PREPARATION FOR ENVIRONMENTAL MONITORING CAREERS INCLUDING ANALYSIS AND STATISTICAL ASSESSMENT OF DATA

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Contents

Summary

In order to arrest, or if possible reverse, the relentless degradation of the natural environment and life-support systems being caused by contaminant emissions from human activities for socio-economic development, it is becoming increasingly important for decision-makers at all levels to have ready access to up-to-date and reliable scientific information on how and the extent to which different compartments of the environment are being degraded. Regular or continuous measurement, collection and analysis of raw data needed for such information, as well as presentation of the processed data in a user-friendly format, belong in the scientific discipline of Environmental Monitoring. The focus of this chapter is on how those who choose Environmental Monitoring as a career ought to prepare for it, including essential skills and qualifications they must have and further scientific education and training they would need to undertake.

1. Introduction

Monitoring and assessment of environmental parameters is a task that may be subdivided in several actions which include:

- Sampling;
- chemical Analysis of Samples; and
- reporting of Analytical Data

The first two actions can be combined in the case where automatic instruments are used. The present work describes in detail the above actions.

2. Sampling

The first step in designing and implementing environmental monitoring sampling system is to define their overall objectives. Typical monitoring objectives are:

- Establishing a sound scientific basis for policy development
- Determining compliance with environmental standards
- Assessment of population/ecosystem exposure
- Assessment of environmental quality trends
- Public information
- Assessment of the effectiveness of control policies
- Forecasting (short/long-term predictions)
- Source-effect detection
- Research needs
- Environmental impact assessment
- Identification/validation of dispersion models

Once those objectives have been clearly identified, a suitable sampling plan requires that:

- Representative samples should be taken. The term "representative sample" is commonly used to denote a sample that (1) has the properties and chemical composition of the population from which it was collected and (2) contains them in the same average proportions as they are found in the population.
- Enough samples should be taken to determine the variability
- Enough replicates for each sample should be taken in order to determine the variance.

Thus, for both regulatory and scientific perspectives, the primary objective of a sampling plan is to collect samples that will allow measurements of the properties of a given environmental medium to be both accurate and precise. When the measurements are sufficiently accurate and precise, then they will be considered reliable estimates.

It is now apparent that a judgment must be made as to the degree of sampling accuracy and precision that is required to estimate reliably the measurements for the purpose of comparing those measurements, with applicable regulatory thresholds. Generally, both high accuracy and high precision are required if the measurements are close to the relative regulatory threshold. Alternatively, relatively low accuracy and low precision can be tolerated if the contaminants of concern occur at levels far below or far above their applicable thresholds. Low sampling precision is often associated with considerable savings in analytical, as well as sampling costs, while low sampling accuracy may not entail cost savings. Therefore, although it is desirable to design sampling plans to achieve only the minimally required precision, it is prudent to design the plans to attain the greatest possible accuracy.

Statistical techniques for obtaining accurate and precise samples are relatively simple and easy to implement. Sampling accuracy is usually achieved by some form of random sampling. In random sampling, every unit in the population (e.g. every site in a lake) has a theoretical equal chance of being sampled and measured. Consequently, statistics generated by the sample (e.g. the mean value) are accurate estimators of true population parameters. One of the commonest methods of selecting a random sample is to divide the population by an imaginary grid, assign a series of consecutive numbers to the units of the grid, and select the numbers to be sampled through the use of a random-numbers table.

Sampling precision is most commonly achieved by taking an appropriate number of samples from the population. From the equation of precision calculation, it is clear that increasing the number of samples increases precision. Another technique for increasing sampling precision is to maximize the physical size (weight or volume) of the samples that are collected. This has the effect of minimizing sample variation and consequently decreasing the standard deviation. Increasing the number or size of samples taken from a population, in addition to increasing sampling precision, has also the effect of increasing the sampling accuracy.

The sampling plan is usually a written document that describes the objectives and details of the individual tasks of a sampling effort and how they will be performed. Under unusual circumstances, time may not allow for the sampling plan to be documented in writing, e.g. sampling during an emergency spill. When operating under those conditions, it is essential that the person directing the sampling effort be aware of the elements of a sampling plan. The more detailed the sampling plan, the less the opportunity for oversight or misunderstanding during sampling, analysis and data treatment.

To ensure that the sampling plan is designed properly, it is wise to have all aspects of the effort represented. Those designing the sampling plan should include the following personnel:

- An end-user of the data, who will be using the data to attain program objectives and, thus, would be best prepared to ensure that the data objectives are understood and incorporated into the sampling plan.
- An experienced member of the field team who will actually collect samples, who can offer hands-on insight into potential problems and solutions, and who, having acquired a comprehensive understanding of the entire sampling effort during the design phase, will be better prepared to implement the sampling plan.
- An analytical chemist, because the analytical requirements for sampling, preservation, and holding times will be factors around which the sampling plan will be written. A sampling effort cannot succeed when an improperly collected or preserved sample or an inadequate volume of sample is submitted to the laboratory for chemical, physical or biological testing. The appropriate analytical chemist should be consulted on these matters.
- An engineer should be involved if a complex manufacturing process is being sampled. Representation of the appropriate engineering discipline will allow for the optimization of sampling locations and safety during sampling
- A statistician, who will review the sampling approach and verify that the resulting data will be suitable for any required statistical calculations and decisions.

- A quality assurance representative, who will review the applicability of standard operating procedures and determine the number of blanks, duplicates, spike samples, and other steps required to document the accuracy and precision of the resulting data base.

When a sampling plan is designed, the properties of the media which will be sampled should be considered. The following properties are important:

- Physical state: The physical state will affect most aspects of a sampling effort. The sampling device will vary according to whether the sample is liquid, gas, solid or multiphase. It will also vary according to whether the liquid is viscous or free-flowing or whether the solid is hard or soft, powdery, monolithic or clay like.
- The volume of the media to be sampled will have an effect upon the choice of sampling equipment and strategies.
- Hazardous properties: Safety and health precautions and methods of sampling and shipping will vary dramatically with the toxicity, ignitability, corrosiveness and reactivity of the waste.
- Composition: The chosen sampling strategy must reflect the homogeneity or stratification of the media in time or over space.
- Site-specific factors must be considered also when designing a sampling plan. At least one person involved in the design and implementation of the sampling plan should be familiar with the site; otherwise a pre-sampling site visit should be arranged.

The choice of sampling equipment and sample containers will depend upon the previously described environmental media and site considerations. For the following reasons, the analytical chemist will play an important role in the selection of sampling equipment:

- The analytical chemist is aware of the potential interactions between sampling equipment and container material with analytes of interest. As a result, he can suggest a material that minimizes losses by adsorption, volatilization or contamination caused by leaching from containers or sampling devices.
- The analytical chemist can specify cleaning procedures for sampling devices and containers that minimize sample contamination and cross contamination between consecutive samples.
- The analytical chemist's awareness of analyte-specific properties is useful in selecting the optimum equipment (e.g. choice of sampling devices that minimize agitation for those samples that will be subjected to analysis for volatile compounds).

The final choice of containers and sampling devices will be made jointly by the analytical chemist and the group designing the sampling plan. The factors that must be considered when choosing a sampling device are:

- Negative contamination: The possibility for the measured analyte concentration to be accidentally in error, i.e., low, because of losses from volatilization or adsorption.

- Positive contamination: The possibility for the measured analyte to be artificially high, because of leaching or the introduction of foreign matter into the sample by particle fallout or gaseous air contaminants.
- Cross contamination: A type of positive contamination caused by the introduction of part of one sample into a second sample during sampling, shipping or storage.
- Required sample volume: For physical and/or chemical analysis.
- "Ease of use" of the sampling device and containers under the conditions that will be encountered on site. This includes the ease of shipping to and from the site, ease of deployment, and ease of cleaning.
- The relative degree of hazard occurrence associated with the deployment of one sampling device versus another.
- Cost of the sampling device and of the labor for its deployment.

For each sampling plan, a quality assurance and quality control program should be enforced in order to have a proper evaluation of the measurements, regarding the accuracy and the precision.

Quality control procedures that are employed to document the accuracy and precision of sampling are:

- Trip blanks: Trip blanks should accompany sample containers to and from the field. These samples can be used to detect any contamination or cross-contamination during handling and transportation.
- Field blanks: Field blanks should be collected at specified frequencies, which will vary according to the probability of contamination or cross-contamination.
- Field duplicates: Field duplicates are collected at specified frequencies and are employed to document precision. The precision resulting from field duplicates is a function of the variance of the environmental media composition, the variance of the sampling technique, and the variance of the analytical technique.
- Field spikes: Field spikes are used occasionally, to determine the loss of parameters of interest during sampling and shipment to the laboratories.

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Biographical Sketches

Dr. Loizos Viras received his Bachelor's degree in Chemistry from the University of Athens in 1971, followed by M.Sc in Hydrocarbon Chemistry from the University of Manchester Institute of Science and Technology (UMIST) in 1973. In 1988 he received the Ph.D degree in Chemistry from the University of Athens. Since 1974 Dr Viras has been working for the Greek Ministry of Environment, Physical Planning and Public Works in the field of air quality monitoring. During 1991 and 1992 he was a visiting Scientist to the Joint Research Centre at Ispra.

During 2001 and 2004 Dr. Viras was responsible for air and noise pollution projects partly financed by the Commission of the European Communities under its Framework 3 Programme. The main areas of his scientific interest are atmospheric pollution by hydrocarbon compounds and photochemical pollution. He has several publications in these areas.

Professor Nicholas Markatos received the Diploma of Imperial College (DIC), University of London, in 1973, and Ph.D in Engineering from the same College in 1974. After working in industry for a number of years, during 1982 and 1986 he was Reader at University of Greenwich, UK, and Director of its Mathematical Modelling and Process Analysis Section. In 1986 he became Professor at the National Technical University of Athens (NTUA), Greece, Head of Chemical Engineering in 1990, and Rector of the same university during 1991 and 1997. In 2002 he was a Senior Visitor to the Department of Applied Mathematics and Theoretical Physics, University of Cambridge, UK, and Fellow of that university's Selwyn College. In 1996 he was awarded the *Doctor Honoris Causa* (Dr.H.C) degree by the University of Chemical Technology and Metallurgy, Sofia, Bulgaria. Currently he is Head of the Department of Chemical Engineering at NTUA.

Professor Markatos is consultant to a number of companies and organizations including NASA Langley Research Centre and Combustion Engineering Boeing Inc., and member of several professional organizations and associations including AIAA and New York Academy of Sciences. His main research interest is in Computational Fluid Dynamics, and Air Pollution Modeling and Control. He has published more than 150 scientific papers including 4 books.