skill level needed for an effort requiring complex instrumentation is high. To be able to interpret the results, participants need to clearly understand the purpose and problem formulation, the data quality objectives, the sampling statistical design plan satisfying the desired uncertainty parameters, and the rationale for the overall analysis plan. Measurement data are interpreted within the boundaries established by the planning stages and should be used only for its intended purpose.

Discussion

Measurements data are needed when an information gap exists to support action(s) or answer a question relevant to a community concern making method selection critical for obtaining the appropriate data. Simple yes/no responses indicating the presence/absence of contaminants may be adequate for a decision. The measurement activity usually is a combination of several methods for sample collection, sample preparation, and detection/determination of the analyte of interest (Quevauviller, P. 2004 a,b, Quevauviller, P. and Donard, O., 2001). Before investing time and effort in measurement collection, it is important to a) have a clear understanding of the purpose and scope of the desired effort, b) identify the participants, approach and resources available to the project, and c) review previous efforts done by communities with similar issues of concern. Those involved in designing a community project need to carefully consider the limitations of resources, data already available and potential measurement methods to be used. Consideration of the potential risks, prioritization of issues and pathways, and the need or availability of technical information should also be included during the planning stages of any measurement endeavor. Once a clear understanding of what question or hypothesis will be answered by the measurement collection, it is time to address the uncertainty, level of confidence, precision, and criteria for selecting the measurement method.

Conclusions

The measurement methods presented in this paper provide an overview of methods representing different levels of confidence and precision. Screening methods are useful to determine the presence or absence of an analyte. They may aid a community to determine if particular analytes are present and if there are any “hot spots”. The data uncertainty from these methods may result from the sample collection step, sample handling, and the interpretation of the results. The user does not need to have technical skills to apply these methods. The results from these methods may inform the decision plan to take a specific action. Quantitative screening methods provide a lower level of uncertainty. The sources of uncertainty are associated with the sample collection, sample handling, and the instruments used to read the results. These methods usually require two levels of skill: a user with minimal technical expertise performing the collection and sample handling, and an analyst with technical skills appropriate to the instrument complexity level. The most sophisticated methods require a high level of technical knowledge. The sample collection, preparation and analysis require careful planning, design, greater resources, and sophisticated instrumentation often with low detection limits.

When a community needs to fill information gaps for action plan development or evaluate the impact of actions taken to reduce exposures, measurement methods produce data to inform community decisions. Selection of a particular method is done based on resources, data quality requirement, and level of uncertainty while focusing on the appropriateness of the produced data to answer the original questions. This paper provided an overview of measurement method tools that could be used as a starting point for an exposure assessment addressing a community concern. These methods provide users with basic information to select the most appropriate measurement tool to address the needs of a community–based exposure project.

Acknowledgements

We would like to thank all the EPA scientists who contributed their suggestions and comments to the development of the Measurement Methods Tool Tables, in particular Kent Thomas, Valerie Zartarian, Tim Barzyk, Matthew Lakin, Kathryn Conlon, Davyda Hammond, Peter Egeghy and Ingrid Ward. We are grateful to Steve Vesper for the donation of his pictures and to Elizabeth Betz for digitalizing the POND's training video.

Disclaimer

This paper has been reviewed in accordance with the United States Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

References

Barceló D., Oubiña, A., Salau, J.S., Perez, S. Determination of PAHs in river water samples by ELISA, Analytica Chimica Acta. 1998: 376 (1), 49-53.

Barzyk T.M., Conlon K.C., Hammond D.M., Chahine T., Zartarian V.G., Schultz B.D. Tools Available to Communities for Conducting Cumulative Exposure and Risk Assessments. J. Expos Sci Environ Epidemiol 2009

Bradham K.D., Dayton E.T., Basta N.T., Schroder J.L., Payton M.E., and Lanno R.P. *Effect of soil properties on lead bioavailability and toxicity to earthworms*. Environmental Toxicology and Chemistry Special Issue: Risk Assessment of Metals in Soils 2006:25(3): 769-775.

Brena, B. M., Arellano, L., Rufo, C., Last, M.S., Montaño, J., Egaña Cerni, E., Gonzalez-Sapienza, G., Last, J.A. ELISA as an Affordable Methodology for Monitoring Groundwater Contamination by Pesticides in Low-Income Countries, *Environ. Sci. Technol.* 2005: 39 (11), 3896 -3903.

Callahan, M. A. and Sexton, K. If Cumulative Risk Assessment is the Answer, What is the Question? Env.Health Perspec. 2007: 115 (5): 799-806.

Chuang, J.C., Van Emon, J.M., Tefft, M.E., Wilson, N.K. Evaluation of an Enzyme-Linked Immunosorbent Assay for Permethrin is Soil and Dust. Bull. Env.Contam. and Toxicol. 2008:

Clayton, C.A., Pellizzari, E.D., Whitmore, R.W., Quackenboss, J.J., Adgate, J., Sefton, K. Distributions, associations, and partial aggregate exposure of pesticides and polynuclear aromatic hydrocarbons in the Minnesota Children's Pesticide Exposure Study (MNCPES), Journal of Exposure Analysis and Environmental Epidemiology 2003: 13:100-111.

Dankwardt, A. and Hock, B. Enzyme immunoassays for analysis of pesticides in water, Food Technol. Biotechnol.1997: 35, 165.

Dayton E.T., Basta N.T., Payton M.E., Bradham K.D., Schroder J.L., Lanno R.P. Contribution of soil properties to modifying lead bioavailability. Environmental

Toxicology and Chemistry Special Issue: Risk Assessment of Metals in Soils 2006: 25(3): 719-725.

Harper, S. L. and Gutknecht, W. F. Sources of Variability in Collection and Preparation of Paint and Lead-Coating Samples, Journal of Environmental Monitoring. 2001: 3(3): 335.

Johnson, J.C. and Van Emon, J.M.1996. Quantitative enzyme-linked immunosorbent assay for determination of polychlorinated biphenyls in environmental soil and sediment samples, Anal. Chem. 1996: 68 (1), 162.

Kelley, M., Brauning S., Schoof, R., Ruby, M. Assessing Oral Bioavailability of Metals in Soil. Battelle Press, Columbus, OH, 2002.

NACCHO. 2000. Protocol for Assessing Community Excellence in Environmental Health: A Guidebook for Local Health Officials. National Association of County and City Health Officials (NACCHO) CEHA Program. May 2000.

Nichkova, M., Galve, R., and Marco, M.P. Biological monitoring of 2,4,5-trichlorophenol:Evaluation of an enzyme-linked immunosorbent assay for the analysis of water, urine and serum samples, Chem. Res. Toxicol. 2002: 15 (11), 1371.

Nichkova, M., Park, E., Koivunen, M.E., Kamita, S.G., Gee, S.J., Chuang, J.C., Van Emon, J.M., and Hammick, B.D. Immunochemical determination of dioxins in sediment and serum samples, Talanta 2004: 63, 1213.

Pleil, J.D., Kim, D., Prah, J.D., Ashley, D.L., and Rappaport, S.M.. "The Unique value of Breath Biomarkers for Estimating Pharmacokinetic Rate Constants and Body Burden from Environmental Exposures", 2005: Book Chapter: Breath Gas Analysis for Medical Diagnostics, World Scientific Publishers, Singapore.

Pleil, J.D., D. Kim, J. Prah, D.L. Ashley and Rappaport, S.M. "Exposure reconstruction for reducing uncertainty in risk assessment: Example using MTBE biomarkers and a simple pharmacokinetic model", Biomarkers 2007: 12(4):331-48.

[a]Quevauviller, P. Challenges for achieving traceability of environmental measurements, Trends in Analytical Chemistry 2004: 23 (3): xi-xii.

[b]Quevauviller, P. Traceability of environmental chemical measurements, Trends in Analytical Chemistry 2004: 23 (3): 171-177.

Quevauviller, P., Donard, O., Stated references for ensuring traceability of chemical measurements for long-term environmental monitoring, Trends in Analytical Chemistry, 2001: 20 (11): 600-613.

Ryan, P.B., Burke, T.A., Cohen Hubal, E.A., Cura, J.J., and McKone, T. Using Biomarkers to Inform Cumulative Risk Assessment, Environmental Health Perspectives 2007, 111 (5), 833-840, 2007.

Sather, M. E., J. L. Varns, J. D. Mulik, Glen, G., Smith, L., Stallings, C. Passive Ozone Network of Dallas: A Modeling Opportunity with Community Involvement. 2, Environ. Sci. Technol. 2001: 35, 4426-4435.

Sexton, K. and Hattis, D., 2007. Assessing Cumulative Health Risks from Exposure to Environmental Mixtures-Three Fundamental Questions, Environmental Health Perspectives, 115 (5), 825-832.

USEPA 1976. Health Risks and economic impact assessments of suspected carcinogens: Interim procedures and guidelines. Fed Reg. 41(102): 21402-21405.

USEPA 1986. Guidelines for the Health Risk Assessment of Chemical Mixtures. EPA/630/R-98/002. Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum, Office of Research and Development.

USEPA 1989. Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A), Section 8.2.2. EPA/540/1-89/002. Washington DC: US Environmental Protection Agency, Office of Sold Waste and Emergency Response.

USEPA 1990. Reducing Risk: Setting Priorities and Strategies for Environmental Protection. SAB-EC-90-021. Washington, DC: US Environmental Protection Agency, Science Advisory Board.

USEPA 1992. Guidelines for Exposure Assessment. EPA/600/Z-92/001. Washington, DC: US Environmental Protection Agency, Risk Assessment Forum, Office of Research and Development.

USEPA 1997. Guidance on Cumulative Risk Assessment, Part 1 Planning and Scoping, Washington, DC: US Environmental Protection Agency, Science Policy Council.

USEPA 2000. Supplementary Guidance for Conducting a Health Risk Assessment of Chemical Mixtures. EPA/630/R-00/002. Washington DC: US Environmental Protection Agency, Risk Assessment Forum, Office of Research and Development.

USEPA 2002a. Revised Organophosphate Pesticide Cumulative Risk Assessment. Washington, DC: US Environmental Protection Agency, Office of Pesticide Program, Office of Prevention, Pesticides and Toxic Substances.

USEPA 2002b. Guidance on Cumulative Risk Assessment of Pesticide Chemicals that have a Common Mechanism of Toxicity. Washington, DC: US Environmental Protection Agency, Office of Pesticide Programs, Office of Prevention, Pesticides, and Toxic Substances.

USEPA 2003. Framework for Cumulative Risk Assessment. EPA/630/P-02/001F. Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum, Office of Research and Development.

USEPA 2005. Community Action for a Renewed Environment Brochure. EPA-400-F-06-003. Available: www.epa.gov/care/library/care_brochure_2006.pdf

USEPA 2007a. A Framework for the Public Health Impacts of Risk Management Decisions. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

USEPA 2007b. Guidance for Evaluating the Oral Bioavailability of Metals in Soils for the Use in Human Health Risk Assessment. 2007, OSWER 9285.7-80. http://www.epa.gov/superfund/bioavailability/guidance.htm

USEPA 2007c. Framework for Metals Risk Assessment.2007, EPA 120/R-07/001.

USEPA 2007d. Estimation of Relative Bioavailability of Lead in Soil and Soil-like Materials Using In Vivo and In Vitro Methods. 2007, OSWER 9285.7-77.

USEPA 2008a. The CARE Roadmap: 10-Step Plan to Improve Community Environment and Health, U.S. Environmental Protection Agency CARE Program. EPA 400-K-08-002. June 2008. http://epa.gov/care/library/20080620roadmap.pdf

USEPA 2008b. The Community CARE Resource Guide. www.epa.gov/osp/care/library/CARE_Resource Guide.pdf

Van Emon, J.M., Hammock, B., and Seiber, J.N. Enzyme-linked immunosorbent assay for paraquat and its application to exposure analysis, Ana. Chem. 1986: 58, 1866.

Van Emon, J.M., Immunochemical applications in Environmental Science. J. of A.O.A.C. 2001: 84(1):125-133.

Van Emon, J.M., ed., Immunoassay and Other Bioanalytical Techniques, CRC Press, Boca Raton, FL, 2006.

Varns, J. L., J. D. Mulik and E. A. Betz. Video: Site Training for the POND (Passive Ozone Network in Dallas), a peer-reviewed video for generic instruction of lay operations in a passive ozone monitoring network; distributed to 30-site network in and surrounding Dallas, TX, 1998: EPA/600-V-98/001, 12 min.

Varns, J. L., Mullik, J.D., Sather, M.E., Glen, G., Smith, L., Stallings, C. Passive Ozone Network of Dallas: A Modeling Opportunity with Community Involvement 1, Environ. Sci. Technol. 2001, 35, 845-855.

[a]Vesper S, McKinstry C, Haugland R, Wyner L, Bradham K, Ashley P, Cox D, DeWalt G, Friedman W. Development of an Environmental Relative Moldiness Index for US Homes. J. Occup. Environ. Med. 2007: 49 (8), 829-833.

[b]Vesper S, McKinstry C, Ashley P, Haugland R, Yeatts K, Bradham K, Svendsen E. Quantitative PCR analysis of molds in the dust from homes of asthmatic children in North Carolina. J. Environ. Monit, 2007: 9, 826-830.

William, K.J., Thorpe, S.A., Reynolds, S.L. The Use of Elisa for the Determination of Pesticide Residues in Food, International Journal of Analytical Chemistry 1996: 65 (1-4), 149-152.

Watanabe, H., Nguyen, M.H.T., Komany, S., Vu, S.H., Asami, Y., Phong, T.K., Tournebize, J. Applicability of ELISA in pesticide monitoring to control runoff of bensulfuron-methyl and simetryn from paddy fields, Journal of Pesticide Science 2006: 31 (2), 123-129.

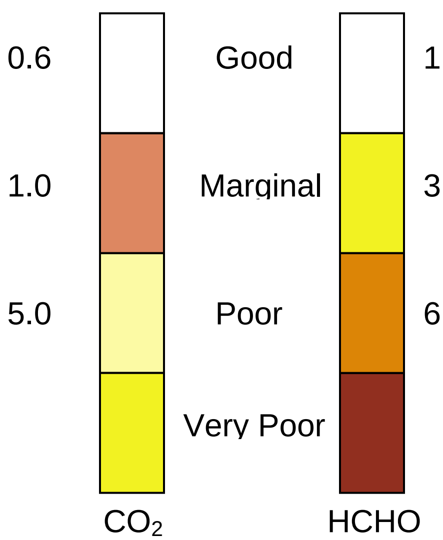
Zartarian V., and Schultz B. EPA's Human Exposure Research Program for Assessing Cumulative Risk in Communities. J. Expos Sci Environ Epidemiol 2009.

Figure 1. Examples of mold colonies in Petri Dishes

Pictures by S. Vesper, USEPA

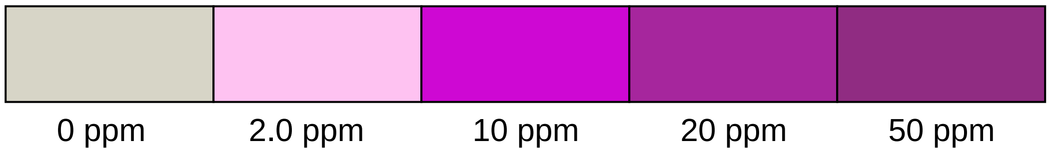
Mold tests require the user to wait at several hours before reading the results. The number of identifiable colonies formed provides the basis ranking the quality of the media tested. For example, good air quality translates to the formation of 1-3 distinct colonies, 4-6 means marginal air quality, 7-12 is considered poor air quality and over 12 is considered very poor air quality. The user needs to know how a colony looks like and how to distinguish among them.

Figure 2. Example of a visual chart used to determine air quality



Some test kits use dosimeter tubes to determine air quality. Each tube is specific for an analyte. The dosimeter tube is opened and exposed to air for 10 hours. After the sampling time has elapsed, a colorimetric change will be observed in the tube. The user compares the color with a visual chart provided by the vendor. The chart provides different color ranges representing different concentration ranges for each analyte. The results are interpreted as good, marginal, poor or very poor air quality for each analyte.

Figure 3. Example of Colorimetric Responses for Total Nitrate/Nitrite Concentrations in Water



Water can be tested for chlorine, nitrate, nitrite, copper as well as pH, hardness, and oxygen content. Some test kits provide strips that can be dipped into the water and provide a colorimetric result within one minute. The user compares the result with a visual chart provided with the kit. Sometimes the color changes may be difficult to interpret as colors in the chart may be similar, perception of color may be different from user to user, and different lights (natural vs. fluorescent) may affect the read-out.

Figure 4. Ambient Air Passive Sampler Device (PSD) used in the POND study. The device has a cylindrical polymeric body (2cm diameter by 3cm long) housing a coated glass fiber disk at each end. The device produced by Ogawa & Co., Inc., FL. This type of passive sampler can be used for NO-NO_2, NOx, SO_2, O_3, and NH_3. It is reusable except for a pre-coated pad.

Table I: Screening Measurement Methods: Examples of Commercially Available Test Kits*

Analyte(s)	Estimated Price Range as of 2007	General Description
Indoor Air		
Mold and Bacteria Formaldehyde, Nitrogen Dioxide, Carbon Monoxide and Carbon Dioxide	$ 69.95 for one; $109.95 for two	Spot tests for rooms and forced hot air heating and air conditioning systems for mold, yeast and fungus. User needs to count colonies formed. Dosimeter tube tests for other gases.
Ozone	$14.95	Kit includes: Four One-Hour Ozone Test Cards. If ozone is present, the card will change color. The color is compared with a color chart.
Toxic black mold, bacteria, and yeast	$19.95	Air from vent tested for 1 minute. Results in 24 to 72 hours by comparing growth to the provided chart.
Mold Spores Bacteria Fungus	$13.95 per set	Air is sampled on a pretreated Petri dish. Results after 36-40 hours. User visually counts the number of mold colonies.
Water		
Phosphate	50 tests- $71.90	For each analyte, swirl or dip strips according to instruction. Read color change and compare with color chart.
Chlorine	50 tests- $ 61.20	
Ammonia Nitrogen	50 tests- $48.50	
Chloride	50 tests- $39.50	
Bacteria/Mold Pesticides-Atrazine & Simazine, Ammonia, Nitrate & Nitrite, Iron, Chlorine Copper ,Hydrogen Sulfide, Lead	$ 8.99 to $35.95	Bacteria test results after 48 hours of collection, a positive or negative color response is obtained. For lead and pesticides a positive/negative visual line is obtained. Test strips results are compared against the color charts provided.
Arsenic	$25.95 for two tests	Requires addition of three reagents. Colorimetric change is compared to a chart.
Ammonia, Nitrogen,	Options ranging from	Individual test kits with colorimetric detection in a

Calcium, Magnesium, Free Carbon Dioxide, Chloride,Chlorine, Chromium(Chromate), Copper, Cyanide, Iron, Nitrate, Phosphorus (Phosphate), Sulfide	$164.35-$516 depending on the number samples and analytes to be detected.	carrying case. Each kit contains multiple tests (40-50), report forms, and handbooks.
Drinking/Tap Water		
Trihalomethanes	$ 449 for 100 tests	Includes 3 reagent solutions and a reagent powder. The analytes react are equimolar with reagents giving a visual change.
Bacteria, atrazine & simazine; nitrate, nitrite , iron, chlorine, copper , lead	$14.95- $59.95	Bacteria tested on vial with growth powder and after 48 hours a positive or negative response is obtained depending on the color observed. Lead and pesticides positive/negative presence compared with line on strip. Nitrate, nitrite, iron- color change observed on the specific strip is compared with color chart.
Surfaces		
Mold	5 tests : $34.95 10 tests: $44.95 15 tests: $54.95	A wipe sample is tested. After 3-7 days user compares dot colonies with reference material for interpretation of results.
Lead	8 tests:$18.45 16 tests:$34.95	Measures leachable lead by turning pink or red on contact with the surface.
Lead	$27.95- 29.95, add $4.50 for shipping.	A solution is mixed; drops are placed onto a paint sample. A black color change indicates that there is lead present in quantities greater than 1 percent.

*An extended table (Table S1) can be found on line as a supplement. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Table II. Examples of Quantitative Screening Methods: Instrument or Laboratory Determination*

Analyte(s)	Estimated Price Rangeas of 2007	General Description
		Indoor Air
Ozone	$ 299- 329.99 +	Monitor for ambient ozone detection. 0.02-0.14 PPM range. LED readout.
Mold	5 tests: $34.95, 10 tests: $44.95, 15 tests: $54.95	Price includes sampling unit with mold collection device, instructions, consumer information handbook, and postage-paid mailer for laboratory testing.
20 types of mold spores, pollen and dust	$149.00	Price includes Air Check Pump Rental (10 Days), 2 Test Cassettes, Free Return Shipping LABORATORY FEES for complete analysis.
mold and mildew	$ 99.95	Price includes 2 Test Swabs or 2 Strips/Vials, Pre-Paid Reply Envelope, Instruction Sheet. Time for Results 5-10 days allowed for colony growth. Colonies are identified by the lab and a measure of growth is provided.
Radon	One test: $ 14.95 3 tests: $ 36.00	Simple instructions are provided. All necessary supplies for sampling and mailing are included without additional cost to the lab for analysis.
Mold Spores Test Dander Test Carcinogenic Fibers Pollen Test	Basic Home Quality Kit (dust & dust mites): $30 Add-mold:$45 Add-dander: $45	Need to order the basic home air quality kit and add on other tests of interest. The price includes laboratory analysis. The users have to create a sampler as describe in the instructions

Bacteria Test	Add-carcinogenic fibers (fiberglass, asbestos): $33 Add-pollen: $ 35 Add-bacteria: $99	and return the sampler card to the lab for analysis. Results are provided within seven days of receipt of samples or 14 days for bacteria analysis.

Water

Aluminum, Ammonia, Bromine, Chlorine, Chloride, Copper, Formaldehyde, Fluoride, Glycol, Iron, peroxide, manganese, molybdate, nitrate, nitrite, phenols, phosphate, sulfate, sulfidie, zinc	Photometer, $920 Packs of 30 disposable ampoules $24-$34	Battery operated photometer pre-programmed to measure 30 analytes. Uses self-filling ampoules. The system can be update by a program upload procedure. Stores up to 100 data points. The readout is given in concentration, absorbance or percent transmittance.
Total Coliform and E.Coli bacteria, 17 heavy metals, 5 inorganic chemicals, 5 physical factors, 4 trihalomethanes, and 44 volatile organic chemicals	Test Price: $122.95 With Pesticide Option: $152.95 ;	Kit includes refrigerant, sampling bottles, Styrofoam box, shipping box, instructions. Return postage is included for mailing the kit back to the laboratory. Results are provided 10-15 business days from date of receipt.

Pesticide Option includes 20 additional organic pesticides,herbicides and PCB's		
Radon	$27.95- $35.00	The price includes water sample collection vial, instructions, first class postage and laboratory analysis. Results are available online the next business day.
Trihalomethanes	$3012 for portable spectrophotometer	Portable Spectrophotometer has over 240 pre-installed analytical methods and can run on electrical power or a lithium-ion battery. Cells and accessories available.
Free & total chlorine Iron Ammonia Fluoride Copper Phosphate Nitrate Ozone, Nickel, Managanese, Lead, Zinc, Molybdate, Aluminum	$352-370 pocket colorimeter	Several options exist for the user including generic Pocket Colorimeter instruments as well as specialized kits for specific analytes. The specific kits are calibrated to specific parameters and wavelengths for the analyte. The colorimeter is reusable and kits include necessary reagents, sample cells, manuals and other necessary materials such as pre-calibrated curves.

Alachlor Atrazine s-Metolachlor	Price depends on the analyte and number of assays.	Uses ELISA methods[a] for the determination of the specific analyte.
Mold	Price depends on sample & sampling media- Tape= $50; Air= $60, Bulk=$100.00, e.g. 4 sq.in. of drywall, 1 sq.ft. of mold-suspect fiberglass	The user is responsible for collecting the sample. Several collection media is accepted such as tape samples (instructions on how to sample with tape are provided), Zefon(R) air sample cassettes, personal air sampler slides, spore traps, vacuum samples, and bulk material samples among others. Processing turnaround time is 24 hrs from the time of receipt.
Asbestos	$20- $37.99, Lab Fees & Shipping Included	User needs personal protective equipment to collect the sample. A razor knife or similar is used for sampling. The fee includes the analysis and pre-paid postage envelope.

* An extended table can be found on-line as Table S2. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

[a]Most ELISA methods commercially available are used in the food safety, pharmaceutical, and agricultural industries therefore only one example is given in the table. More information can be obtained from companies such as Neogen, Agdia, and Romerlabs.

Table III. Refined Quantitative Methods: EPA Measurement Methods tools*

Source	Description	Web address
	EPA Information	
EPA Method Collections	Forum of Environmental Measurements Provides contact information & methods related to: Air and Radiation; Solid Waste and Emergency Response; Sampling Methods; Water; Prevention, Pesticides, and Toxic Substances; Research and Development; Analytical and Sampling Method Sources.	http://www.epa.gov/OSA/fem/methcollectns.htm
Manual of Manuals	Quick cross-reference of EPA methods by analyte	http://www.epa.gov/nerlcwww/methmans.html
EPA Technology Transfer Network, Ambient Monitoring Technology Information Center	Monitoring Programs, Monitoring methods, Documents and articles, Trends & Non-attainment, Regulations.	http://www.epa.gov/ttnamti1/
EPA Emissions Measurement Center Air	Emission Measurement Center (EMC) provides searchable information on test methods for measuring pollutants from smokestacks and other industrial sources. This site compiles the test methods available for emission measurement, and EMC staff provides technical assistance in the use and application of the methods.	http://www.epa.gov/ttn/emc/
Air EPA Technology Transfer Network: Ambient Monitoring Technology Information Center	Operated by EPA's Ambient Air Monitoring Group (AAMG). Information on ambient air quality monitoring programs, monitoring methods, relevant documents, air quality trends and non attainment areas, and federal regulations related to ambient air quality monitoring.	http://www.epa.gov/ttn/amtic/

EPA Clean Water Act Analytical Test Methods	Analytical methods that are approved not promulgated methods, alternative methods, updated methods.	http://www.epa.gov/waterscience/methods/
Safe Drinking Water Act Analytical Methods and Laboratory Certification	Information on approved analytical methods, drinking water programs and laboratory certification.	http://www.epa.gov/safewater/methods/
EPA Microbiology Home page	EPA methods and information related to bacteria, viruses and protozoans.	http://www.epa.gov/nerlcwww/
ORD methods for water	Drinking and Marine water methods.	http://www.epa.gov/nerlcwww/ordmeth.htm#marine
Whole Effluent Toxicity (WET) Page	Methods for measuring acute toxicity and short term chronic toxicity to freshwater and marine organisms, guidance documents and regulatory actions.	http://www.epa.gov/waterscience/methods/wet/
Analytical Methods Developed by the Office of Ground Water and Drinking Water	Chemical methods for the determination of organic chemicals in drinking water.	http://www.epa.gov/safewater/methods/analyticalmethods_ogwdw.html
EPA Office of Solid Waste Test Methods	Information and guidance on analytical chemistry, testing methodologies, environmental sampling and monitoring, and quality assurance in support RCRA. SW-846 methods.	http://www.epa.gov/epaoswer/hazwaste/test/
New Test Methods On-line	new SW-846 methods are intended to be guidance methods which contain general information on how to perform an analytical procedure or technique which a laboratory can use as a basic starting point for generating its own detailed Standard Operating Procedure (SOP).	http://www.epa.gov/epaoswer/hazwaste/test/new-meth.htm
Superfund Analytical	Provides information on EPA's Superfund	http://www.epa.gov/oerrpage/superfu

Services / Contract Laboratory Program	Analytical Services/Contract Laboratory Program (CLP). Provides guidance, analyses, cost for the analyses, tools, and contacts.	nd/programs/clp/index.htm
EPA Corrective Action Guidance Page	Guidance related to RCRA (e.g. regulated hazardous waste). Provides monitoring methods for groundwater & soil screening.	http://www.epa.gov/epaoswer/hazwaste/ca/guidance.htm

*An extended table (Table S3) can be found on line. The extended table provides information on other federal agencies measurement methods websites.