Air Pollution Training Institute
MD 20
Environmental Research Center
Research Triangle Park NC 27711

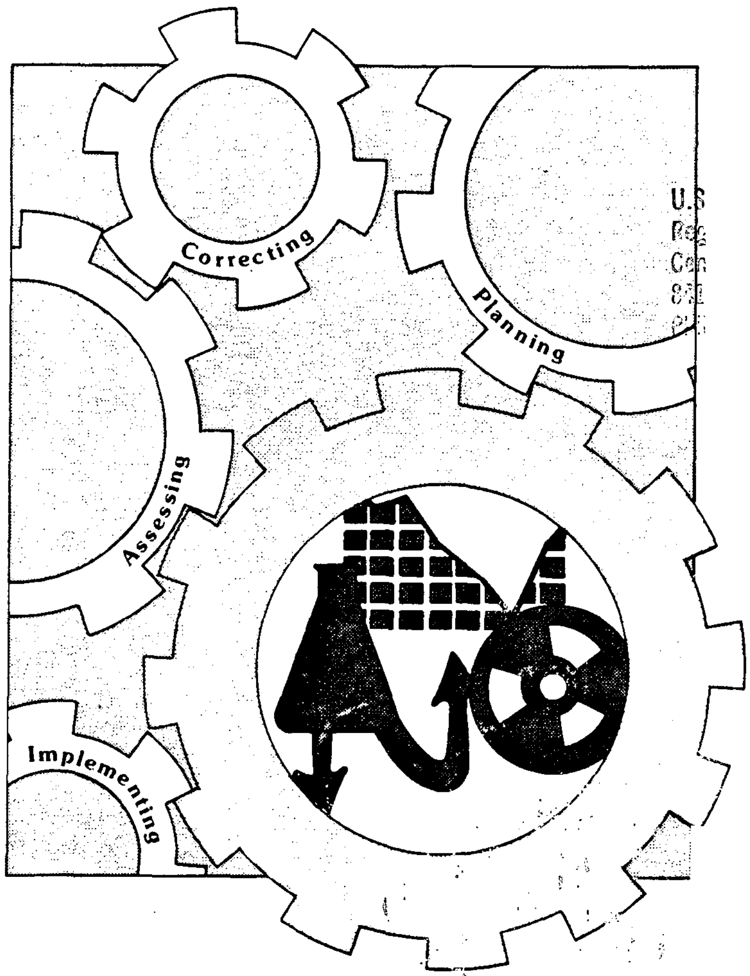
EPA 450/2-81-016
May 1984
Revised December

Air

EPA

APTI
Course 470
Quality Assurance for Air Pollution Measurement Systems

Student Workbook
Second Edition



United States
Environmental Protection
Agency

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APTI
Course 470
Quality Assurance for Air Pollution Measurement Systems

Student Workbook
Second Edition

Prepared by:
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Under Contract No.
68-02-3573
EPA Project Officer
R. E. Townsend

United States Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

Notice

This is not an official policy and standards document. The opinions and selections are those of the authors and not necessarily those of the Environmental Protection Agency. Every attempt has been made to represent the present state of the art as well as subject areas still under evaluation. Any mention of products or organizations does not constitute endorsement by the United States Environmental Protection Agency.

Table of Contents

Section 1

Registration, Course Information, and Pretest

Lesson Goal

To familiarize you with the course structure and objectives, to have you meet instructors and fellow students, to conduct the pretest, to present pertinent logistical information, and to obtain registration information.

Lesson Objectives

At the end of this lesson, you should know—

1. the course goal and objectives,
2. the requirements for passing the course,
3. the nature and use of class materials,
4. the teaching method used in the course,
5. the name of the organization conducting the course and any other contributing organization,
6. the source of the course materials and any similar information,
7. the names of all instructors and their affiliations,
8. the location of emergency exits, restrooms, telephones, refreshments, restaurants, and transportation facilities,
9. the phone number where you may receive messages during the course offering,
10. where to obtain the name and employer of each student in the class, and
11. the address and phone number of the USEPA Air Pollution Training Institute.

Notes

Course Goal

The goal of this course is to train you in quality assurance principles and techniques to the extent that you will understand the usefulness of them and be able to apply them in the development and implementation of a comprehensive quality assurance program for air pollution measurement systems.

Course Objectives

At the conclusion of this course, you will be able to coordinate the design of a comprehensive quality assurance plan for an air pollution measurement system. Specifically, you will be able to—

1. develop an organizational plan for quality assurance, including the development of an organization chart indicating those positions with major quality assurance responsibilities, the delineation of the quality assurance responsibilities for key personnel, and the development of an implementation schedule in terms of the various elements of quality assurance,
2. formulate a quality assurance policy for an air pollution monitoring organization,
3. develop objectives for a measurement process in terms of completeness, precision, accuracy, representativeness, and comparability,
4. describe the principles that should be considered in preparing quality reports to management and the quality facts that should be reported,
5. describe the kinds of training that are available to develop and maintain personnel at the level of knowledge and skill required to perform their jobs,
6. design a reporting format for quality costs that allocates quality-related activities into cost categories,
7. compare and contrast a quality assurance program plan and a quality assurance project plan in terms of their components (elements) and functions,
8. explain the importance of establishing a closed-loop corrective-action system,
9. explain the purposes for and describe how a basic document control system and a basic configuration control system should be established,
10. list the factors that should be considered in designing a preventive maintenance program,
11. describe the mechanisms that can be used to ensure the quality of procured items,
12. define the two kinds of audits recommended by USEPA and describe the steps and factors that must be considered in the design of each,
13. describe the kinds of quality control checks that should be performed on sample collection and analysis systems (manual and continuous) and what statistical analyses and records should be maintained,
14. describe the purposes of both intralaboratory and interlaboratory testing programs, the factors that must be considered in establishing the programs, and the methods of analyzing and reporting results of each program,
15. develop calibration programs incorporating the elements recommended in the *EPA Quality Assurance Handbook, Volume I,*

16. select the appropriate kinds of control charts to be used to control measurement systems, calculate control limits for them, and interpret plotted results,
17. outline the basic elements of a data qualification scheme for estimating accuracy and precision, select the appropriate statistical techniques to be used, and calculate estimates of precision and accuracy, and
18. explain the importance of timely data validation and, using appropriate techniques, develop a data validation scheme for a given air pollution monitoring system.

Name______________________ Date______________________

Course 470
Quality Assurance for Air Pollution Measurement Systems
Pretest

- This test is designed to measure your present knowledge of quality assurance for air pollution measurement systems.
- It is intended to be a ***closed-book*** test. Do not use your notes or books. You ***may*** use a calculator.
- You will have 30 minutes to complete the test.
- On the answer sheet, circle the letter that corresponds to the best answer to each question. Each question has only one "best" answer. Each correct answer is worth five points.
- The results of this test will not affect your final course grade.

1. Activities involving the use of standard reference materials would fall under which basic area of quality assurance?
   a. Management
   b. Measurement
   c. Statistics
   d. Systems
2. In addition to having good precision and accuracy, data should be ___(?)___.
   a. complete
   b. representative
   c. comparable
   d. all of the above
3. The principal objective(s) of quality assurance programs for SLAMS and PSD air monitoring is(are) to ___(?)___.
   a. provide data of adequate quality to meet monitoring objectives
   b. increase the number of quality assurance coordinators
   c. minimize loss of air quality data
   d. both a and b, above
   e. both a and c, above
4. A control chart shows ___(?)___.
   a. how a process is behaving
   b. how a process should behave
   c. when action should be taken to make a process behave as it should
   d. all of the above

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5. A check sample was analyzed each day for three months. A review of the results indicated that they were normally distributed and that 95% of the results fell between 18.0 and 24.0 ppm. Establish an upper control limit such that only 13 analyses in 10,000 should exceed the limit. The limit is __(?)__ ppm.
   a. 21.0
   b. 24.0
   c. 25.5
   d. 27.0

6. One criteria for data entering USEPA's National Aerometric Data Bank is that it must have been acquired by application of standard methodologies and reported in consistent units. That is, the data must be __(?)__.
   a. complete
   b. accurate
   c. comparable
   d. precise

7. A specific preventive maintenance schedule should relate to the __(?)__.
   a. purpose of monitoring
   b. physical location of analyzers
   c. level of operator skills
   d. all of the above

8. Independent checks made by a supervisor or auditor to quantitatively evaluate the quality of data produced by a measurement system are called __(?)__ audits.
   a. performance
   b. system
   c. calibration
   d. analysis

9. An on-site inspection and review to qualitatively evaluate the quality assurance system used for the total measurement system is called a __(?)__ audit.
   a. performance
   b. system
   c. calibration
   d. analysis

10. A quality assurance __(?)__ contains general quality assurance requirements and information for an organization.
   a. narrative statement
   b. project plan
   c. program plan

11. Results of __(?)__ are used to assess the accuracy of SLAMS and PSD air monitoring data.
   a. routine operational checks
   b. collocated sampling
   c. audits
   d. all of the above

12. ____(?)____ measurements are audited in the USEPA's interlaboratory performance audit program.
a. Ambient air
b. Source emission
c. both a and b, above

13. In a quality report, costs should be reported in terms of ____(?)____ costs.
a. prevention
b. appraisal
c. failure
d. all of the above

14. Quality reports should ____(?)____.
a. be obtained from source documents
b. have a baseline for comparison and be easy to interpret
c. present data in summary form
d. all of the above

15. During a performance audit, the ____(?)____ should convert analyzer responses to pollutant concentrations.
a. auditor
b. analyzer operator
c. analyzer operator's supervisor

16. The process of establishing the relationship between the output of a measurement process and a known input is ____(?)____.
a. determination of efficiency
b. ratiocination
c. determination of pollutant concentration
d. calibration

17. In selecting a cylinder gas to be used in a performance audit, one option is to select a high concentration cylinder and use a dilution system. The advantage of this option is ____(?)____.
a. high concentrations have better stability
b. calibration errors are small
c. the gas concentration can be analyzed before and after the audit
d. cylinders can be traced to standards of higher accuracy

18. An out-of-control condition is indicated on a quality control chart when ____(?)____.
a. one point is outside the 3-standard deviation limits
b. two consecutive points are outside the 2-standard deviation limits
c. three consecutive points are above the central line
d. either a or b, above

19. Quality assurance for a monitoring network is concerned with ____(?)____.
  a. all factors that affect the quality of data collected
  b. only field activities
  c. only laboratory activities

20. Routine data validation should include ____(?)____.
  a. checks for transmittal errors
  b. checks for spatial and temporal continuity
  c. a complete recomputation of any arithmetic
  d. both a and b, above

Name____________________ Date____________________

Course 470
Quality Assurance for Air Pollution Measurement Systems
Pretest

1. a b c d
2. a b c d
3. a b c d e
4. a b c d
5. a b c d
6. a b c d
7. a b c d
8. a b c d
9. a b c d
10. a b c
11. a b c d
12. a b c
13. a b c d
14. a b c d
15. a b c
16. a b c d
17. a b c d
18. a b c d
19. a b c
20. a b c d

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Section 2

Basic Areas of Quality Assurance Activities

Lesson Goal

To familiarize you with the four basic areas of quality assurance and the various activities that relate to each.

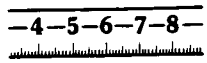
Lesson Objectives

At the end of this lesson, you should be able to—

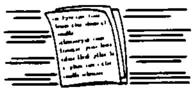
1. define quality assurance,
2. list the four basic areas of quality assurance: management, measurement, systems, statistics,
3. recognize specific activities that relate to each basic area,
4. explain the need for quality assurance to be involved with the wide scope of activities that affect air pollution data quality, and
5. explain the dynamic nature of a quality assurance program; i.e., the need for continual improvement of the program through planning, implementation, assessment, and corrective action.

BASIC AREAS OF QUALITY ASSURANCE ACTIVITIES

Management



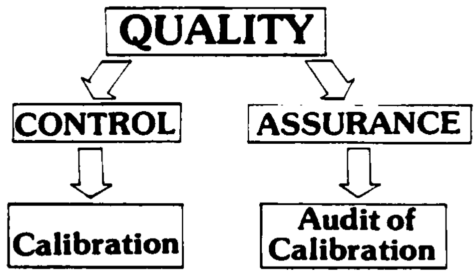
Measurement

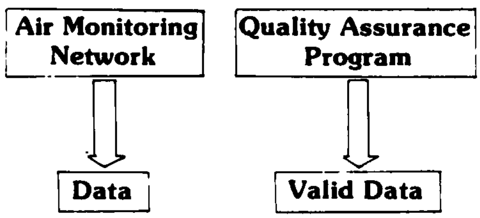


Systems

$$\bar{x} = \frac{\sum x_i}{n}$$

Statistics



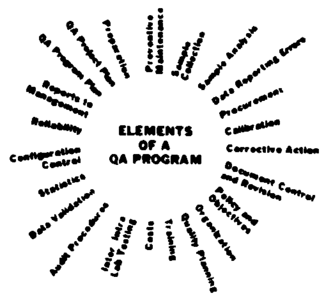


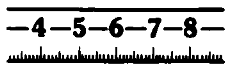
MONITORING SYSTEM

Variable	QC Activity
• method	technical procedure
• materials • machines	procurement
• maintenance	preventive/corrective
• men/women	training
• measurement	calibration procedures operating procedures

MONITORING SYSTEM

Variable	QC Activity
• monitoring sites	conditions
• mathematics	computations
• management	objectives
	policies
	procedures
• meteorology	siting
• money	quality costs





$$\bar{x} = \frac{\Sigma x_i}{n}$$

MANAGEMENT

- QA policy
- QA objectives
- organization
- training
- QA plans
- quality planning
- audit planning
- quality reports
- corrective action
- quality costs

MEASUREMENT

- pre-test preparation
- measurement system reliability
- calibration (standards traceability)
- sample collection and analysis
- audit procedures

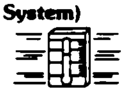
SYSTÉM INTERNATIONALE (SI)
(Metric System)

meter-m
length

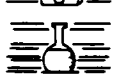
kilogram-kg
mass

second-s
time

ampere-A
electric current



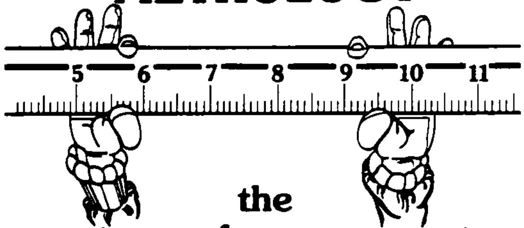
Kelvin-K
temperature



mole-mol
amount of
substance

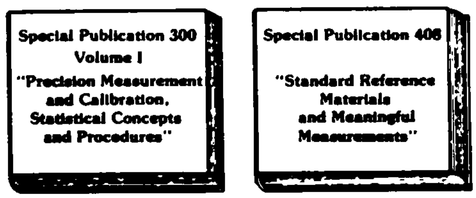
candela-cd
luminous
intensity

METROLOGY



the science of measurement

METROLOGY REFERENCES
(available from
National Bureau of Standards)



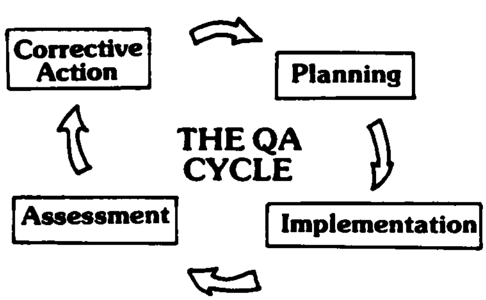
SYSTEMS

- quality planning
- procurement quality control
- document control
- preventive maintenance
- configuration control
- data handling
- data validation
- performance/ system audits
- corrective action
- quality costs

$\bar{x} = \frac{\sum x_i}{n}$

STATISTICS

- control charts
- regression analysis
- outlier tests



Attachment B

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D C 20460

THE ADMINISTRATOR

May 30, 1979

MEMORANDUM

TO: Deputy Administrator
Director, Science Advisory Board
Director, Office of Regional and Intergovernmental Operations
Regional Administrators
Assistant Administrators
General Counsel

SUBJECT: Environmental Protection Agency (EPA) Quality Assurance Policy Statement

The EPA must have a comprehensive quality assurance effort to provide for the generation, storage, and use of environmental data which are of known quality. Reliable data must be available to answer questions concerning environmental quality and pollution abatement and control measures. This can be done only through rigorous adherence to established quality assurance techniques and practices. Therefore, I am making participation in the quality assurance effort mandatory for all EPA supported or required monitoring activities.

An Agency quality assurance policy statement is attached which gives general descriptions of program responsibilities and basic management requirements. For the purpose of this policy statement, monitoring is defined as all environmentally related measurements which are funded by the EPA or which generate data mandated by the EPA.

A detailed implementation plan for a total Agency quality assurance program is being developed for issuance at a later date. A Select Committee for Monitoring, chaired by Dr. Richard Dowd, is coordinating this effort, and he will be contacting you directly for your participation and support. I know that each of you shares my concern about the need to improve our monitoring programs and data; therefore, I know that you will take the necessary actions that will ensure the success of this effort.

Douglas M. Costle

Attachment

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D C 20460

THE ADMINISTRATOR

November 2, 1981

MEMORANDUM

TO: Associate Administrators
Assistant Administrators
Regional Administrators

SUBJECT: Mandatory Quality Assurance Program

One of the major concerns of this administration and myself is that we support all of our actions and decisions with statistically representative and scientifically valid measurement of environmental quality. To meet this objective, it is essential that each of you continue to support and implement the Agency's mandatory Quality Assurance program which is being implemented by the Office of Research and Development. It is especially essential that you assure that the appropriate data quality requirements are included in all of your extramural and intramural environmental monitoring activities. I also am particularly concerned that you do not sacrifice quality for quantity when adjusting your program to meet our new resource targets.

The attached Second Annual Quality Assurance Report demonstrates the importance of this program in achieving our goals and objectives. Recognizing its importance, I have asked Dr. Hernandez to closely monitor this program's implementation and advise me of any problems that affect the scientific data bases of the Agency.

Anne M. Gorsuch

Attachment

cc: Deputy Administrator
Office Directors

CHALLENGES OF IMPLEMENTING QUALITY ASSURANCE FOR AIR POLLUTION MONITORING SYSTEMS

Raymond C. Rhodes
Quality Assurance Specialist

S. David Shearer, Jr., Ph.D.
Director

ABSTRACT

Special considerations are necessary in implementing a quality assurance system for air pollution monitoring. Of particular concern are the following:

(1) Quality characteristics of environmental data.
(2) Network design and sampling.
(3) Measurement methods and standard reference materials.
(4) Statistical quality control.
(5) Data analysis and validation.
(6) Preventive maintenance

Accuracy, precision, completeness and representativeness are the quality characteristics of air monitoring data. The physical sampling of the air environment presents a number of unique and difficult problems. The technology of air pollution measurement has created special demands for measurement methods and standard reference materials. Because of the variability patterns of pollution data, and the non-uniform error variability of the measurement methods, particular types of statistical control and data analysis and data validation are required. The wide diversity in the scope and requirements of compliance and research monitoring makes it necessary to develop flexible quality assurance procedures. In spite of the many difficulties involved, much is being accomplished in implementing quality assurance for air pollution monitoring systems.

INTRODUCTION

With the increased interest and activity in the environment in recent years, a need exists to apply the principles and techniques of modern quality assurance to the various pollution monitoring systems. Pollution measurement methods involve field sampling and chemical laboratory analyses and, to these portions of the measurement process, most of the traditional laboratory quality control (Q.C.) techniques apply. Of concern, however, is the need to apply the general principles and techniques to the entire monitoring system.

The following elements of quality assurance (Q.A.) system are generally applicable to pollution monitoring systems:

Elements of a Quality Assurance System [2,8]

1. Quality Policy
2. Quality Objectives
3. Quality Organization and Responsibility
4. Quality Assurance Manual
5. Quality Assurance Plans
6. Training
7. Procurement Control
   - Ordering
   - Receiving
   - Feedback and Corrective Action
8. Calibration
   - Standards
   - Procedures
9. Internal Q.C. Checks
10. Operations
    - Sampling
    - Sample Handling
    - Analysis

11. Data
    Transmission
    Computation
    Recording
    Validation
12. Preventive
    Maintenance
13. Reliability Records
    and Analysis
14. Document Control
15. Configuration Control
16. Audits
    On-Site System Audits
    Performance Audits
17. Corrective Action
18. Statistical Analysis
19. Quality Reporting
20. Quality Investigation
21. Interlaboratory Testing
22. Quality Costs

However, in a number of very important areas, special considerations must be made. These areas, which require special attention are:

1. Quality Characteristics of Environmental Data.
2. Network Design and Sampling.
3. Measurement Methods and Standard Reference Materials.
4. Statistical Quality Control.
5. Data Analysis and Validation.
6. Preventive Maintenance.

The ultimate uses of air pollution monitoring information are decisions relative to human health and welfare. Air pollution monitoring data are used as measures of air quality to make the best decisions for human health and welfare.

The quality of air is measured by the cleanliness of the air—Are the pollutant concentrations below the levels established as standards? The quality of air pollution data is measured by the accuracy, precision, completeness and representativeness of the data.

QUALITY CHARACTERISTICS OF ENVIRONMENTAL DATA

These quality characteristics of data may be defined as follows:

1. Accuracy—The closeness of a measured value to the true value.
2. Precision—The repeatability of the data (actually the repeatability of the measurement system).[4]
3. Completeness—The amount of valid data obtained as a fraction of that intended or planned to be obtained.
4. Representativeness—The typicalness of the pollution samples with respect to time, location, and conditions from which the pollutant data are obtained.

These quality characteristics are not evident nor can they be determined from examination of the data itself. Measures of accuracy, precision, completeness, and representativeness must be obtained from other information. Provision for obtaining measures of these characteristics must be included in the Quality Plan for each monitoring effort because the relative importance of accuracy, precision, completeness, and representativeness depends upon the specific objectives of each monitoring program.

NETWORK DESIGN AND SAMPLING

The monitoring network design, which incorporates decisions with respect to time, location and conditions of sampling, along with the specification of pollution measurement methods and equipment, specify to a large extent the "process" of obtaining monitoring data. Quality assurance personnel should be involved with the network design for pollution monitoring because of the statistical aspects involved, and because of the need to establish the best possible network at the beginning of a monitoring effort. Changes in monitoring networks can destroy the previous history or baseline necessary for trend studies.

The process or media being sampled for air pollution measurement is not in statistical control, but is subject to many effects such as diurnal cycles, day-of-week differences, seasonal cycles, and local and area meteorological factors. The changing pattern of air pollution is a dynamic process, sometimes "out of control."[6] The objective of a quality assurance program for air monitoring is to assure that the *measurement system* remains "in control," no matter what the state or condition of the air.

Consideration for temporal and spatial effects in the location and scheduling of pollution sampling are critical concerns with respect to representativeness.

Planning of the network design and sampling schedules are very important since resampling in air monitoring is impossible. The air which was at the sampling point a moment ago is no longer available! Although duplicate sampling is desirable, in air monitoring, duplicate sampling is not possible for particulates, and is not very practical for gaseous pollutants. The most satisfactory way of duplicate sampling for quality assurance purposes is to use duplicate sampling equipment at the same site. Although such dual sampling requires an additional sampling instrument, this procedure is invaluable in estimating the precision of the total measurement process.

In most chemical analytical work duplicate analyses are desirable. However, for continuous, automated pollution analysis instruments, reanalysis is not possible. Reanalysis is possible for some of the manual methods where bubbler solutions or filter media have been used to collect the pollutants.

MEASUREMENT METHODS AND STANDARD REFERENCE MATERIALS

Most of the manual analytical measurement methods for gaseous pollutants involve bubbling the air through selective absorbing solutions for an extended period (usually 24 hours) and then analyzing the solution by wet chemical/absorbance techniques. These methods have the limitation of providing daily averages only. In the interest of obtaining more accurate measurements on a short-time basis, numerous automated instrumental methods have been developed in recent years. Problems with these instruments include the manufacturing and reliability problems associated with newly-designed equipment, and the technological problems of measuring minute concentrations (parts per million or parts per billion) in the presence of possible interferents. Further, problems arise relating to the stability and reliability of these instruments if operated remotely or unattended. The development of completely satisfactory measurement methods is a very important effort of quality assurance for air monitoring. Because of the instability of gaseous mixtures, primary standards (Standard Reference Materials of the National Bureau of Standards) are difficult to prepare, and must be prepared and assessed from time to time as required by users. For some gases (for example, ozone), no primary standard has yet been developed. Neither has a particulate standard for particle size or chemical content in a naturally-occurring matrix yet been developed. Because of the problems in developing and using primary standards for air pollution measurement, the achievement of comparability for accuracy among the various agencies and facilities within a country is not an easy task and this concern is further magnified when comparability among different countries is considered. In most other physical measurement areas, comparability among nations is relatively easily achieved through traceability to common primary standards.

STATISTICAL QUALITY CONTROL

In traditional quality control systems much importance is placed on the establishment of average and range ($\bar{X}$, R) control charts to control quality. Averages are obtained from measurement of a sample from some assumed homogeneous rational sub-group of products. In this way, the average is used as a measure and means of control of the level of the quality characteristic and the range of the measurements is used as a measure and means of control of variability. Except in the laboratory, batches or rational sub-groups seldom exist in pollution measurement; and even in these cases, replication is accomplished usually on a duplicate basis only, such as duplicate measures of the same sample, duplicate analyses by different analysts, or measurement from duplicate collocated sampling instruments. Further, except for repeated measurements of homogeneous control samples, the averages of the duplicates vary depending upon the concentration level. Therefore, the $\bar{X}$ chart is of little value in quality control for pollution measurements.

Further, in the cases of duplicate data, some identity can usually be associated with each of the pair of measurements, so that the range is not the best value of interest. Because of suspected bias between the two sources, *signed* differences should be used rather than the unsigned range. Further, since the average levels may vary widely between pairs, and the error variation is usually proportional to levels, the value of concern is the *signed percentage* difference (or signed relative difference). This value is an appropriate parameter to plot on control charts as a means to control variability of the measurement process.

Control on the accuracy of the data must be maintained by frequent calibrations with materials traceable to primary standards. Some type of calibration is usually required on air pollution measurement systems daily or for each use, and occasionally calibration is necessary before, during and after analysis of a given batch of samples. Control charts which may be maintained to assure that the calibration process remains in statistical control are those for the slope, intercept, and standard error of prediction for the calibration curves for multipoint calibrations, and zero and span drift checks to control the drift of continuous instruments.

DATA ANALYSIS AND VALIDATION

A number of special considerations exist in air pollution measurement systems with respect to data analysis and data validation. For most air pollution measurements, the error variations are proportional to the pollutant concentration level, thus complicating error analysis of the measurement system.

The aggregate frequency distributions of air pollution data are skewed, often lognormal or nearly so, requiring logarithmic or other transformations when summarizing or analyzing data distributions.[1,3] Complications arise when taking logarithms of zero values! Also, special treatment of data below the minimum detectable levels may be required in the characterization or summarization of air pollution data.

Because of the many possible causes of variability in air pollution data, the data validation process as a separate activity is very important in air monitoring.[5] Since the quality of the data is not evident from the data itself, the routine checks of ancillary data for accuracy and precision must be made. Some further checks of the data with relation to other data or information may be made to validate the final product. Various types of checks which can and should be made include:

Manual Editing—checks for human error or equipment malfunction, such as:

1. impossibly high or low values,
2. spikes, such as caused by electronic interference, and
3. repetitious values, such as caused by equipment malfunction.

Scientific Validation—checks involving scientific considerations, such as:

1. time continuity,
2. spatial continuity,
3. relationships among different pollutants, and
4. relationships with meteorological data.

PREVENTIVE MAINTENANCE

Preventive maintenance activities are not usually considered as part of quality assurance. However, for air pollution monitoring systems, the effectiveness of preventive maintenance is critical in determining the continuous operation of remote, unattended sampling equipment, particularly automatic sampling/analysis instruments. Unplanned malfunctioning of these instruments can prevent the obtaining of sample results for peak concentration periods, or prevent the accumulation of sufficient data to establish valid trend information.

Needless to say, all the above special and important features indeed make implementation of quality assurance of air pollution monitoring systems an interesting, but difficult and challenging effort.

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QUALITY ASSURANCE FOR POLLUTANT MONITORING

by

R. C. Rhodes

An on-going monitoring system will already have implemented a number of essential elements of a total quality assurance system. When reviewing an existing monitoring operation or when establishing a new monitoring effort, it is very desirable that a systematic review be made to consider or reconsider the quality assurance activities which should be required.

The various elements of a total quality assurance program, listed below, are discussed in the "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I, Principles," EPA 600/9-76-005, March 1976.

- Quality policy
- Quality objectives
- Quality organization and responsibility
- QA manual
- QA plans
- Training
- Procurement control
  - Ordering
  - Receiving
  - Feedback and corrective action
- Calibration
  - Standards
  - Procedures
- Internal QC checks
- Operations
  - Sampling
  - Sample handling
  - Analysis
- Data
  - Transmission
  - Computation
  - Recording
  - Validation
- Preventive maintenance
- Reliability records and analysis
- Document control
- Configuration control
- Audits
  - On-site system
  - Performance
- Corrective action
- Statistical analysis
- Quality reporting
- Quality investigation
- Interlab testing
- Quality costs

The extent to which each of the above elements should be implemented by a given agency will depend upon (1) the objective of the monitoring, (2) the duration of the monitoring period, and (3) the type of sampling/analysis methods utilized. Each monitoring agency should review the quality assurance elements with respect to their particular needs, and should establish a prioritized long-range plan (schedule) for implementation. For on-going monitoring efforts the quality assurance program should be dynamic in nature, being continually improved and revised according to increased knowledge, changing conditions, and assigned priorities.

The elements listed above fall into 4 general categories:

(1) *Management*—those activities which are of particular concern to, and must be initiated and sustained by management, notwithstanding the fact that all activities of a monitoring system are management's responsibility.

(2) *Measurement*—those activities which are directly involved in the sampling and analysis of pollutant concentrations.

(3) *Systems*—those activities mainly involving the paperwork systems essential to operate and support the quality assurance system.

(4) *Statistics*—those computational and statistical analysis techniques and procedures which are necessary as part of the quality assurance system.

From the above, it is evident that a total quality assurance program is concerned with all activities which may affect the quality of the monitoring data, and is not limited in a very narrow sense to essential calibrations and a few routine duplicate analytical checks.

Management. It is obvious that management's responsibilities should include a stated written *policy* and *objectives* concerning quality. The need for monitoring data of high quality must be continually made evident by the management with a continual awareness of such need by all the people whose activities affect the quality of the data. One individual of the *organization* should be specifically designated and assigned the *responsibility* to oversee all quality assurance activities, even though the individual may have other assigned duties, and even though "Quality assurance is everybody's business." This individual should be designated as the "Quality Assurance Coordinator."

Management should establish *training* requirements for each individual whose activities affect quality. Detailed systematic written *plans* should be prepared summarizing the various quality control checks made for each pollutant measurement method or special project. A *manual* containing administrative-type procedures applicable to all measurement methods and projects and to general quality assurance activities should, in time, be prepared to consolidate in one document all quality-related procedures. The manual should incorporate the above-mentioned plans by reference.

Management, obviously, is concerned with costs. And after operation of a monitoring system for, say, a year, a systematic review should be made of the *costs related to quality*, to assess the cost-effectiveness of these activities, and to make indicated changes in expenditures of effort to obtain the most high quality data for the least cost.

Additionally, management should establish some type of periodic (say quarterly) *report* summarizing quality assurance activities and providing some continual assessment or measure of data quality. This report should be prepared by the Quality Assurance Coordinator.

Measurement. Various EPA guideline documents* have been prepared for each measurement method. These documents provide the identification of *calibration standards* and detailed *procedures for calibration* for each of the methods. Also included in these documents are detailed *procedures* and *internal quality control checks* which should be made for the *sampling, sample handling,* and *analysis* for each of the methods.

It may be economically prohibitive to implement all of the recommended checks of these documents, at least initially. Specific minimum checks for ambient methods are included in EPA 600/4-77-027a, "Quality Assurance Handbook for Air Pollution Measurement Systems," Volume II, Ambient Air Specific Methods, May 1977. Specific minimum checks for source emission methods are included in EPA 600/4-77-027b, "Quality Assurance Handbook for Air Pollution Measurement Systems," Volume III, Source Emission Specific Methods, August 1977. Some judgment may need to be exercised as to which checks seem to be most critical and need to be implemented first. However, it is best to implement more checks at a lesser frequency than to concentrate heavily on just a few. The frequency of quality control checks should be flexible, being increased for those which by experience seem to give most problems, and being decreased for those which seem consistently to remain "in control." Similar reasoning applies with respect to the types and frequencies of independent *performance audits* described in the guideline documents.

One essential for obtaining high quality data is the *procurement* of measurement equipment and materials of adequate quality. Adequate specifications should be included in the procurement *ordering* documents, and the equipment and materials should be given adequate inspection when *received*. Generally, procured items should not be paid for until after they have been determined to meet the specifications. Obviously, those methods and equipment designated or specified by the government as official for determining compliance to ambient air or source standards should be strictly and consistently complied with.

*EPA R4-73-028, Environmental Monitoring Series (for ambient monitoring methods)
EPA 650/4-74-005, Environmental Monitoring Series (for source emission monitoring methods)

One part of the measurement method which may not receive adequate attention is that for flow measurement. For those methods which require flow measurement, the flow measurement is equally as important as the pollutant measurement.

A critical requirement of the measurement method (for pollutant and flow) is the use of secondary reference standards for calibration, traceable to a national or international primary standard.

Systems. Detailed, systematic and meticulous records need to be kept concerning all of the necessary measurements and computations integrally involved with the measurement process. Of equal importance is the recordkeeping concerning (1) the written procedures for calibration, operation and computations, (2) *preventive maintenance* procedures and records, and (3) measurement equipment records. A *document control* system should be established to identify by number and date each written procedure or revisions thereof so that the exact procedure used at any specified time (past and present) can be determined. A *configuration control* system should be established to record the nature and dates of any changes in the hardware design, or major corrective maintenance of the sampling, sample handling, and analysis equipment. These records should be kept by manufacturer's serial number or an agency-assigned identification number. Such records should enable one to determine for any past and present time, the exact configuration of any specific piece of equipment. Also considered as part of a configuration control system is the site assignment history for each piece of identified sampling equipment.

Recordkeeping systems are essential to record changes to the procedures and equipment of the monitoring system. Experienced quality assurance and statistical personnel are suspicious of the possible effects of changes to the total measurement process. Their motto might well be "CAVE VICISSITUDINES" or "CAVE VARIETAS."* Oftentimes, seemingly innocuous changes may cause significant changes in the results. As a precaution against the introduction of such undesirable effects into the system, the basic principle of performing overlap checks or comparisons should be made to assure that such changes are appropriately valid.

Statistics. The use of statistical analyses is essential to an adequate quality assurance system. Some of the more basic statistical applications are presented in APTD 1132, "Quality Control Practices in Processing Air Pollution Samples." Other applications are included in the Appendices to EPA 600/9-76-005. If a given agency does not have a person with some training and experience in the basic statistical applications presented in these documents, either (1) an individual of the agency with mathematical capability should attend a course to receive such training or (2) a statistician experienced in these applications should work with individuals of the agency on a temporary consulting basis to establish such techniques and provide such training. The applications of statistics to air monitoring extend from the simplest (control charts) to the very complex (modeling and computer simulation) and are limited only by the statistical and computation capability of available personnel and resources. The techniques of *data validation* and equipment *reliability analyses* are several specific applications of value to a local agency.

In addition to the above, several points deserve further emphasis with respect to the accuracy and precision of the measurement system. In addition to the use of good calibration standards and procedures, *interlaboratory* tests, such as the exchange of stable samples between peer laboratories, or the dissemination of blind samples from some recognized national or international laboratory is quite valuable in determining the accuracy of participating agencies. Such testing may reveal weaknesses in the system which would require special *quality investigations*. The use of statistics in planning such studies and in analyzing the data therefrom, is emphasized.

*CAVE VICISSITUDINES: Beware of changes
CAVE VARIETAS: Beware of differences

An excellent way to check the internal precision of an agency's system, is to establish at one (or a few) selected cities a dual or colocated sampling instrument for each measurement method.* This type of duplicate check is one form of the independent *performance audits* described in the EPA QA Guidelines document for manual integrated methods. The duplicate sampling instruments should be maintained as independently as possible from the regular instrument. For example, where possible, independent calibrations and flow measurements should be made for the colocated duplicate instrument. Similarly, for integrated manual methods the pollutant analyses should be performed as independently as possible in the laboratory. For example, the samples from the colocated instrument should be analyzed on a different batch (using a different calibration) from that in which the regular sample is analyzed. In the above-described manner, the best possible estimate for within-agency precision for the total measurement process can be made. Excessive differences in results between the paired instruments will indicate weaknesses in the system which should be isolated by investigation and corrected by appropriate *corrective action*.

As a part of the recordkeeping system, each agency should compile (or maintain) a "Significant Event History." Documentation of the location, nature, dates and times of special events affecting pollutant concentrations should be kept in a systematic chronological file. Such events which might explain unusual results would be those such as dust storms, large fires, construction work, etc.

Quality Assurance System Review. On occasion, the Quality Assurance System of a given monitoring agency may be subject to an *on-site system audit* or review by an external organization, for the purpose of evaluating the capability of the agency to produce data of acceptable quality. Such an independent review is made of the agency's facilities, equipment, personnel, organization, procedures, etc. by persons knowledgeable in both quality assurance technology and the measurement technologies involved. The audit should include a review of the agency's actual operations, procedures and recordkeeping for all of the elements of quality assurance system discussed herein. The audit team's evaluation should include specific identification of areas of weakness and specific recommendations for improvement.

*This technique may be cost prohibitive for continuous instruments.

Section 3

Managerial Quality Assurance Elements for Establishing a Quality Assurance Program and Recording Changes

Lesson Goal

To familiarize you with managerial quality assurance elements involved in establishing a quality assurance program and recording changes in an air pollution monitoring system.

Lesson Objectives

At the end of this lesson, you should be able to—

1. list the quality assurance elements that are involved in establishing a quality assurance program and discuss the factors that should be considered in their implementation,
2. list the quality assurance elements that are involved in recording changes in an air pollution monitoring system,
3. explain the purpose of document control and design a basic document control system,
4. explain the purpose of a configuration control system, and
5. explain the purpose of preventive maintenance and discuss the factors that should be considered in designing a preventive maintenance system.

MANAGERIAL QUALITY ASSURANCE ELEMENTS

- Establishing a quality assurance program
- Recording changes in the air quality monitoring system

ESTABLISHING A QUALITY ASSURANCE PROGRAM

- policy and objectives
- organization
- quality assurance plans
- training
- audit procedures
- corrective action
- reports to management

QUALITY ASSURANCE POLICY AND OBJECTIVES

Each organization should have a written quality assurance policy that should be made known to all organization personnel

QUALITY ASSURANCE OBJECTIVES

- Data meeting user requirements
  - completeness
  - precision
  - accuracy
  - representativeness
  - comparability

QUALITY ASSURANCE OBJECTIVES

- Data are complete if a prescribed percentage of total measurements is present.
- Precision - spread of data
- Accuracy - nearness to true value

QUALITY ASSURANCE OBJECTIVES

- Data must be representative of the condition being measured (example: ambient sampling at midnight is not representative of CO during rush-hour traffic)
- Data from several agencies should be in the same units and corrected to the same conditions (temperature and pressure) to allow comparability among groups

ORGANIZATION

Quality assurance is normally a separate function in the organization

BASIC FUNCTIONS OF QA ORGANIZATION

QA Policy Formulation

- agency policy
- contracts
- procurement
- staff training and development

QA GUIDANCE AND ASSISTANCE

- laboratory operations
- monitoring network operations
- data reduction
- special field studies
- instrument maintenance and calibration

QA GUIDANCE AND ASSISTANCE

- preparation of legal actions
- source emission testing
- development of control regulations
- preparation of technical reports

TRAINING

- essential for all personnel in any function affecting data quality
  - sample collection
  - analysis
  - data reduction
  - quality assurance

TRAINING

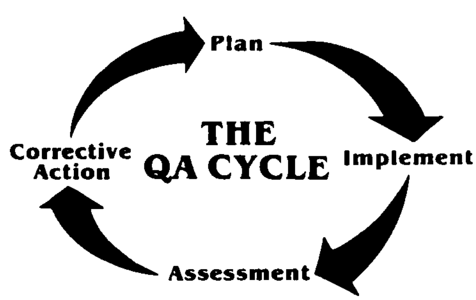
- on-the-job training (OJT)
- short-term course training (normally 2 weeks or less)
- long-term course training (quarter or semester in length)

AUDIT PROCEDURES
Performance Audits

- independent checks
- made by supervisor or auditor
- evaluate data quality of total measurement system
- quantitative appraisal of quality

AUDIT PROCEDURES
System Audits

- on-site inspection and review of quality assurance system
- qualitative appraisal of quality



QUALITY REPORTS TO MANAGEMENT

Quality data usually reported:

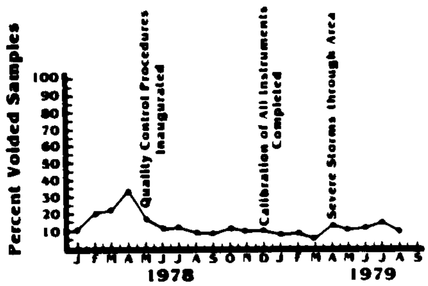
- percentage duplication or replication of determinations
- instrument or equipment downtime
- percentage voided samples versus total samples
- quality cost in terms of prevention, appraisal, and correction costs

QUALITY REPORTS TO MANAGEMENT

Quality data usually reported:

- system audit (on-site inspection) results
- performance audit results
- interlaboratory test results and intralaboratory test results (precision and accuracy)
- status of solutions to major quality assurance problems

GRAPHIC REPORT TO MANAGEMENT



A SYSTEM FOR RECORDING CHANGES IN THE MONITORING SYSTEM IS NEEDED

- for written procedures - document control
- for design and location of the monitoring system - configuration control
- for routine service after operation has begun - preventive maintenance

DOCUMENT CONTROL SYSTEM

Purpose:

To provide the latest written procedures to all concerned personnel

DOCUMENT
CONTROL SYSTEM

Should include:

- an easy way to make changes
  - removable pages
  - easily identifiable pages

  indexed by Section #
  Revision #
  Date
  Page #
  Total pages

DOCUMENT CONTROL SYSTEM

Should include:

- a distribution record system

DOCUMENT CONTROL SYSTEM

A new table of contents should be distributed with each revision

CONFIGURATION CONTROL SYSTEM

To record changes in equipment and the physical arrangement of equipment

CONFIGURATION
CONTROL SYSTEM

Purpose:

- Provide a history of changes during the life of a monitoring project
- Provide design and operational data on the first monitoring equipment or system when multiples are planned

PREVENTIVE MAINTENANCE

An orderly program of positive actions for preventing failure of a monitoring system

- cleaning equipment
- lubricating
- reconditioning
- adjusting
- testing

PREVENTIVE MAINTENANCE

Increased Measurement System Reliability

⬇

Increased Data Completeness

DEVELOPMENT OF A PREVENTIVE MAINTENANCE PROGRAM

- review equipment - highlight items most likely to fail
- define spare parts list
- define frequency for servicing
- prepare a checklist

DAILY CHECK LIST FOR NO_2 ANALYZER

City ______________
Site location ______________
Site number ______________
Serial number ______________

At last calibration	NO	NO_2
Scale range		
Zero knob setting		
Span knob setting		

Date last calibration

	Date	Mon	Tues	Wed	Thur	Fri	Sat	Sun
	Oxygen pressure - lbs.							
	Oxygen cylinder pressure							
	Unadjusted NO zero reading							
	Unadjusted NO_2 zero reading							
	NO zero knob setting (new)							
	NO span knob setting							
	NO_2 zero knob setting (new)							
	NO_2 span knob setting							
✓	Valve in NO-NO_x, NO_2 position							
✓	NO-NO_x range in 0.5 position							
✓	Inspect oxygen line							
✓	Inspect inlet line, probe & filter holder	✓						
	Vacuum gauge reading							
	Comments or problems:							
	Operator initial							

Section 3A

Review of Precourse Problem 3

Lesson Goal

To ensure that you can perform the calculations assigned in precourse problem 3.

Lesson Objectives

At the end of this lesson, you should be able to calculate—

1. arithmetic mean, $\bar{x}$;
2. standard deviation, s;
3. range, R;
4. geometric mean, $\bar{x}_g$; and
5. geometric standard deviation, s_g.

Section 4

Basic Concepts of Statistical Control Charts

Lesson Goal

To familiarize you with basic concepts in developing and using control charts.

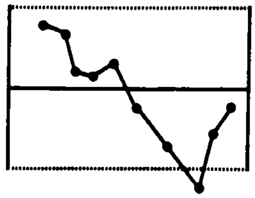
Lesson Objectives

At the end of this lesson, you should be able to—

1. describe a control chart based upon a period of acceptable performance,
2. distinguish between assignable (non-random) and unassignable (random) causes of variation,
3. describe steps in developing a control chart system,
4. describe the characteristics of a normal (Gaussian) frequency distribution, and
5. describe considerations in using control charts.

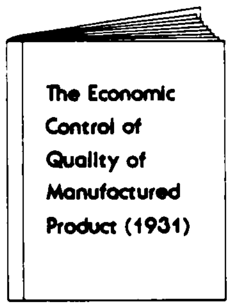
CONTROL CHART

- how a process should behave
- how a process is behaving
- when action should be taken to make the process behave as it should



Walter A. Shewhart

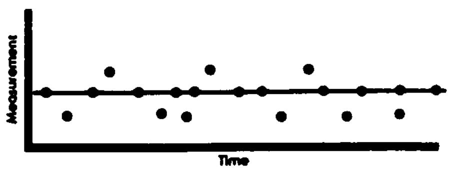
Bell Telephone Laboratories



"CONSTANT CAUSE" SYSTEM

A system in which we measure something whose variability remains constant

Measurements will vary over time due to random variations.

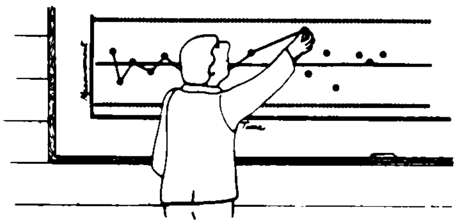


RANDOM VARIATIONS	NONRANDOM VARIATIONS
• unassignable	• assignable
• statistical control	• out-of-control

OBJECTIVES OF A CONTROL CHART

- detect assignable causes
- trigger investigation leading to corrective action

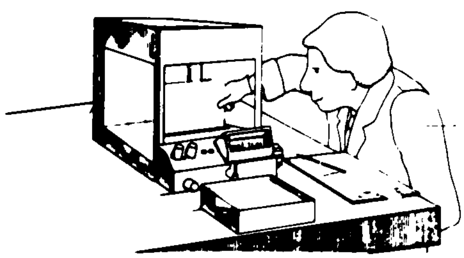
DEVELOPMENT AND USE OF A CONTROL CHART



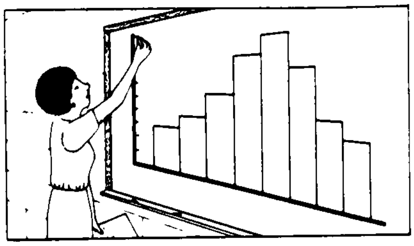
1. Determine what data to chart
2. Accumulate data
3. Prepare histogram
4. Determine form of frequency distribution
5. After eliminating outliers, calculate mean and standard deviation
6. Establish limits
7. Construct chart
8. Plot points
9. Highlight out-of-control conditions
10. Take corrective action
11. Revise control limits
12. Maintain historical file

Determine what data to chart

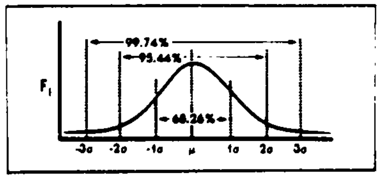
Accumulate data



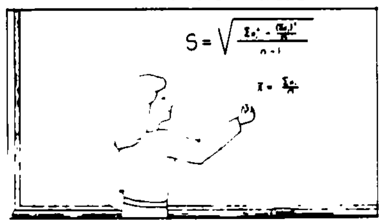
Prepare histogram



Determine form of frequency distribution



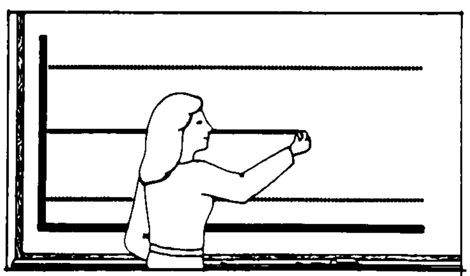
After eliminating outliers, calculate mean and standard deviation



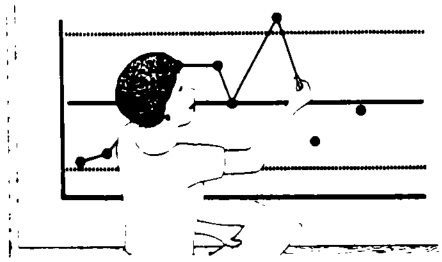
Establish limits

	control	warning
USA	$\pm 3\sigma$	$\pm 2\sigma$
	99.7%	95:4%
British	$\pm 3.09\sigma$	$\pm 1.96\sigma$
	99.8%	95.0%

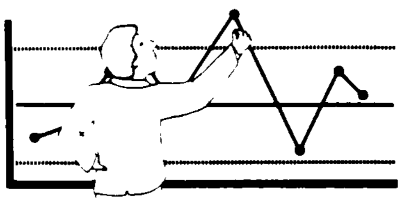
Construct chart



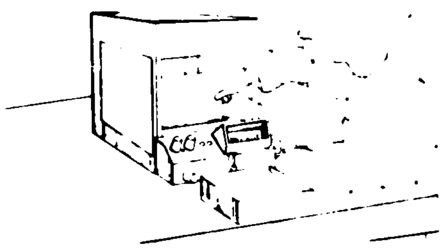
Plot points



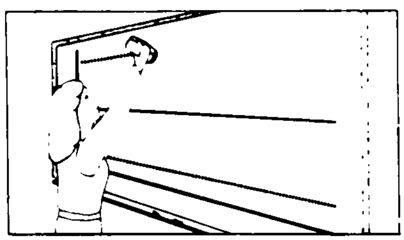
Highlight out-of-control conditions



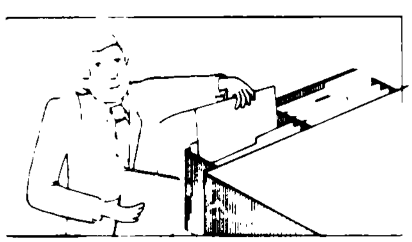
Take corrective action



Revise control limits



Maintain historical file



Section 5

$\bar{x}$-R Statistical Control Charts

Lesson Goal

To familiarize you with the preparation and use of $\bar{x}$-R statistical control charts.

Lesson Objectives

At the end of this lesson, you should be able to—

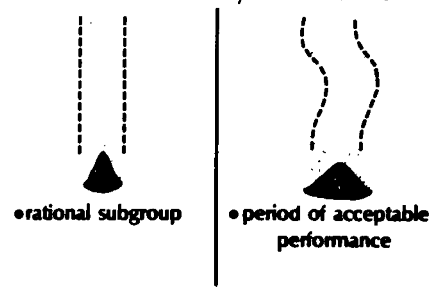
1. explain the Shewhart concept of local control (i.e., use of rational subgroups) as a basis for developing control charts,
2. distinguish between situations involving rational subgroups and situations where no rational subgroups exist,
3. distinguish between control charts that are based upon only a period of acceptable performance and control charts that are based upon rational subgroups,
4. compute control limits for $\bar{x}$-R control charts,
5. recall three rules for detecting out-of-control data points,
6. describe five types of out-of-control patterns that can be visually detected using a control chart, and
7. list three assumptions concerning the detection and correction of assignable causes of measurement-process variability.

LOCAL STATISTICAL CONTROL
Shewhart

Control limits based on:

- short term rational subgroups
- small or homogeneous variation

Control charts may be based on:



CONSTRUCTING A $\bar{x}$-R CONTROL CHART

- identify rational subgroup
- calculate subgroup arithmetic mean ($\bar{x}$) and range (R)
- calculate overall average arithmetic mean ($\bar{\bar{x}}$) and average range ($\bar{R}$)
- use factors to establish control limits for two control charts ($\bar{x}$ and R)
  - $\bar{x}$ chart controls between-subgroup variability
  - R chart controls within-subgroup variability

$\bar{x}$ CHART CONTROL LIMITS

$$UCL_{\bar{x}} = \bar{\bar{x}} + (A_2)(\bar{R})$$

Where:

$\bar{\bar{x}} = 29.92$

$A_2 = 1.88$ (for subgroups containing two data values)

$\bar{R} = 4$

$UCL_{\bar{x}} = 29.92 + (1.88)(4)$

$UCL_{\bar{x}} = 37.44$

$$LCL_{\bar{x}} = \bar{\bar{x}} - (A_2)(\bar{R})$$

$$LCL_{\bar{x}} = 29.92 - (1.88)(4)$$

$$LCL_{\bar{x}} = 22.40$$

$$UWL_{\bar{X}} = \bar{\bar{X}} + \left(\tfrac{2}{3}\right)(A_2)(\bar{R})$$

$$UWL_{\bar{X}} = 29.92 + \left(\tfrac{2}{3}\right)(1.88)(4)$$

$$UWL_{\bar{X}} = 34.93$$

$$LWL_{\bar{X}} = \bar{\bar{X}} - \left(\tfrac{2}{3}\right)(A_2)(\bar{R})$$

$$LWL_{\bar{X}} = 29.92 - \left(\tfrac{2}{3}\right)(1.88)(4)$$

$$LWL_{\bar{X}} = 24.91$$

R CHART CONTROL LIMITS

$$UCL_R = (D_4)(\bar{R})$$

Where:

$D_4 = 3.27$ (for subgroups containing two data values)

$\bar{R} = 4$

$UCL_R = (3.27)(4)$

$UCL_R = 13.08$

$$LCL_R = (D_3)(\bar{R})$$

Where:

$D_3 = 0$ (for subgroups containing two data values)

$\bar{R} = 4$

$LCL_R = (0)(4)$

$LCL_R = 0$

$$UWL_R = (D_6)(\bar{R})$$

Where:

$D_6 = 2.51$ (for subgroups containing two data values)

$\bar{R} = 4$

$UWL_R = (2.51)(4)$

$UWL_R = 10.4$

$$LWL_R = (D_5)(\bar{R})$$

Where:

$D_5 = 0$ (for subgroups containing two data values)

$\bar{R} = 4$

$LWL_R = (0)(4)$

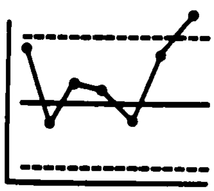
$LWL_R = 0$

- construct $\bar{x} - R$ control chart
  - draw control and warning limits
  - plot individual $\bar{x}$'s and R's
- use prepared $\bar{x} - R$ control chart for evaluating future $\bar{x}$'s and R's

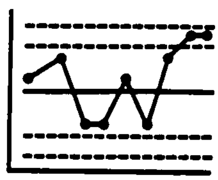
OUT-OF-CONTROL CRITERIA

- Points beyond Limits
- Runs
- Patterns

Points beyond Limits

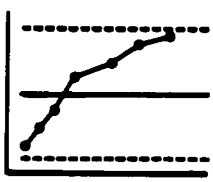


one point outside control limits

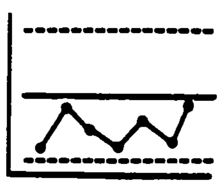


two points outside warning limits

Runs



seven points - up or down

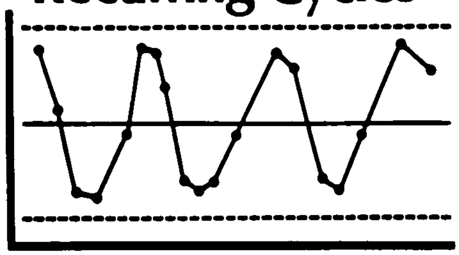


seven points - above or below central line

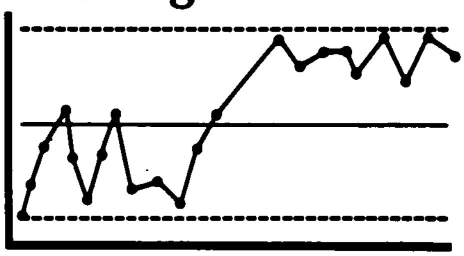
Patterns

- Recurring Cycles
- Change in Level
- Lack of Variability
- Trends
- Most Points near Outside Limits

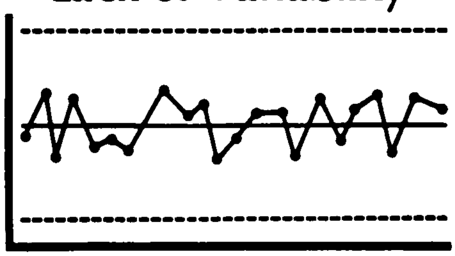
Recurring Cycles



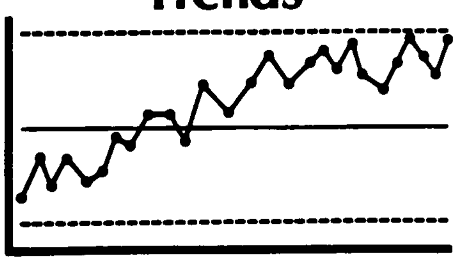
Change in Level



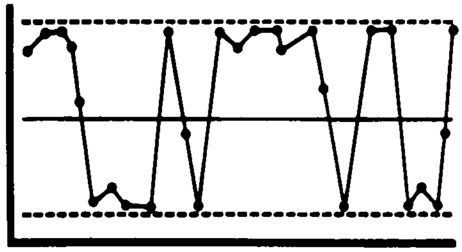
Lack of Variability



Trends



Most Points near Outside Limits



ASSUMPTIONS: Concerning Assignable Causes

- possible to identify and correct
- technically feasible to correct
- economically practical to correct

I. Homework Assignment

A standard material is checked at periodic intervals during routine analyses to ensure that the analytical measurement process remains in control. Following are the results in the chronological order in which they were obtained:

1. 19.0	14. 18.5
2. 18.3	15. 19.1
3. 18.0	16. 21.8
4. 17.2	17. 20.1
5. 17.4	18. 20.6
6. 18.3	19. 18.4
7. 19.6	20. 21.0
8. 20.7	21. 25.1
9. 18.2	22. 21.1
10. 18.8	23. 20.9
11. 20.4	24. 20.8
12. 20.1	25. 23.3
13. 19.6	26. 20.2

A. Prepare and plot a control chart with appropriate limits, assuming a single analysis is performed each day.

B. Prepare and plot $\bar{x}$ and R control charts with appropriate limits, assuming two analyses are performed each day; i.e., results Number 1 and 2 were performed on day 1, results Number 3 and 4 were performed on day 2, etc. (Hint: each day is a subgroup.)

C. Do the charts indicate any out-of-control conditions? If so, describe them.

PROJECT NAME: No Subgroups

MEASUREMENT PERFORMED: ______

MEASUREMENT UNITS: ______

DATE																									
MEASUREMENT CODE 1																									
MEASUREMENT CODE 2																									
MEASUREMENT CODE 3																									
MEASUREMENT RESULT 1																									
MEASUREMENT RESULT 2																									
MEASUREMENT RESULT 3																									
SUM																									
AVERAGE, $\bar{x}$																									
RANGE, R																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

INDIVIDUAL VALUES, x

RANGES, R

Comments (Correct. Action, etc.)

Comments (Correct Action, etc.)	RANGES, R	AVERAGES, $\bar{x}$	RANGE, R	AVERAGE, $\bar{x}$	SUM	MEASUREMENT RESULT 3	MEASUREMENT RESULT 2	MEASUREMENT RESULT 1	MEASUREMENT CODE 3	MEASUREMENT CODE 2	MEASUREMENT CODE 1	DATE

PROJECT NAME ______ Using Subgroups

MEASUREMENT PERFORMED ______

MEASUREMENT UNITS ______

Section 6

The Measurement Process with Emphasis on Calibration

Lesson Goal

To familiarize you with quality control considerations (especially calibration) for the measurement of air pollutants.

Lesson Objectives

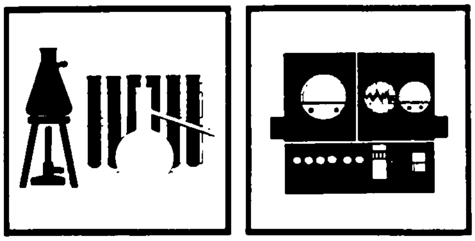
At the end of this lesson, you should be able to—

1. discuss quality control considerations for the three components (pollutant separation from the air matrix, determination of the amount of pollutant and the volume of air sampled, and calculation of pollutant concentration) of an air pollutant measurement,
2. define *calibration,*
3. list and discuss the six general elements of a calibration program,
4. define *traceability,* and
5. identify services available from the EPA's Standards Laboratory.

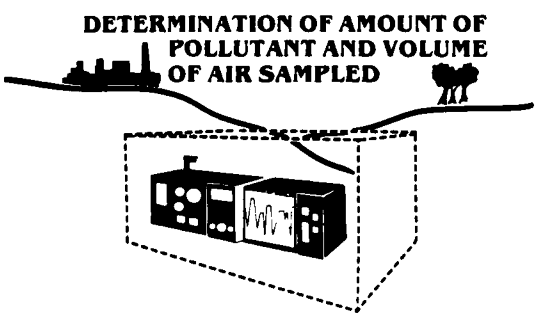
AIR POLLUTION MEASUREMENT

- separate pollutant from air
- determine pollutant quantity and air volume
- calculate pollution concentration by dividing pollutant quantity by air volume

SEPARATION OF POLLUTANT

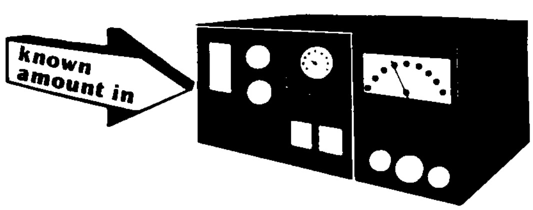


Manual   Automated



CALIBRATION

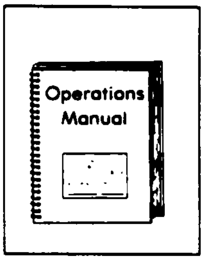
The process of establishing the relationship between the output of a measurement process and a known input.

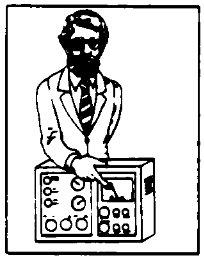


ELEMENTS OF A CALIBRATION PROGRAM

- **statements of allowable time between calibrations**

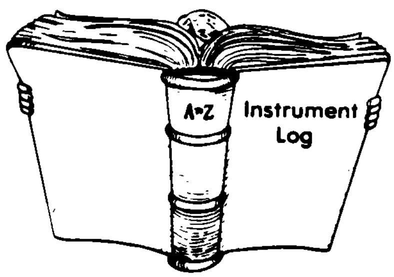
VENDOR RECOMMENDATIONS



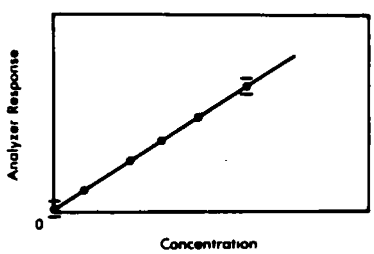


Contact Users for Opinions

IN-HOUSE RECORDS/FORMER EXPERIENCE



ZERO AND SPAN LIMITS



ELEMENTS OF A CALIBRATION PROGRAM

- statements of allowable time between calibrations
- statements of minimum quality of calibration standards

ELEMENTS OF A CALIBRATION PROGRAM

- statements of allowable time between calibrations
- statements of minimum quality of calibration standards
- provisions for standards traceability

- **NBS-SRMs**
- **CRMs**

EPA'S STANDARDS LABORATORY

- **certification of client-owned calibration and auditing materials**

CERTIFICATION SERVICES AVAILABLE

- cylinder gases
- permeation tube rates
- flow measuring devices
- calibration/audit devices
- static calibration/audit standards
- special analyses upon request

WRITE TO:

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
Quality Assurance Division
US EPA, MD-77
Research Triangle Park, NC 27711

ELEMENTS OF A CALIBRATION PROGRAM

- statements of allowable time between calibrations
- statements of minimum quality of calibration standards
- provisions for standards traceability
- provisions for written procedures

ELEMENTS OF A CALIBRATION PROGRAM

- statements of allowable time between calibrations
- statements of minimum quality of calibration standards
- provisions for standards traceability
- provisions for written procedures
- statements of proper environmental conditions

ELEMENTS OF A CALIBRATION PROGRAM

- statements of allowable time between calibrations
- statements of minimum quality of calibration standards
- provisions for standards traceability
- provisions for written procedures
- statements of proper environmental conditions
- provisions for proper record keeping

CALCULATION OF AMBIENT POLLUTANT CONCENTRATION

25 °C or 298 K	760 mm Hg or 1 atmosphere
EPA Standard Ambient Temperature	EPA Standard Pressure

United States Environmental Protection Agency

Environmental Monitoring and Support Laboratory
Cincinnati OH 45268

Volume 3 Number 1 February 198

EPA NEWSLETTER Quality Assurance

Environmental Monitoring Systems Laboratory
Research Triangle Park, NC 27711

Sample Repository

A repository of quality control materials is maintained for use by governmental industrial and commercial laboratories. A wide variety of samples is available without charge to the user. These materials are intended as independent measures of working standards or as internal quality control samples. A certification of analysis is furnished with each sample. Materials currently available are listed below.

Quality Control Samples for Ambient Air and Stationary Source Analyses

Compressed Gases	
NITRIC OXIDE	Multiple levels from 50 to 1500 ppm
SULFUR DIOXIDE	Multiple levels from 50 to 10,000 ppm
CARBON MONOXIDE	3 levels from 5 to 50 ppm
CARBON DIOXIDE	3 levels from 3 to 8 percent
OXYGEN	3 levels from 1 to 8 percent
NITROGEN DIOXIDE	3 levels from 25 to 100 ppm
METHANE	Multiple levels from 1 to 10 ppm
METHANE/PROPANE	2 ppm methane with propane ranging from 0.5 to 6 ppm
Static Samples	
LYOPHILIZED MIXTURE OF SODIUM SULFITE-TETRACHLOROMERCURATE	Simulate collected ambient level SO_2 samples from 10 to 200 $\mu g/m^3$ of SO_2. Samples are furnished as a set of 5 different concentrations.
AQUEOUS SODIUM NITRITE	Simulate collected ambient level NO_2 samples from 40 to 200 μ /m^3 of NO_2. Samples are furnished as a set of 5 different concentrations.
DILUTE SULFURIC SOLUTIONS	Simulate collected source level SO_2 (Method 6) samples from 200 to 2500 μg/dscm of SO_2. Samples are furnished as a set of 5 different concentrations.
AQUEOUS POTASSIUM NITRATE	Simulate collected source level NO_2 (Method 7) samples from 150 to 900 μg/dscm of NO_2. Samples are furnished as a set of 5.

EMSL-RTP (Cont'd)	Filter Samples	
	LEAD FILTER STRIPS	Lead nitrate deposited on ½" x 8" glass-fiber filter strips Samples simulate collected concentrations from 0.4 to 15 $\mu g/m^3$ of lead Nine levels are available
	ARSENIC FILTER STRIPS	Arsenious oxide deposited on ½" x 8" glass-fiber filter strips Samples simulate collected concentrations from 0 02 to 1 0 $\mu g/m^3$ of arsenic Nine levels are available
	SULFATE-NITRATE FILTER STRIPS	Sodium sulfate and potassium nitrate deposited on ½" x 8" glass-fiber filter strips Samples simulate collected concentrations from 0 6 to 40 $\mu g/m^3$ of sulfate, and from 0 6 to 15 $\mu g/m^3$ nitrate Nine levels are available
	SULFATE ON CELLULOSE MEMBRANE FILTERS	Sodium sulfate deposited on ¼ of 4" diameter cellulose membranes Samples simulate collected concentrations from 25 to 320 μg of sulfate. Seven levels are available.
	SULFATE-NITRATE ON TEFLON MEMBRANE FILTERS	Sodium sulfate and potassium nitrate deposited on 37 mm diameter teflon membranes Samples simulate collected concentrations from 50 to 200 μg of sulfate and from 50 to 200 μg of nitrate Three levels are available
	LEAD ON CELLULOSE MEMBRANE FILTER	Lead nitrate deposited on ¼ of 4" diameter cellulose membranes Samples simulate collected concentrations from 10 to 100 μg of lead Five levels are available
	Flow Measurement Devices	
	HI-VOL REFERENCE DEVICE	Consists of a set of resistance plates to simulate various filter loading conditions used to confirm flow calibration for the measurement of Suspended Particulate in the air by the High Volume (Hi Vol) method
	CRITICAL ORIFICES	Consists of an orifice assembly to verify the volume meter calibration of Method 5 sampling train
	Organic Materials	Compressed gas mixtures of the following organic materials Very limited quantities are available for short-term loan only
	BENZENE	Multiple levels from 8 to 300 ppm
	ETHYLENE	Multiple levels from 5 to 20 000 ppm
	METHANE/ETHANE	Several levels from 1000 to 8000 ppm of methane and 200 to 700 ppm of ethane
	PROPANE	Several levels from 5 to 700 ppm

EMSL-RTP (Cont'd)

PROPYLENE	Several levels from 5 to 700 ppm
TOLUENE	Several levels from 5 to 700 ppm
METHYL ACETATE	Several levels from 5 to 700 ppm
VINYL CHLORIDE	Several levels from 5 to 40 ppm
HYDROGEN SULFIDE	Several levels from 7 to 650 ppm
m-XYLENE	Several levels from 8 to 600 ppm
CHLOROFORM	Several levels from 5 to 700 ppm
PERCHLOROETHYLENE	Several levels from 5 to 700 ppm
BUTADIENE	One level 25 ppm
HEXANE	Several levels from 30 to 3000 ppm
METHYL MERCAPTAN	Several levels from 5 to 10 ppm
METHYL ETHYL KETONE	One level 50 ppm

(Robert Lampe, FTS 629-2573, COML 919-541-2573)

Standards Laboratory

The Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Quality Assurance Division, Research Triangle Park, NC (EPA/EMSL/QAD/RTP) Standards Laboratory offers calibration, standardization and certification of client-owned sample material There is no charge for this service. Where applicable, certifications are referenced directly to National Bureau of Standards (NBS) Standard Reference Materials (SRM). The following services are offered.

- verification of compressed gas standards used for calibration, span checks or audits of air quality analyzers (NO, NO_2, SO_2, CO, CO_2, CH_4, hydrocarbons)
- verification of permeation tube rates (gravimetric or direct comparison with SRM)
- verification of flow measuring devices (mass flowmeter, hi-vol orifice meters)
- verification of outputs of calibration or audit devices (SO_2, ozone, NO, NO_2, CO, CO_2, CH_4, hydrocarbons)
- verification of static audit or calibration standards (nitrite solution, potassium tetrachloromercurate sulfite freeze-dried powders; sulfate and lead on glass-fiber filter strips)
- other special analyses are available upon request.

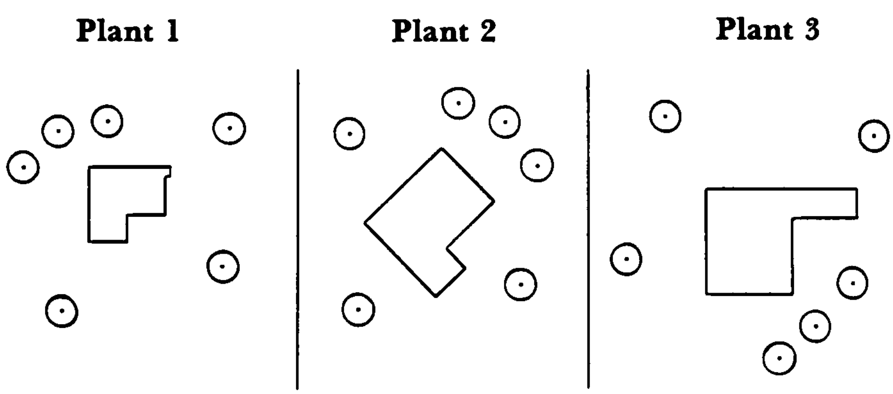
For detailed information or to receive sample material, contact Berne I Bennet at the Quality Assurance Division, Standards Laboratory, EMSL, MD-77 Research Triangle Park, NC 27711.
(Berne Bennett, FTS 629-2366, COML: 919-541-2366)

Section 6A
Group Problem

The occurrence in ambient air of a highly toxic gaseous pollutant, cyclolehmdone (CL), has recently been reported. Each group is to develop a monitoring and quality assurance plan that will determine the ambient level of CL.

The following data are provided:

- This is a state-wide problem. All efforts are coordinated through the state central office.
- There are three local offices located throughout the state. The local offices will be engaged in the field work. Each local office has a laboratory where CL analyses will be performed. Assume each local office and the state office have adequate staff and funding.
- Just by coincidence, there are three plants suspected of CL emissions located in the state—one plant is located in each of the jurisdictional areas of the local offices. Each plant uses CL in the manufacture of its products.
- Both a manual method and a continuous monitoring (instrumental) method exist. Each local office and the state office has one gas chromatograph for analyzing manual samples and one continuous monitoring instrument available for use in the study. Gas chromatographs must remain in their labs. Continuous monitoring instruments of the local offices must remain in the field. The purchase of additional continuous monitors is not possible.
- The length of the sampling program is two months.
- For manual sampling, 24-hour integrated sampling will be done every day.
- Sampling sites have been properly selected around each plant using historical meteorological data available. The siting team has decided that six stations are needed:



- Manual-sampling equipment and supplies must be procured.
- An NBS-SRM (permeation tube) exists (located at the state office); cylinders of "known" concentrations of CL are available from FBN, Inc. Purchase of additional permeation tubes is not possible.

Manual Method—Attachment I

Continuous Method—Attachment II

Group Problem Planning Sheet

Group ______________________________

1. Write what you consider to be the QA policy for the group problem.

2. List the data quality objectives that your group will require to be met with regard to the group problem.

Section 6B

Review of Control Chart Homework

Lesson Goal

To ensure that you can perform the tasks assigned in the control chart homework exercise.

Lesson Objectives

At the end of this lesson, you should be able to—

1. prepare a control chart based on individual data values (no rational subgroups),
2. prepare an $\bar{x}$-R control chart (based on rational subgroups), and
3. detect out-of-control conditions indicated by the prepared charts.

Section 7

Regression Analysis and Control Charts for Calibration Data

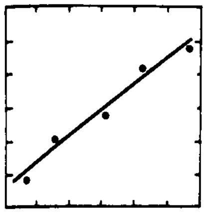
Lesson Goal

To familiarize you with regression analysis techniques (especially the linear least-squares method) and control chart considerations for calibration data.

Lesson Objectives

At the end of this lesson, you should be able to—

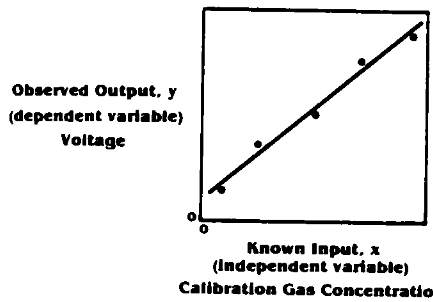
1. list three advantages of using the least-squares method for determining calibration curves,
2. list four implied assumptions of the linear least-squares method,
3. discuss the mathematical basis for the least-squares method,
4. compute a linear least-squares calibration equation from calibration data (given the appropriate formulas),
5. compute the standard error for a calibration curve (given the appropriate formulas),
6. compute an inverse calibration equation (given the appropriate formulas),
7. select appropriate control-chart calibration parameters to plot for a specific monitoring situation, and
8. list two non-linear calibration-data analysis techniques.



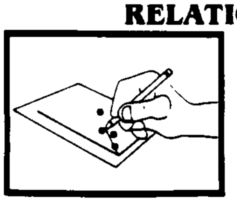
REGRESSION ANALYSIS AND CONTROL CHARTS FOR CALIBRATION DATA

CALIBRATION

The process of establishing the relationship between the output of a measurement process and a known input.



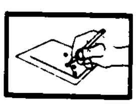
METHODS OF DETERMINING THE INPUT-OUTPUT RELATIONSHIP



Manual

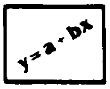
$y = a + bx$

Computation



MANUAL METHODS

- **draw line by eye**
- **draw line using ruler**



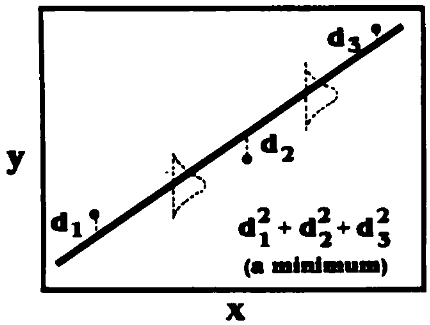
COMPUTATIONAL METHODS

- mathematically determine relationship (least-squares method)
- advantages
  - more precise
  - everybody gets same line
  - provides formula for transfer

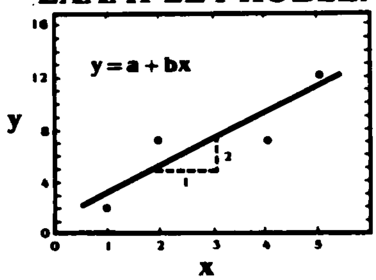
LEAST-SQUARES METHOD

Assumption :

- linear relationship
- error in y - no error in x
- scatter of error is uniform
- errors normally and independently distributed



EXAMPLE PROBLEM



- Obtain sums and averages of data

	x	y	x^2	y^2	xy	$x-\bar{x}$	$y-\bar{y}$
	1	2	1	4	2	-2	-5
	2	7	4	49	14	-1	0
	4	7	16	49	28	1	0
	5	12	25	144	60	2	5
Σ =	12	28	46	246	104		
avg. =	3	7					

- **Obtain sums of squares and sum of products**

$(x-\bar{x})^2$	$(x-\bar{x})(y-\bar{y})$	$(y-\bar{y})^2$
4	10	25
1	0	0
1	0	0
4	10	25
10	20	50

- **Calculate slope of line: acceptable method**

$$\text{Slope: } b = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\Sigma(x-\bar{x})^2}$$

$$= \frac{20}{10} = 2$$

- **Calculate slope of line:**

preferred method – regression analysis

$$b = \frac{\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}$$

$$= \frac{104 - \frac{(12)(28)}{4}}{46 - \frac{(12)^2}{4}}$$

$$= \frac{104-84}{46-36} = \frac{20}{10} = 2$$

- **Determine y-intercept**

$$\text{Intercept: } a = \bar{y} - b\bar{x}$$

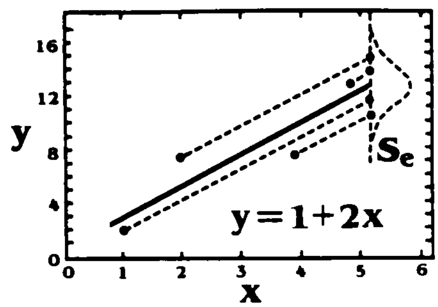
$$= 7 - 2(3)$$

$$= 1$$

$$\text{Equation: } y = 1 + 2x$$

STANDARD ERROR: S_e

The standard deviation of the residuals distribution.



DETERMINATION OF STANDARD ERROR

x	Obs. y	Pred. y	d	d^2
1	2	3	-1	1
2	7	5	2	4
4	7	9	-2	4
5	12	11	1	1
			$\Sigma d^2 =$	10

$$S_e = \sqrt{\frac{\Sigma d^2}{n-2}}$$

$$= \sqrt{\frac{\Sigma d^2}{4-2}}$$

$$S_e = \sqrt{\frac{10}{2}} = \sqrt{5} = 2.236$$

INVERSE CALIBRATION EQUATION

$$y = a + bx$$

- used to relate output value (y) to input value (x)

- Using the basic equation :

$$y = a + bx$$

- Obtain the inverse equation (by solving for x) :

$$x = \frac{y-a}{b}$$

- Then : $x = \frac{1}{b}y + (-\frac{a}{b})$

$$x = b'y + a', \text{ where } b' = \frac{1}{b}$$

$$a' = -\frac{a}{b}$$

$$y = a + bx$$

$$y = 1 + 2x$$

$$x = \frac{y-1}{2}$$

$$x = \frac{1}{2}y + (-\frac{1}{2})$$

$$x = b'y + a', \text{ where } b' = \frac{1}{2}, \; a' = -\frac{1}{2}$$

APPLYING DATA FROM EXAMPLE PROBLEM

CONTROL CHARTS FOR MULTIPOINT CALIBRATION DATA

Purpose:

to assure that the calibration process remains in statistical control

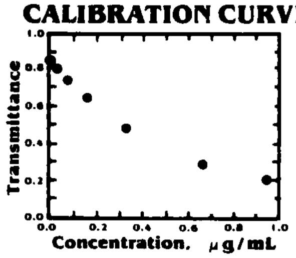
---

OPERATING METHOD	CONTROL CHART
• no intervening adjustments for zero or span	• zero/span drifts • span-zero • slope
• intervening adjustments for zero and span	• standard error

NON-LINEAR CALIBRATION DATA ANALYSIS TECHNIQUES

- **make linear by transformation**
- **compute non-linear least-squares equation**

CALIBRATION CURVE



DATA

µg/mL	Transmittance
0.000	0.863
0.032	0.815
0.081	0.752
0.162	0.650
0.326	0.484
0.663	0.279
0.952	0.165

EQUATION

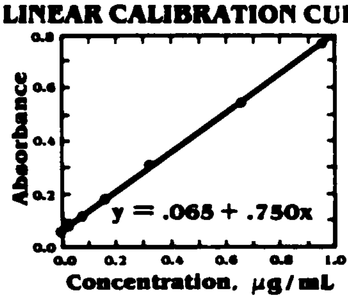
$$A = \log\left(\frac{1}{T}\right)$$

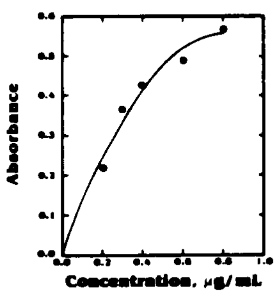
$$A = -\log T$$

- **Determine absorbance values**

µg/mL	T	A
0.000	0.863	0.064
0.032	0.815	0.089
0.081	0.752	0.124
0.162	0.650	0.187
0.326	0.484	0.315
0.663	0.279	0.555
0.952	0.165	0.782

LINEAR CALIBRATION CURVE





- **Compute non-linear least-squares equation**

Section 7A

Review of Precourse Problems 1 and 2

Lesson Goal

To ensure that you can perform the tasks assigned in precourse problems 1 and 2.

Lesson Objectives

At the end of this lesson, you should be able to—

1. recognize the usefulness of data plotting in detecting outliers,
2. calculate percentage differences of paired data values, and
3. recognize the usefulness of percentage difference determinations in detecting outliers.

Section 8

Identification and Treatment of Outliers

Lesson Goal

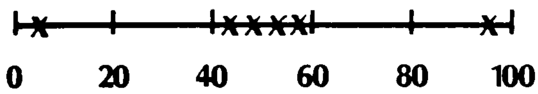
To familiarize you with the need for identifying and investigating outliers and with three statistical outlier tests.

Lesson Objectives

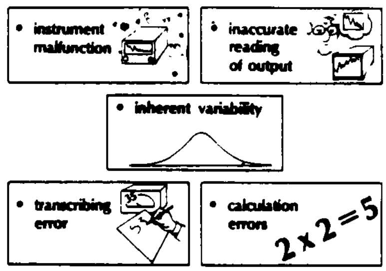
At the end of this lesson, you should be able to—

1. define *outlier,*
2. recall five possible reasons for the existence of an outlier in a data set,
3. discuss the need for identifying and eliminating outliers of quality control data,
4. recall that data are initially screened for suspect values using visual techniques,
5. employ the Dixon Ratio and Grubbs T tests (given the appropriate formulas and critical values tables) to identify outliers,
6. explain in general terms the meaning and derivation of the significance level critical values of the Dixon and Grubbs critical values tables,
7. discuss advantages and disadvantages of using either the Dixon Ratio test or the Grubbs T test,
8. recognize the use of control charts for identifying outliers, and
9. recall the underlying assumption of the Dixon Ratio test, the Grubbs T test, and the control chart technique.

IDENTIFICATION AND TREATMENT OF OUTLIERS



CAUSES OF OUTLIERS



NEED FOR IDENTIFICATION / ELIMINATION OF OUTLIERS

Identification:

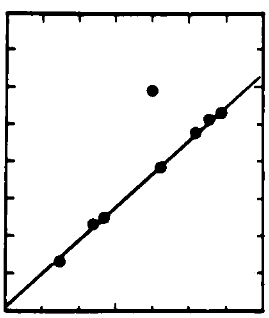
- indicates need for closer control

Elimination:

- ensures analysis is valid
- ensures conclusions are correct

PROCEDURE FOR IDENTIFYING OUTLIERS

- screen data
- subject suspect data to statistical tests



USE OF DATA PLOTS FOR INITIAL SCREENING

STATISTICAL OUTLIER TESTS

- Dixon Ratio Test
- Grubbs T Test
- Control Chart Technique

DIXON RATIO TEST PROCEDURE

1. Arrange data in ascending or descending order
2. Calculate a ratio
3. Compare ratio to Dixon table
4. Determine if suspect value is an outlier

1 Arrange data values in either ascending or descending order

- If smallest data value is suspect

  $x_1 \leq x_2 \leq x_3 \leq \ldots\ldots x_n$

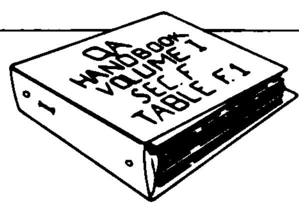
- If largest data value is suspect

  $x_1 \geq x_2 \geq x_3 \geq \ldots\ldots x_n$

2 Calculate a ratio - equation depends upon sample size

- 3 to 7 $\quad r_{10} = x_1 \; x_2 \ldots\ldots x_n$
- 8 to 10 $\quad r_{11} = x_1 \; x_2 \ldots\ldots x_{n-1} \; x_n$
- 11 to 13 $\quad r_{21} = x_1 \; x_2 \; x_3 \ldots\ldots x_{n-1} \; x_n$
- 14 to 25 $\quad r_{22} = x_1 \; x_2 \; x_3 \ldots\ldots x_{n-2} \; x_{n-1} \; x_n$

3 Compare ratio value to Dixon table of critical ratio values



4 Suspect value is an outlier if ratio is greater than critical value

0.465	>	0.406
calculated ratio value		critical value

EXAMPLE PROBLEM #1

Using the Dixon Ratio test, determine if the data value, 25.1, is an outlier at the 5% significance level.

DATA VALUES

19.0	19.1	18.3	21.0
18.0	20.1	20.7	21.1
17.4	18.4	18.8	20.8
19.6	25.1	20.1	20.2
18.2	20.9	18.5	
20.4	23.3	21.8	
19.6	17.2	20.6	

DATA VALUES: ARRANGED

(25.1)	20.7	19.6	18.2
23.3	20.6	19.1	(18.0)
(21.8)	20.4	19.0	17.4
21.1	20.2	18.8	17.2
21.0	20.1	18.5	
20.9	20.1	18.4	
20.8	19.6	18.3	

SOLUTION:

r_{22} = 25.1 23.3 21.8 ..... 18.0 17.4 17.2

$r_{22} = \frac{3.3}{7.1}$

$r_{22} = .465$

Since 0.465 > 0.406
Then 25.1 is an outlier

GRUBBS T TEST PROCEDURE

1. Calculate arithmetic mean
2. Calculate standard deviation
3. Calculate a ratio
4. Compare ratio to Grubbs table
5. Determine if suspect value is an outlier

1 Calculate arithmetic mean ($\bar{x}$) of data set values

$$\bar{x} = \frac{\Sigma x_i}{n}$$

2 Calculate standard deviation (s) of data set values

$$s = \sqrt{\frac{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}{n-1}}$$

3 Calculate a ratio

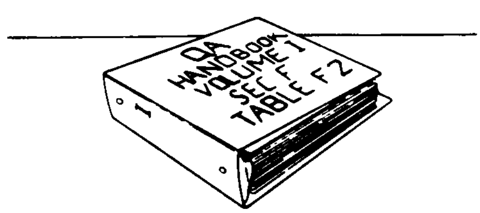
- If smallest data value is suspect

$$T_1 = \frac{\bar{x} - x_1}{s}$$

- If largest data value is suspect

$$T_n = \frac{x_n - \bar{x}}{s}$$

4 Compare ratio to Grubbs table



5 Suspect value is an outlier if ratio is greater than critical value

2.87	>	2.82
calculated ratio value		critical value

EXAMPLE PROBLEM # 2

Using the Grubbs T test, determine if the data value, 25.1, is an outlier at the 5% significance level for the data set used in the Dixon Ratio test procedure (example problem # 1).

DATA VALUES

19.0	19.1	18.3	21.0
18.0	20.1	20.7	21.1
17.4	18.4	18.8	20.8
19.6	25.1	20.1	20.2
18.2	20.9	18.5	
20.4	23.3	21.8	
19.6	17.2	20.6	

SOLUTION:

Determine Σx_i, Σx_i^2, and n

$$\Sigma x_i = 498.2$$

$$\Sigma x_i^2 = 10{,}005.98$$

$$n = 25$$

To find $\bar{x}$:

$$\bar{x} = \frac{\Sigma x_i}{n}$$

$$\bar{x} = \frac{498.2}{25}$$

$$\bar{x} = 19.93$$

To find s:

$$s = \sqrt{\frac{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}{n - 1}}$$

$$s = \sqrt{\frac{10{,}005.98 - \frac{(498.2)^2}{25}}{25 - 1}}$$

$$s = 1.80$$

Because largest data value is suspect, calculate T_n :

$$T_n = \frac{x_n - \bar{x}}{s}$$

$$T_n = \frac{25.10 - 19.93}{1.80}$$

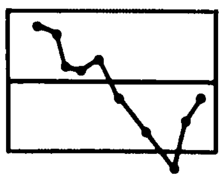
$$T_n = 2.87$$

Since $2.87 > 2.822$

Then 25.1 is an outlier

Control Chart Technique

- Construct from historical data
- Plot subsequent data



DIXON RATIO TEST

Advantage

- simple calculations

Disadvantages

- not all data set values used
- limited to data sets with 25 values or less

GRUBBS T TEST

Advantages

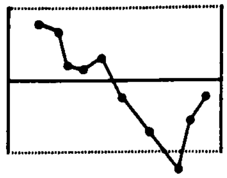
- more powerful than Dixon Ratio Test
- can be used for large data sets

Disadvantage

- involved calculations

Control Chart Technique

- Detects individual outliers
- Detects sets of outliers



An underlying normal (Gaussian) distribution of data is assumed.

Treatment of Outliers

- Determine causes
- Eliminate if appropriate

Section 9

Intralaboratory Testing

Lesson Goal

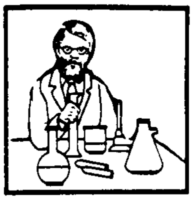
To familiarize you with intralaboratory testing considerations.

Lesson Objectives

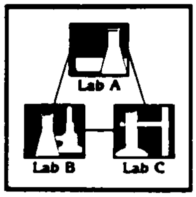
At the end of this lesson, you should be able to—

1. distinguish between intralaboratory and interlaboratory testing,
2. discuss the purposes of intralaboratory testing,
3. distinguish among three levels of precision measurement: replicability, repeatability, and reproducibility, and
4. discuss considerations necessary for designing an intralaboratory testing program.

TESTING



Intralaboratory



Interlaboratory

PURPOSES OF INTRALABORATORY TESTING

Identify :

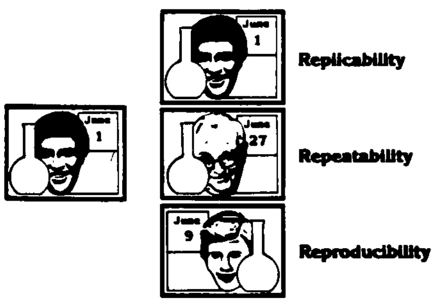
- sources of measurement error

Estimate :

- bias (accuracy)
- variability (replicability, repeatability)

THREE LEVELS OF PRECISION MEASUREMENT

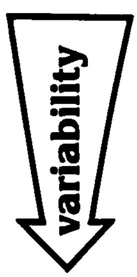
- Replicability
- Repeatability
- Reproducibility



Reproducibility

Repeatability

Replicability



INTRALABORATORY TESTING DESIGN CONSIDERATIONS

- types of measurement methods
- potential sources of error
- testing philosophy

MEASUREMENT METHODS

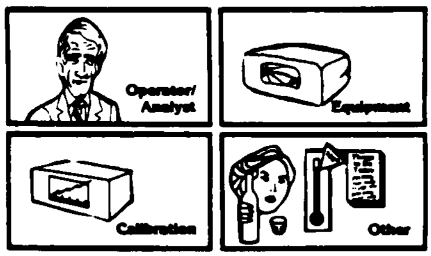
Manual :

- collection
- analysis

Continuous :

- collection/analysis

POTENTIAL SOURCES OF ERROR



MEASUREMENT OF OPERATOR PROFICIENCY
Major Problems

- what kinds of audit samples to use
- how to introduce samples into analytical process without analyst's knowledge
- how frequently to audit

KINDS OF AUDIT SAMPLES

- duplicate of real samples
- prepared reference samples

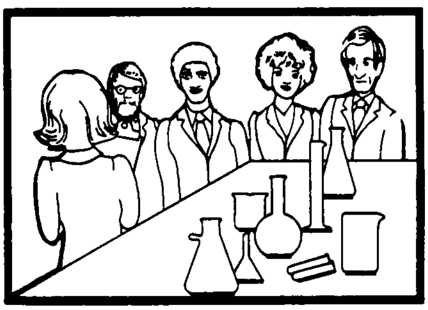
AUDIT SAMPLE INTRODUCTION

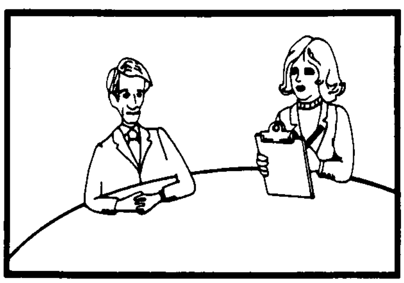
- samples should have identical sample labels and appearance as real samples
- supervisor and analyst should alternate the process of logging in samples

AUDITING FREQUENCY

Decision based on :

- degree of automation
- total method precision
- analyst's training, attitude, and past performance





Section 10

Interlaboratory Testing

Lesson Goal

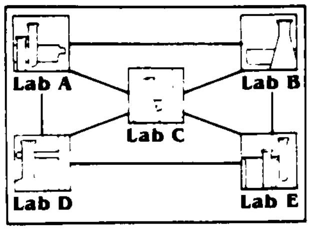
To familiarize you with interlaboratory performance testing considerations and USEPA's interlaboratory performance audit program.

Lesson Objectives

At the end of this lesson, you should be able to—

1. describe and distinguish between the two kinds of interlaboratory tests—collaborative tests and periodic performance tests,
2. describe considerations in designing an interlaboratory performance test,
3. describe USEPA's interlaboratory performance audit program,
4. list the common types of performance audits conducted by USEPA,
5. identify the audit materials that are available from USEPA,
6. list sources of information concerning USEPA's interlaboratory performance audit program,
7. discuss data analysis performed on the results of USEPA's interlaboratory performance audits, and
8. discuss results of USEPA's interlaboratory performance audits.

INTERLABORATORY TESTS

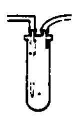


INTERLABORATORY PERFORMANCE TEST

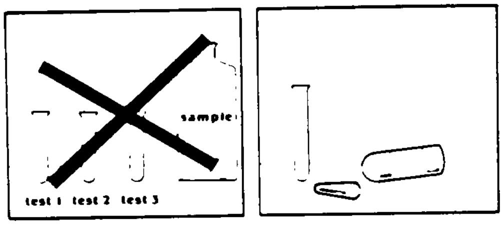
- **identifies biased labs (and / or analysts)**
- **estimates "between laboratory" measurement method reproducibility**

CONSIDERATIONS IN PLANNING THE INTERLABORATORY PERFORMANCE TEST

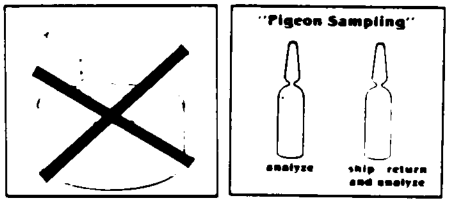
- **Selection of the parameter to be tested**
  - **automated method - total**
  - **manual method - portion**

- **Selection of the proper sample**
  -  **collection**
  -  **analysis**

SAMPLE SIZE



- **Sample preparation —
  ensure uniformity, stability**



- **Sample preparation — evaluate sample-to-sample variability**

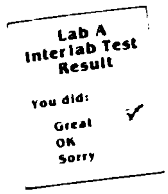
- **Test instructions**
  - **clear and complete**
  - **only one interpretation**
  - **specify handling - routine or special?**
  - **specify reporting form and units**

SELECTION OF METHODOLOGY

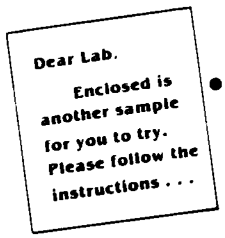
- **inter-method lab variability — lab selects method**
- **same method lab variability — specify method**

Always require written copy of method used!

- **Report results to the labs**



- **timely**
- **confidential**
- **recommend corrective action if needed**

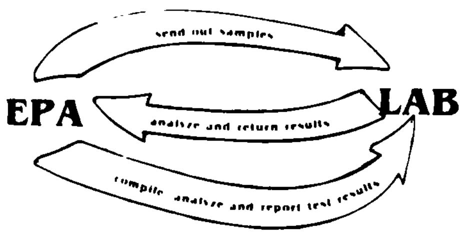


- **Follow-up**

RECAP

- select the parameter to be tested
- select the sample
- prepare the sample
- prepare the instructions
- provide feedback of results
- specify corrective action
- follow-up

EPA INTERLABORATORY PERFORMANCE AUDIT PROGRAM



ENVIRONMENTAL MONITORING SYSTEMS LABORATORY

- **sample repository**
- **free samples for quality control**

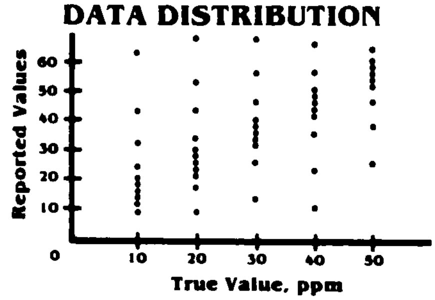
ADDITIONAL QC SAMPLES FOR AMBIENT AIR AND STATIONARY SOURCE MEASUREMENTS

- cylinder gases
- filter samples
- organic gas mixtures

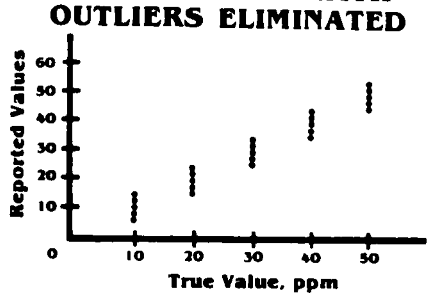
WRITE TO:

ENVIRONMENTAL MONITORING
SYSTEMS LABORATORY
Quality Assurance Division
US EPA, MD-77
Research Triangle Park, NC 27711

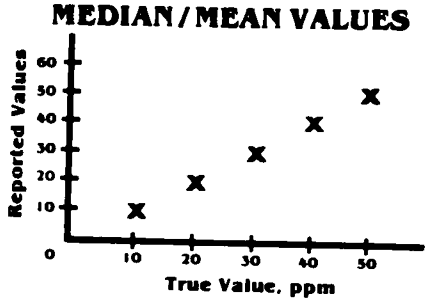
DATA DISTRIBUTION



DISTRIBUTION WITH OUTLIERS ELIMINATED



MEDIAN / MEAN VALUES



$$\% \text{ Accuracy} = \left(\frac{\text{audit median or mean} - \text{true value}}{\text{true value}} \right) 100$$

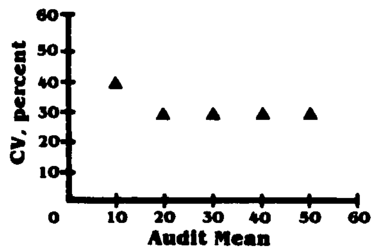
STANDARD DEVIATION

$$s = \sqrt{\frac{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}{n-1}}$$

COEFFICIENT OF VARIATION

$$CV = \left(\frac{s}{\text{audit mean}} \right) 100$$

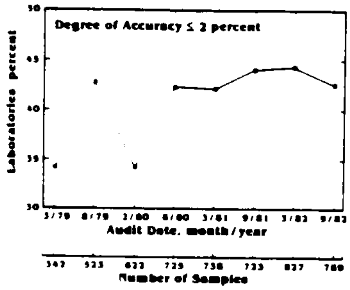
CV VERSUS AUDIT MEAN



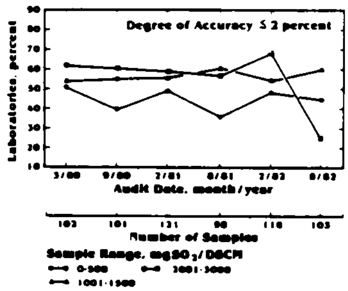
1982 AMBIENT AIR AUDIT RESULTS

Parameter	Accuracy Range (%)	CV Range (%)	Range of Reported Values within ±20% of True Values (%)
SO_2 (pararosaniline)	-5.7 to 6.4	6.6 to 18.5	66.7 to 100
NO_2	-1.3 to 1.6	2.4 to 4.3	93.8 to 100 (±10%)
CO	-2.7 to 0.5	2.7 to 7.6	97.0 to 100
SO_4^{-2} (conc.>6μg/m3)	-1.4 to 1.7	6.3 to 14.8	82.5 to 100
NO_3^{-1} (conc.>3μg/m3)	-1.4 to 2.2	4.9 to 10.9	90.5 to 100
Pb	-3.1 to 0.0	4.5 to 11.6	88.9 to 100
SO_2 (continuous)	-1.6 to -0.7	—	—
Hi-vol Flow	—	—	90% (±8%)

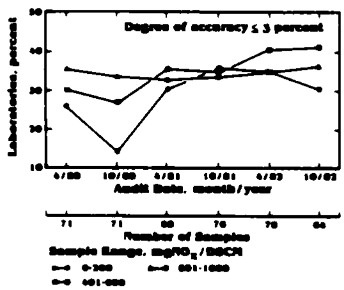
METHOD 5 AUDIT RESULTS



METHOD 6 AUDIT RESULTS



METHOD 7 AUDIT RESULTS



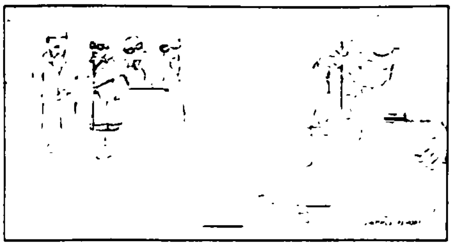
SEPTEMBER 1982
COAL ANALYSIS AUDIT RESULTS

True Value	Labs Reporting Values within ±5% of True Value (%)	Labs Reporting Values within ±10% of True Value (%)
1.22% Sulfur	55	78
3.22% Sulfur	75	91
2.11% Moisture	15	31
2.40% Moisture	18	40
11.43% Ash	96	100
16.34% Ash	98	99
12277 BTU/lb	96	100
12832 BTU/lb	99	100

JUNE 1982
METHOD 3 AUDIT RESULTS

True Value	Labs Reporting Values within ±5% of True Value (%)	Labs Reporting Values within ±10% of True Value (%)
14.8% CO_2	34	67
5.2% O_2	28	46
7.0% CO	14	31

Why are audit results optimistic?



Section 11

Procurement Quality Control

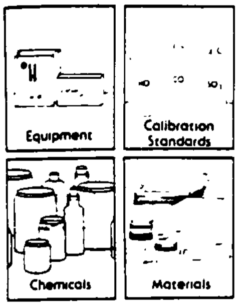
Lesson Goal

To familiarize you with quality control procedures for the procurement of supplies and equipment.

Lesson Objectives

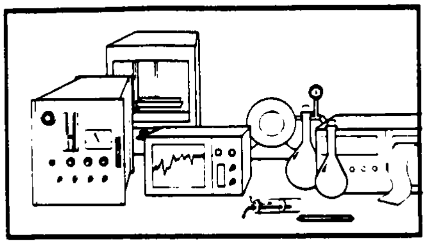
At the end of this lesson, you should be able to—

1. recall the four major groups of procured items of concern in procurement quality control,
2. list at least two procured items from each major group that affect air monitoring data quality,
3. describe a quality control procedure for the procurement of an ambient air quality analyzer, and
4. describe quality control considerations in the procurement of calibration standards, chemicals, and materials.

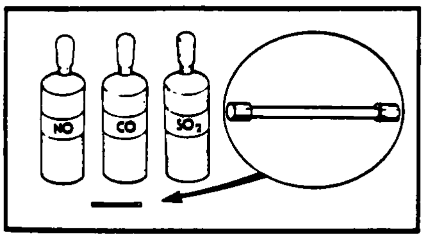


PROCUREMENT QUALITY CONTROL

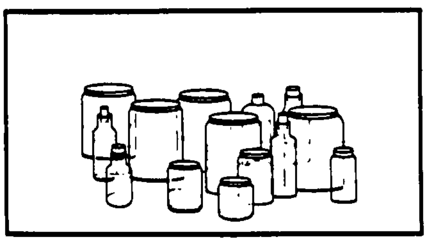
EQUIPMENT



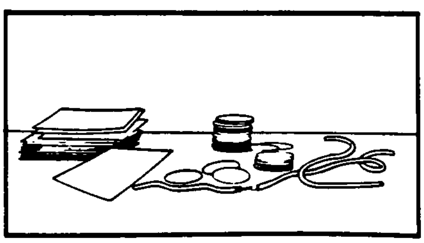
CALIBRATION STANDARDS



CHEMICALS



MATERIALS



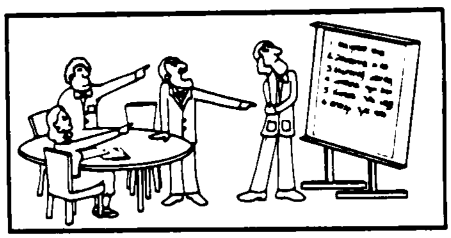
PROCEDURE FOR PROCURING AN AMBIENT AIR QUALITY ANALYZER

1. Prepurchase Evaluation/Selection
2. Writing of Purchase Contract Specifications
3. Acceptance Testing
4. Overlap Testing
5. Record Keeping

1 Prepurchase Evaluation/Selection

- analysis of analyzer performance specifications
- assessment of analyzer

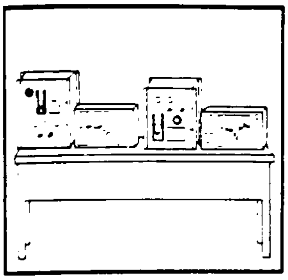
Analysis of Analyzer Performance Specifications



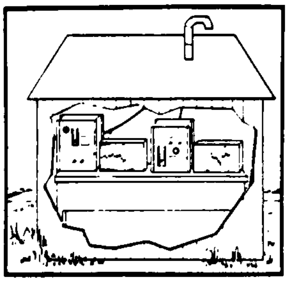
Assessment of Analyzer

- review operations manuals

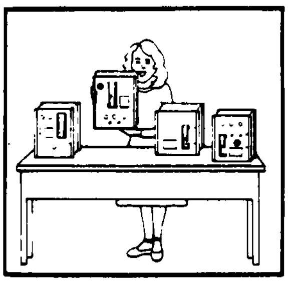
Contact Users for Opinions



In-House Testing



Field Testing

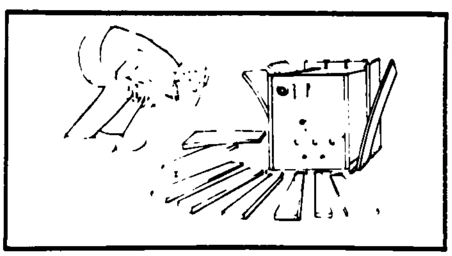


Selection of Analyzer

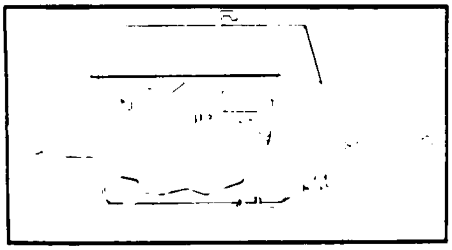
2 Writing of Purchase Contract Specifications

- inclusion of performance specs test data
- payment contingent upon successful acceptance testing
- inclusion of warranty
- inclusion of consistent operating manuals
- provision of operator training
- provision for burn-in
- inclusion of consumables and spare parts

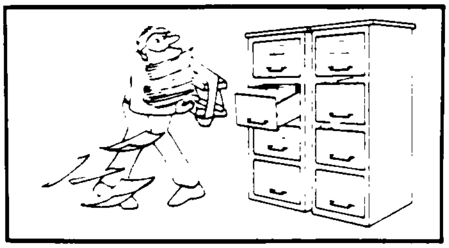
3 Acceptance Testing



4 Overlap Testing



5 Record Keeping



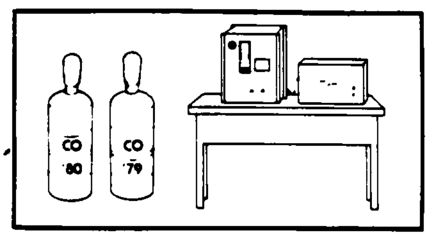
PROCUREMENT CONSIDERATIONS FOR CALIBRATION STANDARDS

- Purchase Contracts
- Overlap Testing

Purchase Contracts Requirements:

- NBS or CRM traceability
- certificate of analysis
- calibration curves
- user instructions

Overlap Testing



PROCUREMENT CONSIDERATIONS FOR CHEMICALS

- Certified Analyses
- Overlap Testing
- Record Keeping

PROCUREMENT CONSIDERATIONS FOR MATERIALS

- Performance Parameter Specs
- Acceptance Testing
- Overlap Testing

QUALITY ASSURANCE FOR PROCUREMENT OF AIR ANALYZERS

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ABSTRACT

Ambient air monitoring in the vicinity of a point source requires different characteristics in an analyzer than monitoring for background data in an area where there are no point sources. Different degrees of sensitivity, different response times, and the degree of automation required, will differ in each setting.

Before purchasing an analyzer the user must, therefore, define his needs in terms of sensitivity, accuracy, data completeness, response to changes in ambient concentrations, reliability and maintainability, degree of automation, ease of operation and cost. The Wisconsin Department of Natural Resources has established a program of procurement quality assurance to both define the user's needs and to evaluate the ability of different analyzers to meet these needs. This program is divided into four stages: 1) User Needs Analysis, 2) Pre-Purchase Evaluation, 3) Purchase Specifications and Contract Conditions, and 4) Acceptance Testing.

This four stage process was applied in the recent purchase of twelve sulfur dioxide analyzers for the Department's Monitoring Program. Surprisingly, the instrument that looked the best at the beginning of the pre-purchase evaluation, and toward which the user group was leading, was not the analyzer that scored highest in the final evaluation. As a result of the Department's evaluation process, a different analyzer was purchased. By defining the user needs in quantifiable form, and then objectively measuring the ability of different analyzers to meet these needs, the Department of Natural Resources has assured itself of purchasing the best available analyzer that can do the job required.

INTRODUCTION

Environmental Protection Agency regulations state that no later than February 1980, all ambient air analyzers used in state monitoring programs as specified in their state implementation plan must be approved reference or equivalent analyzers. For most states this will mean replacing "obsolete" analyzers with newer models. The money spent on this new equipment in the next two years could easily reach ten million dollars. Unless state agencies and private air monitoring groups take precautions, newly purchased analyzers may not meet their needs, or if they do, it may be at an excessive cost. To avoid such problems, a Quality Assurance Plan for procurement of analyzers and other capital purchases, is desirable.

The Wisconsin Department of Natural Resources (DNR) has developed such a plan for its instrument procurement and has recently used the plan in the purchase of sulfur dioxide analyzers for its statewide monitoring network. This paper describes the general features of the DNR procurement plan, and how the plan was applied in selecting a specific model of sulfur dioxide analyzer for Wisconsin. This plan provided DNR with an objective means of selecting an analyzer which best meets the needs and resources of the agency. It has general applicability to all agencies and to private consultants and corporations as well.

The plan consists of three parts:

I. Pre-purchase evaluation and selection of the analyzer.
II. Purchase Contract Specifications based on the pre-purchase evaluation.
III. Acceptance Testing of the purchased analyzers.

PRE-PURCHASE EVALUATION

The pre-purchase evaluation defines the specifications that the analyzer must meet and then to determine which analyzer best meets these specifications.

1. Analysis and Rating of Performance Needs

Before evaluating individual analyzers, the performance required of the analyzer must be defined. Where will the analyzer be used - around a point source where concentrations of sulfur dioxide exceeding 500 parts per billion are not uncommon, or in a rural setting where values as high as 50 parts per billion are quite rare? What levels of accuracy and precision are needed? What should the response time of the analyzer be? Do the expected ambient concentrations change rapidly or over a period of hours? What maintenance requirements does the agency have - will operators attend the site daily, or only once per week? How much funding is available for this purchase?

Once the performance specifications are defined, they are ranked in order of their importance to the monitoring network. The most important specification receives the highest number and the least important specification receives a ranking of "1".

2. Instrument Assessment

An evaluation of each specific type of instrument must be made to decide which analyzers should be brought to the lab for further checkout. This assessment is a two step process.

a. The advantages and disadvantages of each type of instrument are determined by evaluating information provided by the manufacturer, as well as that found in the analyzer's operating manual. This involves a comparison of measurement principles, performance characteristics and the relative complexity of operation.

b. Several users of each analyzer are contacted to check on the analyzer's performance in the field. A user contact questionnaire which was developed by DNR which includes such information as the percent of valid data capture, the average number of instrument breakdowns since the analyzers were purchased, the parts replaced most frequently, and the percent span drift experienced.

The analyzer's ability to meet each of the performance specifications is converted to a numerical rating, with the highest number assigned to the analyzer which best meets the specification. The rating is multiplied by the ranking assigned that specification in the earlier needs analysis. This process is repeated for each specification, and the results for all specifications are added. The result is a ranking of instruments according to their apparent ability to meet the performance specifications. The three top rated analyzers are then evaluated further.

3. In-House Testing

The three analyzers with the highest scores in the Instrument Assessment are subjected to a laboratory checkout to determine which analyzer should be purchased. The in-house testing consists of evaluating the critical performance parameters identified in the earlier needs analysis. For example, if low ambient levels are routinely measured, instrument noise will be an important parameter. Each instrument is then checked for its noise level using the methods described by EPA in their regulations for equivalency testing. If low maintenance costs are required, the instrument is evaluated as to the type of parts used and the expected frequency of replacement, in an effort to estimate the costs.

Each analyzer is rated using the same rating method used in the earlier instrument assessment. The in-house testing scores are combined with the scores from the instrument assessment to give a grand total for each analyzer. The instrument with the highest score will be the one which best meets the monitoring need.

PURCHASE CONTRACT SPECIFICATIONS

The performance specifications for the instrument with the highest ranking are written into the contract for purchase. The purchase contract specifies a 60-day period, after instrument delivery, in which DNR can evaluate each instrument to assure that each one meets the performance specifications written into the contract. Instruments not meeting the specifications can be returned to the manufacturer for replacement, without charge to DNR.

The contract also requires the vendor to post a performance bond - 20% of the total purchase price - for a one year period. The bond would be forfeited for:

a. failure of any instrument to meet the performance specifications for at least one year,

b. failure of the vendor to honor a one year warranty on all instrument components,

c. failure of the vendor to provide a substitute analyzer to replace a faulty analyzer being repaired under the one year warranty, and

d. failure of any instrument to operate properly for more than 30 days during the first year of operation.

These contract specifications help insure that DNR will have reliable, functioning analyzers providing maximum data capture.

ACCEPTANCE TESTING

Before a new instrument is considered capable of generating valid ambient air quality data, it must be checked to insure that it meets the performance specifications in the purchase contract. As each instrument is received it is:

1. Inspected to be sure that all parts and optional equipment are present, connections are tight, and that each analyzer is configured the same way - same number of circuit boards, same type and size of pumps, etc.

2. Operated in the laboratory for at least one week to detect immediate malfunctions due to defective parts, poor connections, etc.

3. Tested for critical parameters - e.g., the noise level.

In addition, a random sampling of analyzers is chosen and more in-depth performance checks are conducted. If these checks fail to meet the performance specifications in the purchase contract, all analyzers will be checked in-depth.

Instruments passing through this process without problems are placed at monitoring sites and run simultaneously with the "old" analyzers for at least 30 days. The data obtained is used to determine if the new analyzer is functioning properly, and also to establish any difference in the data base due to the switch to the new analyzer. It is important to have this information when evaluating data from a site over a period of years.

PRACTICAL APPLICATION OF PROCUREMENT PLAN

The procedures previously discussed were used during the summer of 1978 by the State of Wisconsin to purchase 12 new sulfur dioxide analyzers. The first step in this process was to perform a needs analysis. This analysis indicated we were required to generate valid continuous ambient sulfur dioxide data at seven permanent stations in the Milwaukee area and at three mobile vans which collect data statewide. Also, there was a requirement to obtain continuous SO_2 data from sites in Green Bay and Madison. As mentioned earlier, by February 1980, all ambient air analyzers in state monitoring programs must be approved reference or equivalent model analyzers. Therefore, it was determined that the state needed to purchase 12 sulfur dioxide monitors approved by EPA as being a reference or equivalent method. In addition to this basic need, the following items were also specified in the analysis:

1) Generation of continuous SO_2 data.
2) Operate unattended for long periods of time (over weekends, etc.).
3) Generate valid SO_2 data in areas of both high and low ambient concentrations (minimum detectable limit to 1.000 ppm).
4) Capability of automated zeroing and spanning.
5) Efficient, cost-effective operation (low maintenance).

At the time of our study EPA-designated equivalent continuous SO_2 analyzers were available for purchase from five manufacturers. Following the needs analysis our next step in the procurement process involved contacting these companies for operating manuals of these analyzers, written results of their equivalency testing, plus a list of firms or governmental agencies that owned or operated their analyzers. We will refer to the five analyzers as A, B, C, D, and E. It should be noted here that most members of our monitoring staff leaned toward purchase of analyzer B at the beginning of the study. Analyzer B was favored due to the fact that it used the same method of detection presently in use by the Department - it was familiar to monitoring personnel. A number of major improvements in this method incorporated into analyzer B also made it much more attractive than the existing monitors using the same basic method of detection.

Within two weeks of notification by telephone, all companies had furnished us with operational manuals for their analyzers. Only company A provided us with a written report on their equivalency testing. The other companies indicated the data were available, however, it was in the form of very extensive technical documentation which they would provide us with if we absolutely needed the data. All of the manuals were examined and judged on the following criteria:

1) Readability and ease of understanding.
2) Sufficient information available to allow a chemist to troubleshoot the analyzer at the site.
3) Sufficient information available to allow an electronic technician to work on the analyzer (circuit diagrams, etc.).
4) Understandable start-up, operation, calibration, and maintenance instruction.
5) Listing of spare parts inventory.

In addition to the above information, operating specifications for each of the analyzers were taken from the manuals. This information included the following:

1) Standard ranges
2) Noise
3) Lower detectable limit
4) Rise, fall, lag time
5) Precision
6) Sample flow
7) Length of unattended operation
8) Hydrogen flow rate (if using H_2)
9) Ambient operating temperature

All the above information was organized into tables to allow easy comparison of criteria between analyzers. These are shown in Tables I and II attached to this report.

The user's list in all cases did not come as quickly as the manuals. Company E was so late in sending their user's list that we did not have sufficient time to contact users of their analyzers. A minimum of four users of each analyzer was contacted and questioned concerning each of the following:

1) Mechanical dependability
2) Electrical dependability
3) Chemical dependability
4) Ease of working with instrument
5/6) User experience with vendor
7) Cost of operation
8) Instrument downtime
9) Interference problems
10) Number of instruments in use and number of years in use

The above information for all of the users questioned for each analyzer was put in table form. Tables III-VI at the end of this report contain that data. Each manufacturer was then contacted again and asked about the following:

1) Location of factory repair service and response time
2) Warranty terms
3) Auto zero/span availability
4) Standard instrument ranges
5) Unit cost of instrument with auto zero/span and amount of discount with multiple order

This information was also placed in table form (Table VII) for all the analyzers to allow for ease of comparison between analyzers. Also considered in the pretesting segment of the procurement process were the following:

1) Vendor cooperation for pre-purchase agreement concerning in-house testing - This involved contacting each vendor to determine if they would allow us to use an analyzer of theirs, without cost, for a period of two to three weeks for the purpose of performance testing.
2) Required support equipment, e.g., electronic equipment, gas cylinders, high mortality parts, etc.
3) Conformity to existing calibration devices and site sampling manifolds.
4) Conformity to existing data acquisition systems and ability to be rack mounted.

The above information was also placed in a table (Table VIII) to allow for comparison between the analyzers. Finally a table (Table IX) of major advantages and disadvantages for each of the analyzers was drawn up for consideration in determining which three analyzers should be chosen for in-house testing.

To determine which three analyzers would be tested we used a total point-rating system. Each of the criteria considered in the pretesting data search was rated from 1-6 depending on its degree of importance. In our particular situation noise and precision were considered very important and were given a rating of 6. Sample flow, not considered as important, was given a rating of 2. Each analyzer was ranked from 1-5 depending upon how favorably they compared to other analyzers being checked for a particular criteria. A ranking of 5 meant that the analyzer was best among the analyzers considered for that particular criteria. To determine the number of points each analyzer received for each criteria, the rating and ranking numbers were multiplied together. These products were then summed for each analyzer. The analzyers with the highest total points would be the ones chosen for in-house testing. The pretesting work indicated that analyzers A, B, and C should be chosen for further testing. At this point in the procurement process analyzer B was still the favored analyzer.

In-house testing performed on the analyzers generated test data concerning the following parameters:

1) Noise
   - Zero Baseline
   - 80% Full Scale
2) Zero Drift
   - 12-Hour
   - 24-Hour
3) Span Drift
   - 24-Hour at 20% of Full Scale
   - 48-Hour at 80% of Full Scale
4) Precision
   - 20% of Full Scale
   - 80% of Full Scale
5) Lag, Fall, Rise, and Calibration Times

The testing procedures followed were taken from the Federal Register, Vol. 40, No. 33, Part II, Ambient Air Monitoring Reference and Equivalent Methods. Company C was slow in providing us with an analyzer for testing. We were not able to complete all the testing procedures on that analyzer. Results of the testing were summarized in a table (Table X). Prior to the in-house testing we had feared that response time for analyzer A would be too slow for our needs. Analyzer B was expected to have the most rapid response time. The surprising test results indicated that analyzer A had a more rapid response time than analyzers B and C.

Next analyzers A and B were moved to an active monitoring site where they were installed and operated for a two week period as if they were being used to routinely collect ambient SO_2 data. This included routine calibrations and zero/span checks. Testing was also done at the monitoring site to determine if analyzer response was adversely affected by any interference. The analysis method for analyzer B was flame photometry. A Technical Assistance Document (EPA-600/4-78-024) concerning the use of flame photometric detectors for measurement of SO_2 in ambient air referred to a suppression of analyzer response for this method by carbon dioxide (CO_2) gas. We discovered at this point in the testing that analyzer B was subject to the above interference from CO_2. We also found that analyzer B was less stable than analyzer A during calibration and zero/span checking.

SELECTION OF ANALYZER AND CHOICE

At the end of the testing we had obtained sufficient information to allow a decision to be made on instrument procurement. Copies of all the data generated during the procurement process were distributed to all DNR parties affected by the instrument purchase. A meeting between these parties was held to decide on which analyzer to purchase. All the data was reviewed and the advantages and disadvantages of each of the analyzers were discussed. As mentioned earlier analyzer B was heavily favored before the procurement process began. However, as a result of the data collected and testing done, analyzer A (T.E.C.O. Model #43) emerged as the analyzer which would best satisfy our needs expressed earlier in the needs analysis. Had we not involved ourselves in this procurement process, it is possible we would have purchased analyzer B, and its associated problems, without giving full consideration to the T.E.C.O. We intend on using this procurement process for purchasing all capital equipment in the future and strongly recommend other agencies use this or a similar process for all their equipment purchases.

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Section 12

Performance Audits

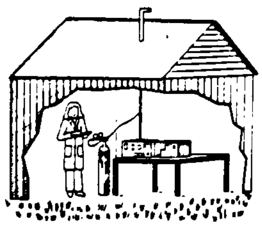
Lesson Goal

To familiarize you with performance auditing considerations (especially when conducting performance audits of continuous ambient air quality analyzers).

Lesson Objectives

At the end of this lesson, you should be able to—

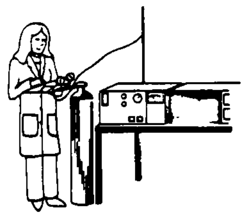
1. distinguish between a performance audit and a system audit,
2. describe differences in performance audit procedures for continuous versus manual measurement methods,
3. list the four purposes of performance audits, and
4. describe considerations in conducting performance audits of continuous ambient air quality analyzers.

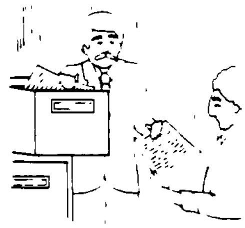


PERFORMANCE AUDITS

AUDITS

Performance | System





• Quantitative | • Qualitative

PURPOSES OF PERFORMANCE AUDITS

- identify sensors operating out-of-control
- identify systematic bias of monitoring network
- measure improvement in data quality
- assess accuracy of monitoring data

PERFORMANCE AUDITS

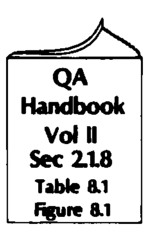
Continuous

- sampling/analysis/data reduction

Manual

- sampling
- analysis
- data reduction

PROCEDURE FOR MANUAL METHODS



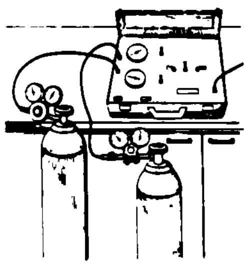
- Sampling – check flow rate with rotameter
- Analysis – analyze reference samples
- Data Reduction – perform independent calculations
- Plot audit results on control chart

PROCEDURE FOR CONTINUOUS AMBIENT AIR ANALYZERS

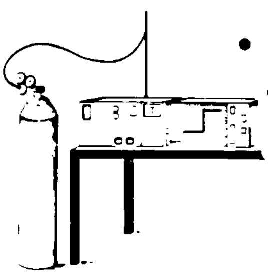
1. Select audit materials
2. Select audit concentration levels
3. Determine auditor's proficiency
4. Select out-of-control limits

5. Establish communications system
6. Conduct audit
7. Verify stability of audit materials
8. Prepare audit report
9. Follow up audit recommendations

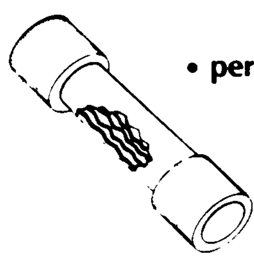
1. Select audit materials



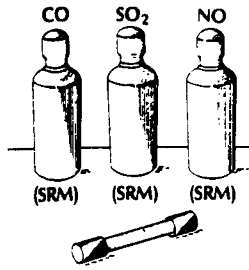
- high concentration audit cylinder with dilution system



- low concentration audit cylinder

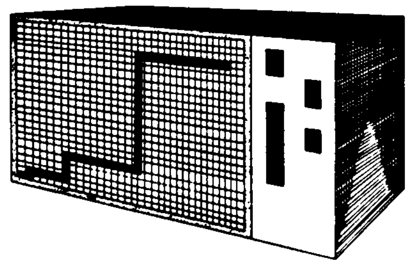


- permeation tube



- use materials traceable to NBS Standard Reference Materials or CRMs

2. Select audit concentration levels



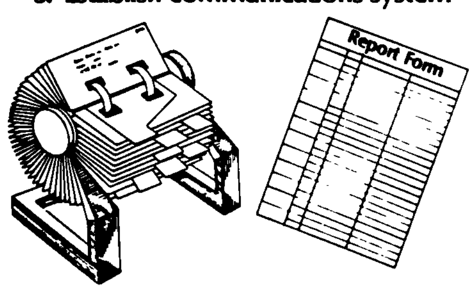
3. Determine auditor's proficiency

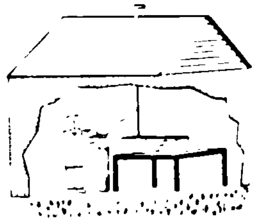
Cylinder No.	Known Concentration Value	Auditor's Measured Concentration Value
1		
2		
3		

4. Select out-of-control limits

$$\% \text{ Diff.} = \frac{\text{analyzer value} - \text{known value}}{\text{known value}} \times 100$$

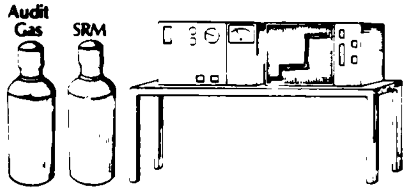
5. Establish communications system



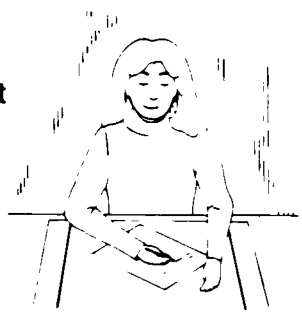


6. Conduct audit

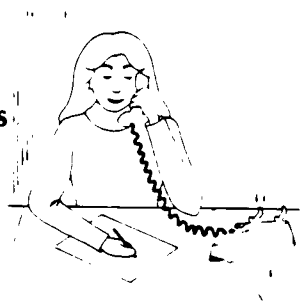
7. Verify stability of audit materials



8. Prepare audit report



9. Follow up audit recommendations



Section 13

System Audits

Lesson Goal

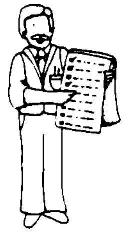
To familiarize you with system auditing procedures.

Lesson Objectives

At the end of this lesson, you should be able to—

1. state the purpose of system auditing,
2. recognize items that should be evaluated during a system audit, and
3. describe the procedure for conducting a system audit.

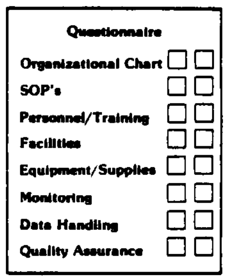
SYSTEM AUDIT



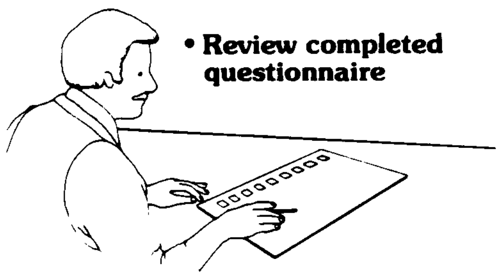
- independent, on-site inspection and review of quality assurance system
- qualitative appraisal of system

PROCEDURE FOR CONDUCTING A SYSTEM AUDIT

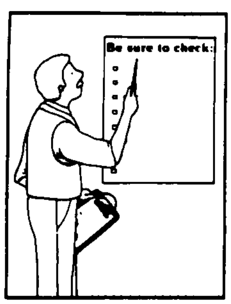
- Prepare questionnaire
- Review questionnaire
- Identify weaknesses/prepare check list
- Arrange entrance interview
- Perform audit
- Conduct exit interview
- Prepare report
- Follow up recommendations



- Prepare pre-audit survey questionnaire

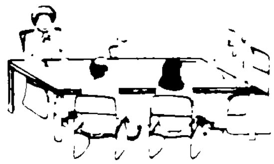


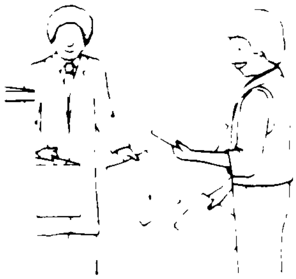
- Review completed questionnaire



- Identify organization's weaknesses and prepare audit check list

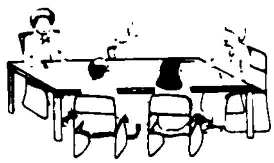
• Arrange entrance interview

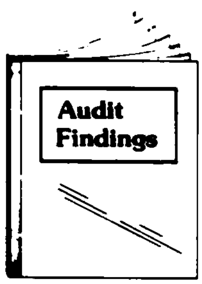




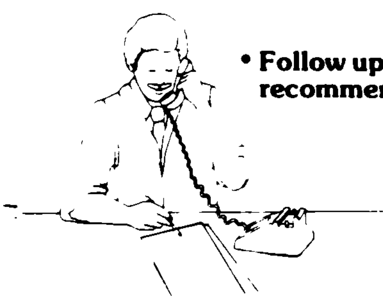
• Perform audit

• Conduct exit interview





• Report findings to audited organization



• Follow up audit recommendations

Section 14

Quality Assurance Requirements for SLAMS and PSD

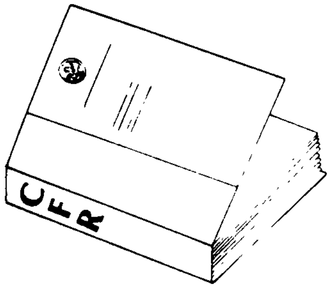
Lesson Goal

To familiarize you with quality assurance regulations pertaining to ambient air quality monitoring (especially data-quality assessment in terms of precision and accuracy requirements).

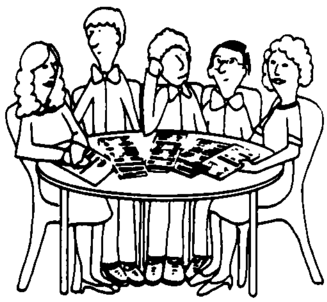
Lesson Objectives

At the end of this lesson, you should be able to—

1. briefly describe the Standing Air Monitoring Work Group (SAMWG) and its major quality assurance finding and recommendation,
2. list the four types of ambient air monitoring stations defined in 40 CFR Part 58,
3. list the appendixes of 40 CFR Part 58 that describe quality assurance requirements for ambient air monitoring,
4. recognize that Appendixes A and B describe quality assurance requirements for SLAMS and PSD stations, respectively,
5. list the two quality assurance functions required by 40 CFR Part 58 Appendixes A and B,
6. describe air monitoring activities that must be addressed by the quality assurance program,
7. distinguish between precision and accuracy,
8. recognize the need for precision and accuracy assessments,
9. describe the precision and accuracy checks required for manual and automated measurement methods,
10. compute precision and accuracy assessments for manual and automated measurement methods (given necessary equations),
11. describe quality assurance reporting requirements, and
12. compare and contrast quality assurance requirements for SLAMS and PSD stations.



QUALITY ASSURANCE FOR SLAMS AND PSD



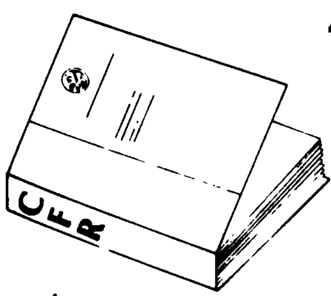
STANDING AIR MONITORING WORK GROUP (SAMWG)

MAJOR QA FINDING

- questionable data quality

MAJOR QA RECOMMENDATION

- establish formal QA programs



40 CFR 58

MONITORING STATIONS

SLAMS	State and Local Air Monitoring Stations
NAMS	National Air Monitoring Stations
SPMS	Special Purpose Monitoring Stations
PSD	Prevention of Significant Deterioration

40 CFR 58

APPENDIX A — "Quality Assurance Requirements for State and Local Air Monitoring Stations (SLAMS)"

APPENDIX B — "Quality Assurance Requirements for Prevention of Significant Deterioration (PSD) Air Monitoring"

APPENDIX A

QA Functions

- control requirements
- data quality assessment

CONTROL REQUIREMENTS

- are in general terms
- states to develop and implement a QA program which will:
  - provide data of adequate quality to meet monitoring objectives
  - minimize loss of air quality data due to malfunction or out-of-control conditions
- must be approved by Regional Administrator

GUIDANCE

- Quality Assurance Handbook for Air Pollution Measurement Systems
  - Volume I - Principles
  - Volume II - Ambient Air Specific Methods
- Reference and Equivalent Methods given in 40 CFR 50 and 40 CFR 53
- Operation and Instruction Manuals of Designated Analyzers

PROGRAM CONTENT

- method or analyzer selection
- equipment installation
- calibration
- zero and span checks and adjustment
- quality control checks
- control limits for zero, span and other quality control checks - corrective action

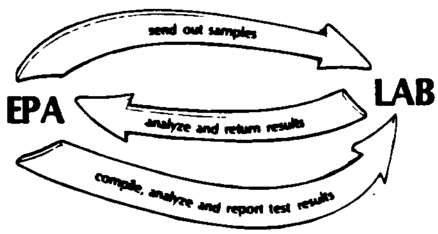
PROGRAM CONTENT
(continued)

- use of multiple ranges
- preventive maintenance
- quality control procedures for episode monitoring
- recording and validating data
- documentation of QC information

TRACEABILITY REQUIREMENTS

- gaseous standards for CO, SO_2, and NO_2 traceable to NBS or CRM
- O_3 test concentrations measured by UV photometer
- flow measuring instruments traceable to authoritative volume

EPA INTERLABORATORY
PERFORMANCE AUDIT PROGRAM

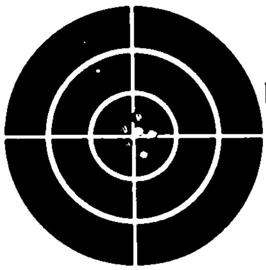


EPA SYSTEM AUDIT

- facilities
- equipment
- procedures
- documentation
- personnel
- (all 23 QA elements)

QA program reviewed for:

- adequacy
- compliance

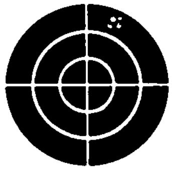


DATA QUALITY ASSESSMENT:
Precision and Accuracy

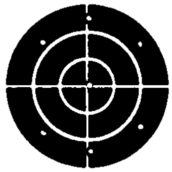
PRECISION AND ACCURACY

PRECISION REFERS TO REPRODUCIBILITY

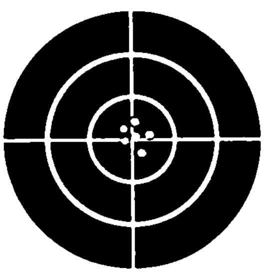
ACCURACY REFERS TO CORRECTNESS



Precision is good but accuracy is poor.



Accuracy is good but precision is poor.



Both precision and accuracy are good.

IMPORTANCE OF
PRECISION AND ACCURACY
DETERMINATIONS

- needed to determine quality of data recorded
- useful for data validation
- minimizes generation of erroneous data

MANUAL METHODS

Internal Checks

	Precision	Accuracy	
		Flow	Analytical
SO_2	Collocated Sampler	–	Local Audit
NO_2	" "		Local Audit
TSP	" "	Local Audit	
Pb	Duplicate Filter Strips/Aliquots	Local Audit	Local Audit
Extent or Frequency	SO_2, NO_2, TSP - 2 Sites Pb - 1 Site	1 Level 25% each quarter At least 1 per quarter All samplers each year	SO_2, NO_2 - 3 Levels each analysis day at least twice per quarter Pb - 3 Levels at least 3 times per quarter

MANUAL METHODS

External Audits

	Performance		System
	Flow	Analytical	
SO_2		EMSL	Region
NO_2	–	EMSL	Region
TSP	EMSL		Region
Pb	EMSL	EMSL	Region
Extent or Frequency	Annual	Semi-Annual	Annual

MANUAL METHODS
Precision

COLLOCATED SAMPLER DATA BY SITE

Day	Duplicate Sampler	Official Sampler	Difference	d_i (%)
1 ↓ n_j	y_i ↓	x_i ↓	$y_i - x_i$ ↓	$\frac{y_i - x_i}{x_i}(100)$ ↓
				$\bar{d}_i$

95% probability limits $= \bar{d}_j \pm \frac{1.96}{\sqrt{2}} s_j$

$$\bar{d}_j = \sum_{i=1}^{n} d_i / n$$

$$s_j = \left[\frac{\sum d_i^2 - (\sum d_i)^2 / n}{n-1} \right]^{1/2}$$

COLLOCATED SAMPLER DATA BY REPORTING ORGANIZATION

Site	Number Days	Average Percent Difference	Standard Deviation Percent Differences
1	n_1	$\bar{d}_1$	s_1
↓	↓	↓	↓
k	n_k	$\bar{d}_k$	s_k

95% probability limits $= \bar{D} \pm \frac{1.96}{\sqrt{2}} s_a$

$$\bar{D} = (n_1\bar{d}_1 + n_2\bar{d}_2 + \ldots + n_k\bar{d}_k)/(n_1 + n_2 + \ldots + n_k)$$

$$s_a = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2 + \ldots (n_k-1)s_k^2}{(n_1 + n_2 + \ldots + n_k)-k}}$$

COLLOCATED TSP SAMPLERS

To do:

Compute 95% probability limits

Given:

Site	Duplicate	Official
1	83.0 μg/m³	81.9 μg/m³
	119.9	113.5
	128.4	122.7
2	127.9	129.0
	137.5	134.2
	118.0	113.4

FOR SITE 1

Day	Duplicate Sampler	Official Sampler	Difference	d_i (%)
1	83.0	81.9	+ 1.1	+ 1.3
2	119.9	113.6	+ 6.3	+ 5.5
3	128.4	122.7	+ 5.7	+ 4.6
				$\bar{d}_1 = +3.80$

$s_1 = 2.21$

FOR SITE 2

Day	Duplicate Sampler	Official Sampler	Difference	d_i (%)
1	127.9	129.0	- 1.1	- 0.9
2	137.5	134.2	+ 3.3	+ 2.5
3	118.0	113.4	+ 4.6	+ 4.1
				$\bar{d}_2 = 1.90$

$s_2 = 2.55$

Site	Number Days	Average Percent Difference	Standard Deviation Percent Differences
1	3	- 3.80	2.21
2	3	+ 1.90	2.55

$$\overline{D} = \left[(3)\,(3.80) + (3)\,(1.90) \right] \quad 3 + 3 = 2.85$$

$$s_a = \sqrt{\frac{(3-1)\,(2.21)^2 + (3-1)\,(2.55)^2}{(3+3)-2}} = 2.38$$

$$\text{95\% probability limits} = \overline{D} \pm \frac{1.96}{\sqrt{2}} (s_a)$$

$$= 2.85 \pm \frac{1.96}{\sqrt{2}} (2.38)$$

$$= 2.85 \pm 3.30$$

$$= +6.15\% \text{ or } +06$$

$$= -\ 0.45\% \text{ or } -\ 00$$

MANUAL METHODS
Accuracy

ACCURACY DATA BY REPORTING ORGANIZATION

Analysis Day or Hi-Vol Sampler Audit	Observed Level	Known Level	Difference	d_i (%)
1	y_i	x_i	$y_i - x_i$	$\frac{y_i - x_i}{x_i}$ (100)
↓	↓	↓	↓	↓
k				
				$\overline{D}$

$$\text{95\% probability limits} = \overline{D} \pm 1.96\,(s_a)$$

$$\overline{D} = (d_1 + d_2 + \ldots + d_k)/k$$

$$s_a = \sqrt{\frac{1}{k-1}\left[\sum_{i=1}^{k} d_i^2 - \frac{1}{k}\left(\sum_{i=1}^{k} d_i\right)^2\right]}$$

AUTOMATED METHODS

Internal Checks

	Precision	Accuracy
SO_2	Precision Check	Local Audit
CO	Precision Check	Local Audit
NO_2	Precision Check	Local Audit
O_3	Precision Check	Local Audit
Extent or Frequency	Biweekly	3-4 Levels 25% each quarter At least 1 per quarter All analyzers each year

AUTOMATED METHODS

External Audits

	Performance	System
SO_2	EMSL	Region
CO	EMSL	Region
NO_2	—	Region
O_3	—	Region
Extent or Frequency	Semi-Annual	Annual

AUTOMATED METHODS
Precision

CO PRECISION CHECKS BY ANALYZER 1

Biweekly Check	Observed Concentration (Y_i)	Known Concentration (X_i)	Difference ($Y_i - X_i$)	d_i (%)
1	8.00	8.15	- 0.15	- 1.8
2	8.05	8.15	- 0.10	- 1.2
3	8.07	8.15	- 0.08	- 1.0
4	8.17	8.15	+ 0.02	+ 0.2
5	8.10	8.15	- 0.05	- 0.6
6	8.04	8.15	- 0.11	- 1.3
				$\bar{d}_1 = - 0.95$

$s_1 = 0.69$

$$95\%\ \text{probability limits} = \bar{d}_1 \pm 1.96\ (s_1)$$

$$= - 0.95 \pm 1.96\ (0.69)$$

$$= +0.40\%\ \text{or}\ +00$$

$$= - 2.30\%\ \text{or}\ - 02$$

CO PRECISION CHECKS
BY REPORTING ORGANIZATION

Analyzer	Number Biweekly Checks	$\bar{d}_i$	s_i
1	n_1	$\bar{d}_1$	s_1
↓	↓	↓	↓
k	n_k	$\bar{d}_k$	s_k

$$\bar{D} = \frac{\sum_{i=1}^{k} n_i \bar{d}_i}{\sum_{i=1}^{k} n_i}$$

$$s_a = \sqrt{\frac{\Sigma (n_i - 1) s_i^2}{\Sigma (n_i - 1)}}$$

95% probability limits $= \bar{D} \pm 1.96(s_a)$

Analyzer	Number Biweekly Checks	$\bar{d}$	s
1	6	- 0.95	0.69
2	6	+1.03	0.94
3	6	- 1.76	0.51

$$\bar{D} = \frac{(6)(-0.95) + (6)(+1.03) + (6)(-1.76)}{6+6+6}$$

$$= -0.56$$

$$s_a = \sqrt{\frac{(5)(0.69)^2 + (5)(0.94)^2 + (5)(0.51)^2}{5+5+5}}$$

$$= 0.73$$

95% probability limits $= \bar{D} \pm 1.96\ (s_a)$

$= -0.56 \pm 1.96\ (0.73)$

$= +0.87\%$ or $+01$

$= -1.99\%$ or -02

AUTOMATED METHODS

Accuracy

ACCURACY DATA BY CONCENTRATION LEVEL

Analyzer Audit	Observed Level	Known Level	Difference	d_i (%)
1	y_i	x_i	$y_i - x_i$	$\frac{y_i - x_i}{x_i}(100)$
↓	↓	↓	↓	↓
k				
				$\bar{D}$

95% probability limits $= \bar{D} \pm 1.96\ (s_a)$

SO_2 AUTOMATED METHOD
LEVEL 3 (0.35 - 0.45 ppm)

Analyzer Audit	Observed Level	Known Level	Difference	d_i (%)
1	0.39	0.43	- 0.04	- 9.3
2	0.40	0.42	- 0.02	- 4.8
3	0.45	0.44	+ 0.01	+ 2.3
				$\bar{D}$ = - 3.9

$s_a = 5.8$

95% probability limits $= \bar{D} \pm 1.96\ (s_a)$

$= -3.9 \pm 1.96\ (5.8)$

$= +7.5\%$ or $+08$

$= -15.0\%$ or -15

REPORTING REQUIREMENTS

SLAMS

- pooled quarterly precision and accuracy averages
- reported through EPA Regional Office to EMSL within 90 days after end of quarter

REPORTING ORGANIZATION

A state or subordinate organization responsible for a set of stations which monitor the same pollutant and for which precision and accuracy assessments can be pooled.

A reporting organization should usually have:

- common team of field operators
- common calibration facilities
- common laboratory support

PRECISION AND ACCURACY SUMMARY ANALYSIS

- quarterly summary analysis from EMSL to states — within 6 months after end of each quarter
- annual summary analysis from EMSL to states — within 9 months after end of year

EPA REGIONAL SYSTEM AUDIT

- **Verbal Report**
  From: Regional Audit Team
  To: Auditee
  When: Immediately following audit
- **Written Report**
  From: Regional Audit Team
  To: Auditee
  Copy: State
  When: Within 1 month of audit

- **Annual Regional Summary**
  From: EPA Regional Offices
  To: States/EMSL
  When: Within 6 months after end of year
- **Annual National Summary**
  From: EMSL
  To: States (EPA Regional Offices)
  When: Within 12 months after end of year

EMSL PERFORMANCE AUDITS

- **True Values (written)**
  From: EMSL
  To: Each Reporting Organization
  When: Within 1 month after each audit

- **Annual Summary Report**
  From: EMSL
  To: Regions, States, Reporting Organizations
  When: Within 9 months after end of year

APPENDIX B

Quality assurance requirements are the same as Appendix A requirements except for the following:

APPENDIX B

Topic	Appendix A	Appendix B
Monitoring and QA Responsibility	State Local agency	Source Owner Operator
Monitoring Duration	Indefinitely	Up to 12 months
QA Reporting Period	Calendar Quarter	Sampling Quarter
Accuracy Assessment - Audits	Standards and equipment different from spanning and calibration, prefer different personnel.	Personnel, standards, and equipment different from spanning and calibration.

APPENDIX B (continued)

Topic	Appendix A	Appendix B
Audit rate		
Automated	25% per quarter	100% per quarter
Manual	Hi-Vol 25% per quarter SO_2 & NO_2 - each analysis day Pb - 1 [illegible] per quarter	100% per quarter Pb each analysis day
Precision Assessment		
Collocated Sampling	Two sites every sixth day for SO_2, NO_2, TSP	One site once per week for TSP and Pb
Pb	Duplicate filter strips, Aliquots	Collocated Sampling
Reporting	By reporting organization	By monitoring [illegible]

DATA ASSESSMENT REPORT

Expires

STATE	REPORTING ORGANIZATION	YEAR	QUARTER
1 2	3 4 5	6 7	8

SEND COMPLETED FORM TO REGIONAL OFFICE WITH COPY TO EMSL/RTP

NAME OF REPORTING ORGANIZATION ______________________________

AUTOMATED ANALYZERS

PRECISION

		NO. OF ANALYZERS[1]	NO. OF PRECISION CHECKS	PROBABILITY LIMITS LOWER	PROBABILITY LIMITS UPPER
A. CO	C 4 2 1 0 1 (9–14)	15–17	18–21	+/- (22–27)	+/-
B. NO_2	C 4 2 6 0 2 (9–14)	15–17	18–21	+/- (22–27)	+/-
C. O_3	C 4 4 2 0 1 (9–14)	15–17	18–21	+/- (22–27)	+/-
D. SO_2	C 4 2 4 0 1 (9–14)	15–17	18–21	+/- (22–27)	+/-
E. ___	C (9–14)	15–17	18–21	+/- (22–27)	+/-

ACCURACY

		TRACEABILITY	SOURCE OF LOCAL PRIMARY STANDARD[2]	NO. OF AUDITS	LEVEL 1 LOWER	LEVEL 1 UPPER	LEVEL 2 LOWER	LEVEL 2 UPPER	LEVEL 3 LOWER	LEVEL 3 UPPER	LEVEL 4 LOWER	LEVEL 4 UPPER	NO. OF AUDITS AT LEVEL 4
A. CO	C 4 2 1 0 1 (28–33)	34	35	36–38	+/- (39–44)	+/-	+/- (45–50)	+/-	+/- (51–56)	+/-	+/- (57–62)	+/-	63–65
B. NO_2	C 4 2 6 0 2 (28–33)	34	35	36–38	+/- (39–44)	+/-	+/- (45–50)	+/-	+/- (51–56)	+/-	+/- (57–62)	+/-	63–65
C. O_3	C 4 4 2 0 1 (28–33)	34	35	36–38	+/- (39–44)	+/-	+/- (45–50)	+/-	+/- (51–56)	+/-	+/- (57–62)	+/-	63–65
D. SO_2	C 4 2 4 0 1 (28–33)	34	35	36–38	+/- (39–44)	+/-	+/- (45–50)	+/-	+/- (51–56)	+/-	+/- (57–62)	+/-	63–65
E. ___	C (28–33)	34	35	36–38	+/- (39–44)	+/-	+/- (45–50)	+/-	+/- (51–56)	+/-	+/- (57–62)	+/-	63–65

1 COUNT ONLY REFERENCE OR EQUIVALENT MONITORING METHODS

2 Identify according to the following code

A. NBS SRM
B. EMSL REFERENCE GAS
C. VENDER CRM
D. PHOTOMETER
E. BAKI
F. OTHER, SPECIFY ______________

OMB No. 158-R0012
Expires

DATA ASSESSMENT REPORT

STATE	REPORTING ORGANIZATION	YEAR	QUARTER
1 2	3 4 5	6 7	8

SEND COMPLETED FORM TO REGIONAL OFFICE WITH COPY TO EMSL/RTP

NAME OF REPORTING ORGANIZATION ____________________

MANUAL METHODS

PRECISION

		NO. OF SAMPLERS [1]	NO. OF COLLOCATED SITES	NO. OF COLLOCATED SAMPLES < LIMIT	PROBABILITY LIMITS LOWER	PROBABILITY LIMITS UPPER	NO. OF VALID COLLOCATED DATA PAIRS
A. TSP	1 1 1 1 0 1 (9–14)	15–17	18–19	20–23	+/– (24–29)	+/–	58–60
B. SO_2	1 4 2 4 0 1 (9–14)	15–17	18–19	20–23	+/– (24–29)	+/–	58–60
C. NO_2	1 4 2 6 0 2 (9–14)	15–17	18–19	20–23	+/– (24–29)	+/–	58–60
D. Pb	1 1 2 1 2 8 (9–14)	15–17	18–19	20–23	+/– (24–29)	+/–	58–60

LIMITS APPLICABLE TO BLOCKS 20–23

TSP: 20 μg TSP/m^3

SO_2: 40 μg SO_2/m^3

NO_2: 30 μg NO_2/m^3

Pb: 0.15 μg Pb/m^3

ACCURACY

			NO. OF AUDITS	PROBABILITY LIMITS LEVEL 1 LOWER	LEVEL 1 UPPER	LEVEL 2 LOWER	LEVEL 2 UPPER	LEVEL 3 LOWER	LEVEL 3 UPPER
A. TSP	1 1 1 1 0 1 (30–35)	A (36)	37–39	+/– (40–45)	+/–	+/– (46–51)	+/–	+/– (52–57)	+/–
B. SO_2	1 4 2 4 0 1 (30–35)	B (36)	37–39	+/– (40–45)	+/–	+/– (46–51)	+/–	+/– (52–57)	+/–
C. NO_2	1 4 2 6 0 2 (30–35)	C (36)	37–39	+/– (40–45)	+/–	+/– (46–51)	+/–	+/– (52–57)	+/–
D. Pb	1 1 2 1 2 8 (30–35)	D (36)	37–39	+/– (40–45)	+/–	+/– (46–51)	+/–	+/– (52–57)	+/–

[1] COUNT ONLY REFERENCE OR EQUIVALENT MONITORING METHODS.

Precision and Accuracy Data from State and Local Air Monitoring Networks: Meaning and Usefulness

Raymond C. Rhodes
U.S. Environmental Protection Agency

Presented at 73rd APCA Annual Meeting and Exhibition in Montreal, Quebec, Canada, June 1980.

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Precision and Accuracy Data from State and Local Air Monitoring Networks: Meaning and Usefulness

R. C. Rhodes

Introduction

Appendix A of the EPA air monitoring regulations of May 10, 1979 include requirements aimed at improving the quality of air monitoring data obtained by state and local networks. The requirements involve such aspects as network design, site and probe location, use of reference or equivalent methodology, and the establishment and documentation of quality assurance programs. State and local agencies are also required to perform special checks to determine the precision and accuracy of their pollutant measurement systems and to report the results of the checks to EPA Regional Offices and to the Environmental Monitoring Systems Laboratory (EMSL) at Research Triangle Park, North Carolina. The requirements for reporting precision and accuracy data are effective January 1, 1981.

Precision and Accuracy

Precision and accuracy are two fundamental measures of the quality of data from a measurement process. Simply stated, "precision" is a measure of repeatability of the measurement process when measuring the same thing, and "accuracy" is a measure of closeness of an observed measurement value to the truth. Precision and accuracy of air monitoring or measurement data cannot be ascertained from the data themselves, but require the use of specially planned checks from which precision and accuracy can be estimated.

Precision

In general, precision can be determined under various conditions. For example, precision will be better when repeated laboratory measurements are made with a single instrument on the same day and by the same analyst than when the repeated measurements are made on different instruments, on different days, and by different analysts. The conditions under which precision is measured are carefully defined in the regulation to properly interpret and use the estimates and to assure comparability of the precision estimates.

Because all components of a total measurement process contribute error to a reported value, it is necessary to determine the precision under conditions which involve all components of the measurement process. For air monitoring systems, the best and easiest way to accomplish this is to use duplicate, or collocated, measurement systems to obtain duplicate results when sampling the same air. The agreement between the results is a measure of precision of the entire measurement process.

For manual methods, the regulations specify the technique of using collocated samplers for estimation of precision. Not only does this technique involve all parts of the total measurement process, but it determines the precision using actual concentrations of pollutants in the ambient air.

For automated analyzers, the use of collocated sampling instruments would be best to measure repeatability. However, the cost would be prohibitive. The next most desirable technique would be to perform "span" checks at approximately ambient concentration levels at random points in time between successive instrument adjustments. In this way, the precision is a measure of instrument drift from the time of the most recent instrument adjustment or calibration to the time of the precision check. The regulations require the precision checks to be made at two-week intervals or more frequently. Although not stated in the regulation, following introduction of the "precision" gas and after reaching equilibrium conditions, an average of the instrument output should be obtained over some relatively short period of time, e.g., five minutes. Thus, the precision estimates have meaning only with respect to the time-averaging period over which the average values are obtained. Precision estimates for other time-averaging periods would have to be determined by knowing or assuming a drift pattern between successive instrument adjustments/calibrations.

Accuracy

To measure the closeness of an observed measurement value to the truth, some material or condition of known (true) property must be measured by the measurement system being checked. The measurement system is "challenged" with the "known" to obtain the observed measurement. For automated analyzers, "known" gaseous pollutant concentrations, determined using different standards and different equipment from those used for routine calibration and spanning, are introduced into the measurement instruments. In this way, two different calibration systems are involved: the one used for routine monitoring and the one used to assess the "known."

For manual methods, it is difficult to challenge the total measurement system with "knowns." Therefore, an accuracy audit is made of only a portion of the measurement system. The two major portions of manual measurement systems are the flow and the analytical measurements. The flow measurement portion of the TSP method, and the analytical measurement portion of the NO_2 and SO_2 bubbler methods are audited for accuracy.

Regulation Requirements

Based on the above considerations, special checks/audits were devised. Table I summarizes the minimum requirements specified in Appendix A of the May 10, 1979 regulation.

Precision, Automated Analyzers

Precision checks are conducted at least biweekly and are made with the following concentrations of gases: 0.08—0.010 ppm for SO_2, O_3, NO_2, and 8—10 ppm for CO. These precision checks may be made using the same materials, equipment, and personnel routinely used for instrument calibration spanning.

Table I. Special checks and audits for estimation of precision and accuracy.

	Precision	Accuracy (local audit)	
Automated analyzers (SO_2, CO, NO_2, O_3)			
Type check	Precision check at one concentration	3 or 4 concentrations	
Frequency	Biweekly	25% of the analyzers each quarter At least 1 per quarter	
Scope	All monitoring instruments	All analyzers each year	
Manual methods			
Type check		*Flow*	*Analytical*
SO_2	Collocated samplers 2 sites	—	3 levels
NO_2		—	
TSP		1 level	—
Frequency	Each monitoring day	25% of the sites each quarter At least 1 per quarter	Each analysis-day At least twice per quarter
Scope	2 sites (of high concentration)	All sites each year	(Not applicable)

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Precision, Manual Methods

Precision checks are made using collocated samplers at at least two sites (of high concentration). One of the collocated samplers will be randomly designated as the official sampler for routine monitoring; the other shall be considered the duplicate. Results from the duplicate are to be obtained each day the designated sampler is operated unless the samplers are operated more frequently than every sixth day, in which case at least one duplicate is required each week.

Accuracy, Automated Analyzers

Automated analyzers are challenged (audited) with known pollutant concentrations at three levels (or four levels, in the case of episode analyzers), in accordance with Table II:

Table II. Automated analyzer audit concentrations (ppm)

	Concentration range	
Audit level	SO_2, NO_2, O_3	CO
1	0.03—0.08	3— 8
2	0.15—0.20	15—20
3	0.40—0.45	40—45
4	0.80—0.90	80—90

Twenty-five percent of the automated analyzers of each type in the monitoring network are to be audited once each calendar quarter so as to represent a random sample for the entire network. Thus, for each quarter, the results represent a random sample from all of the analyzers. However, at least one analyzer shall be audited each quarter and all analyzers shall be audited each year. Since the audits are to be conducted with standards and equipment different from that used for calibration and spanning (the analyst should also be different), when the audit is performed within the quarter is not critical.

Accuracy, Manual Methods

For manual methods an accuracy audit is made of only a portion of the measurement system. For TSP, only the flow measurement portion is audited; for NO_2 and SO_2, only the chemical analytical portion is audited.

The flow rate audits for TSP are made at the normal operating level. Twenty-five percent of the sites shall be audited each quarter, so as to represent a random sample for the entire network. However, at least one site shall be audited each quarter and all sites shall be audited each year.

For the NO_2 and SO_2 methods, audit samples in the following ranges are used: 0.2—0.3 μg/ml; 0.5—0.6 μg/ml; 0.8—0.9 μg/ml. An audit at each concentration level shall be made on each day of analysis of routine monitoring samples, and the audits shall be made at least twice each quarter.

Computations

Signed Percentage Differences

The general form for computing individual signed percentage differences, d_i, whether for precision checks or for accuracy audits, is:

$$d_i = \frac{Y_i - X_i}{X_i}(100), \quad (1)$$

where, for accuracy audits (both automated analyzers and manual methods) and for automated analyzer precision checks, Y represents the observed value and X represents the known value. For manual method precision estimates (collocated samplers), Y represents the duplicate sampler value and X represents the designated sampler value.

Percentage differences instead of actual differences are used because errors in precision and errors in accuracy are generally proportional to concentration levels.

Signed percentage differences instead of absolute percentage differences are used to reveal or highlight any systematic errors that may need to be investigated and corrected to further improve the precision and accuracy of the monitoring data. Absolute percentage differences would not enable a separation of the systematic errors from the random errors.

Data Summarization

Precision and accuracy data are summarized and reported for each calendar quarter.

Precision. For each analyzer or site, the individual signed percentage differences are summarized by calculating an arithmetic average, $\bar{d}_j$, and a standard deviaion, S_j. Ninety-five percent probability limits can be calculated for each instrument or site for local network information, using the following formula:

$$\bar{d}_j \pm 1.96\ S_j. \quad (2)$$

Although the regulations do not require such limits to be computed, they should be of particular interest and value for the local network as a supplement to their routine internal quality control. However, for reporting to EPA, a consolidated set of 95 percent probability limits,

$$\bar{D} \pm 1.96\ S_a, \quad (3)$$

are computed for automated analyzers: where the $\bar{D}$ is the weighted average of the $\bar{d}_j$, and S_a is the pooled, weighted valued computed from the S_j.

The expression for the probability limits for precision for collocated samplers is:

$$\bar{D} \pm 1.96\ S_a/\sqrt{2}. \quad (4)$$

This $\sqrt{2}$ factor is introduced to correct for the statistical accumulation of imprecision of results from both the duplicate and the designated samplers. The probability limits are thereby put in terms of individual reported values, the same as for the other probability limits.

Accuracy. From the d_i values obtained from the accuracy audit checks at a given concentration (or flow) level, an average $\bar{D}$ and S_a are computed. For reporting to EPA, 95 percent probability limits are computed using Equation 3.

Meaning of Probability Limits

Average Value, Precision

Automated Analyzers. The $\bar{d}_j$ values for each instrument represent the average bias of results due to instrument drift. The $\bar{D}$ simply represents, for the network, the average of the $\bar{d}_j$.

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Manual Methods. The $\bar{d}_j$ values at each collocated site represent the average bias between the results from the collocated samplers. The $\bar{D}$ simply represents, for the network, the average of the $\bar{d}_j$.

Probability Limits, Precision

Automated Analyzers. The width or spread of the limits represents the variability of the individual instrument drift values for each instrument. The spread of the limits, $\bar{D} \pm 1.96\ S_a$, represents the average within instrument variability for the network.

Manual Methods. The spread of the limits, $\bar{d}_j \pm (1.96)\ S_j/\sqrt{2}$, represents $1/\sqrt{2}$ times the variability of differences between the daily results of the collocated samplers, or the expected variability of results from a given site, if repeated daily values could be obtained when measuring the same pollutant concentration. For the network, the spread of the limits, $\bar{D} \pm 1.96\ S_a/\sqrt{2}$, represents the corresponding values based on the average within-site variability.

Average Value, Accuracy

Automated Analyzers. The d_i represents for each instrument, the bias at the concentration level audited. The $\bar{D}$ represents the average bias for the network at the given concentration level.

Manual Methods. The d_i represents either (a) for TSP, the bias of the flow rate at each site audited, or (b) for NO_2 and SO_2, the bias of the analytical results for a given audit at a given concentration. The $\bar{D}$ represents the average bias for the laboratory.

Probability Limits, Accuracy

Automated Analyzers. The width or spread of the limits, $\bar{D} \pm 1.96\ S_a$, represents the variability of accuracy of the audited analyzers, at a given concentration level.

Manual Methods. The width or spread of the limits, $\bar{D} \pm 1.96\ S_a$, represents either (a) for TSP, the variability of accuracy for the audited sites, or (b) for NO_2 and SO_2, the variability of accuracy for the audits at each given concentration.

Use of Precision and Accuracy Data

The precision and accuracy data obtained by the networks and reported to EPA will be of considerable value to various organizations. These estimates will be helpful to the user of routine monitoring data by providing the user information on the quality of the data with which he is working. The estimates will be valuable to EPA in obtaining "real world" information on the precision and accuracy of the reference and equivalent methods. The data should also be of particular interest and value to the originating agencies as a supplement to the routine quality control system.

Originating Agencies

The measures of precision and accuracy are obtained by each network in the form of probability or control chart-type limits that can and should be used within each agency as supplementary information for internal quality control. The information obtained within a network on a given site or instrument can be used for local quality control purposes for the particular site or instrument. It is important to emphasize, however, that the precision and accuracy checks required by Appendix A *do not* take the place of the need to maintain a routine quality control system. Such checks are too infrequent to be adequate for day-to-day control. Furthermore, the precision and accuracy results should not be used to make any after-the-fact adjustments or corrections to monitoring data.

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Various control charts can be used for plotting the results of the precision and accuracy data. As indicated above, the results of the precision and accuracy checks, if used in a timely way, can provide a valuable supplement to normal routine internal quality control checks.

Quality Control Charts. Although the prime objective of the precision and accuracy audits is to obtain an assessment of data quality, a number of statistical control charts can be maintained to provide some long-term internal control. With control limits established on the basis of past history (at least one quarter for precision, at least one year for accuracy), future data values can be plotted to detect any significant change from past experience.

In general, the control chart limits will be similar to the computed probability limits except that the 1.96 value will be replaced by a 3. (The 1.96 corresponds to an expected 95 percent probability—the 3 corresponds to an expected 99.7 percent probability.) In the case of manual method precision, the $\sqrt{2}$ factor is not included because the points to be plotted will be the percentage differences, which include variability from the imprecision of both samplers. Also, since the intuitively expected value for $\bar{d}_j$ is zero for precision and accuracy, the centerline for the control charts should be zero. Table III summarizes the various control charts which can be plotted for the individual precision checks and accuracy audits.

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Table III. Recommended control charts and limits for state and local agencies.

Pollutant Measurement Method	Control Charts	Number of Control Charts	Control Limits	Frequency of Plotting and Values to be Plotted	Variability or Bias to be Controlled
Automated methods for SO_2, NO_2, O_3, and CO	Precision-Single Instrument	One control chart for each instrument	Zero ± 3 S_a	After each biweekly precision check, plot each individual d_i value	Excessive variability and drift of each instrument
	Accuracy-Single Instrument, each audit level	One control chart for each audit level	Zero ± 3 S_a	After each audit check, plot each individual d_i value	Excessive bias of each instrument
Manual methods TSP, SO_2, NO_2	Precision-Single Site	One control chart for each collocated site	Zero ± 3 S_a	Each day, plot d_i for each site	Excessive lack of agreement between collocated samplers
TSP (flow rate)	Accuracy-Single Site	One control chart per agency	Zero ± 3 S_a	After each audit, plot each individual d_i	Excessive bias of each instrument
SO_2 (analysis), NO_2 (analysis)	Accuracy for each audit level	One for each audit level	Zero ± 3 S_a	After each audit, plot each individual d_i	Excessive bias for each audit

Other control charts could be plotted with the $\bar{D}$ values to detect biases from quarter to quarter. Similarly, the quarterly values of S_a could be plotted to control or display the variability aspects of the measurement systems.

States and Regional Offices

The precision and accuracy reports will be helpful to the states in comparing these measures of data quality from the networks within the states. Similarly, the EPA Regional Offices will be able to make comparisons within and between Regions. These comparisons may point out particular organizations, states, or Regions in need of further improvement in their quality assurance programs.

Environmental Protection Agency (EPA)

Evaluation of the precision and accuracy data is important to EPA (EMSL, Research Triangle Park, North Carolina) in its role of responsibility for quality assurance of air pollution measurements. The precision and accuracy data will be useful in (a) determining possible needs for additional research efforts related to particular measurement methods, (b) indicating measurement methods or portions thereof, which may require improved quality control, and (c) indicating particular agencies, states, or Regions that may require technical assistance or improved quality control. In other words, the precision and accuracy information will enable comparisons to be made across measurement methods, and across networks or other organizational entities for purposes of identifying possible areas in need of improvement of data quality. With knowledge of the precision and accuracy information, EPA can consider appropriate statistical allowances or risks in setting and enforcing the standards, and in developing control strategies.

User

After January 1, 1981, when the precision and accuracy reporting becomes effective, users of monitoring data maintained in the National Aerometric Data Bank (NADB) will receive along with the monitoring data, the precision and accuracy data for the corresponding time periods and locations. The availability of the precision and accuracy data will assist the users in their interpretation, evaluation, and use of the routine monitoring data.

Environmental Monitoring Systems Laboratory Reports

To assist Regions and states in making the above comparisons as well as to perform other analyses of the reported precision and accuracy data, EMSL/RTP will perform various types of statistical analyses and will prepare evaluation and summary reports each quarter and each year.

Summary

The implementation of the May 10, 1979, regulation should result in an improvement in the quality of air pollution data obtained from the states and local agencies. Particularly from a quality assurance standpoint, the quality assurance plans of the states and local agencies will be documented in detail, and quantitative estimates of precision and accuracy will be available for users of air monitoring data.

Section 14A

Precision Work Session

Lesson Goal

To ensure that you can perform precision and accuracy calculations as described in Lesson 14, "Quality Assurance Requirements for SLAMS and PSD."

Lesson Objective

At the end of this lesson, you should be able to calculate 95% probability limits for the precision of air monitoring data collected by a reporting organization using collocated samplers.

I. Problem

Under the conditions described below, calculate the upper and lower 95% probability limits for the precision of TSP monitoring data collected by the reporting organization.

Given:

Collocated TSP Sampling Data for the Reporting Organization

Sampling Site 1

Sampling period	Duplicate sampler results ($\mu g/std\ m^3$)	Official sampler results ($\mu g/std\ m^3$)
1	227	236
2	268	275
3	258	256

Sampling Site 2

Sampling period	Duplicate sampler results ($\mu g/std\ m^3$)	Official sampler results ($\mu g/std\ m^3$)
1	245	257
2	227	240
3	164	166
4	212	221

Section 15

Data Validation

Lesson Goal

To familiarize you with data validation considerations.

Lesson Objectives

At the end of this lesson, you should be able to—

1. define *data validation,*
2. describe nine characteristics of a data validation system,
3. describe factors that affect the selection of data validation techniques,
4. list the levels of data validation for State Implementation Plan (SIP) air monitoring data, and
5. explain the importance of having data validation performed by the organization that generates the data.

25	40
150	480
63	36
112	

DATA VALIDATION

DATA VALIDATION

The process whereby data are filtered and either accepted or flagged for further investigation based on a set of criteria.

DATA VALIDATION

A systematic procedure of reviewing a body of data against a set of criteria to provide assurance of its validity prior to its intended use.

RELATED TERMS

- **data editing**
- **data screening**
- **data auditing**
- **data verification**
- **data evaluation**
- **data qualification**
- **data quality assessment**

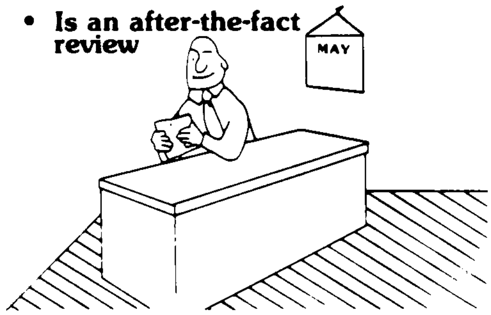
CHARACTERISTICS OF A DATA VALIDATION SYSTEM

- **Is an after-the-fact review**
- **Is applied to blocks of data**
- **Is systematically/uniformly applied**
- **Uses set of criteria**
- **Checks for internal consistency**

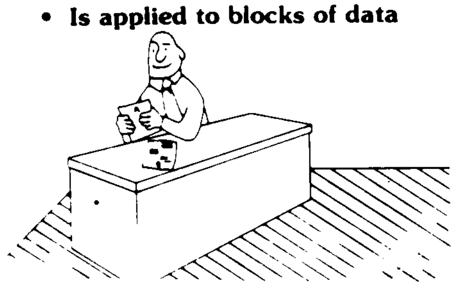
CHARACTERISTICS OF A DATA VALIDATION SYSTEM (continued)

- Checks for temporal/spatial continuity
- Checks for proper identification
- Checks for transmittal errors
- Flags/rejects questionable data

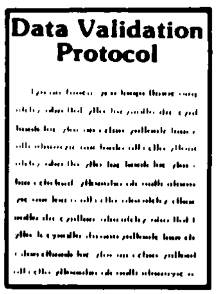
- Is an after-the-fact review



- Is applied to blocks of data



- **Is uniformly/ systematically applied**



- **Uses set of criteria**

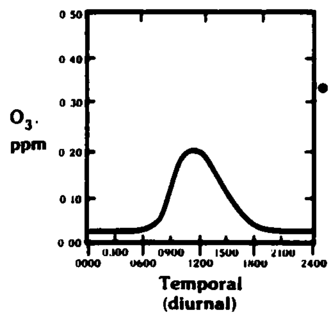
CRITERIA

Maximum span drift

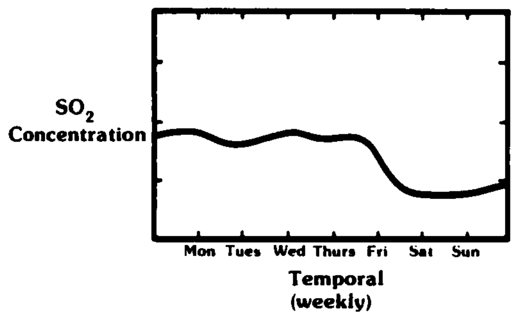
Maximum temperature

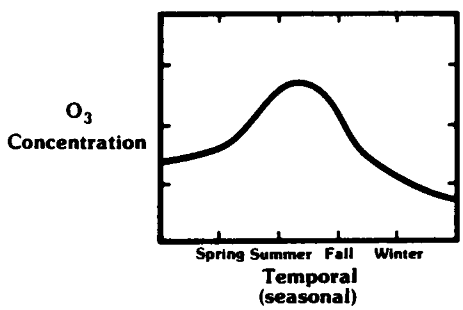
Concentration limit

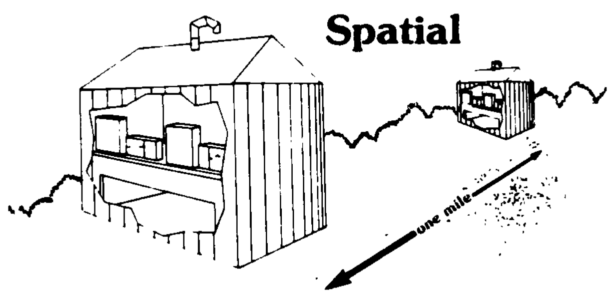
- **Checks for internal consistency**
  - **uniform sampling methodology**
  - **uniform monitor siting**
  - **uniform data reduction and reporting**
  - **pollutant relationships**
  - **pollutant/meteorological relationships**

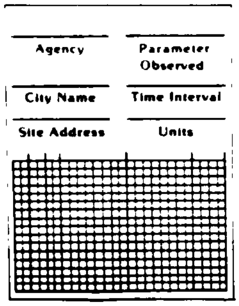


- **Checks for temporal/ spatial continuity**



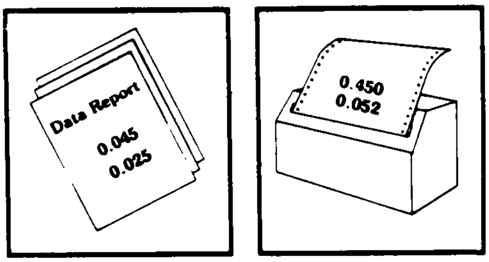




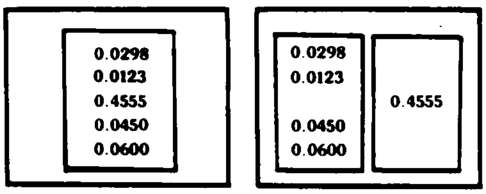


- **Checks for proper identification**

- **Checks for transmittal errors**



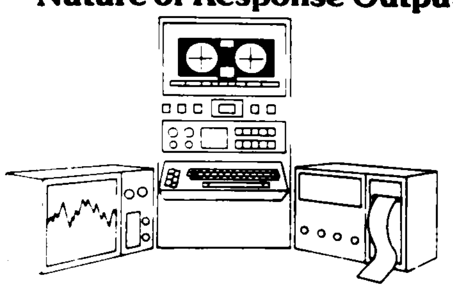
- **Flags/rejects questionable data**



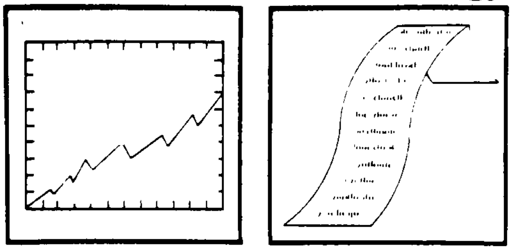
TECHNIQUES EMPLOYED
Monitoring Network Characteristics

- **Nature of Response Output**
- **Data Reduction Methodology**
- **Data Transmittal Methodology**
- **Types and Amount of Ancillary Data**
- **Computing/Plotting Capability**
- **Intended Uses of Data**
- **Amount of Data**

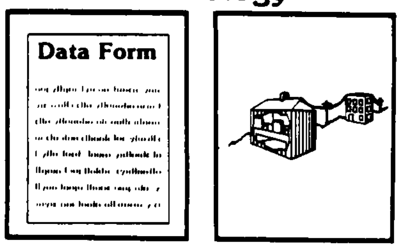
- **Nature of Response Output**



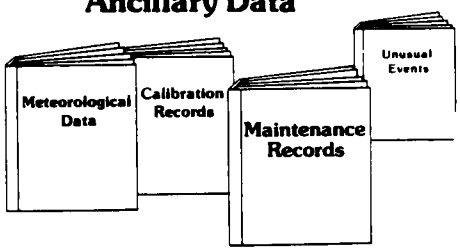
- **Data Reduction Methodology**



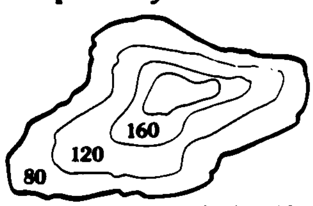
- **Data Transmittal Methodology**



- **Types and Amount of Ancillary Data**

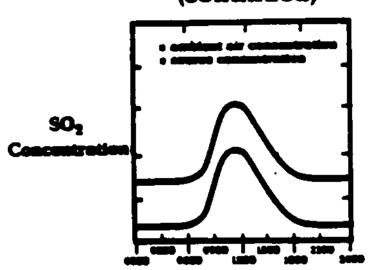


- **Computing/Plotting Capability**

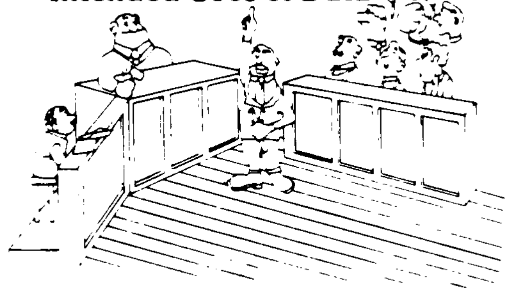


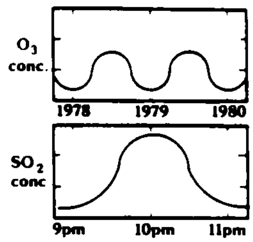
Concentration Isopleths Plot

- **Computing/Plotting Capability (continued)**



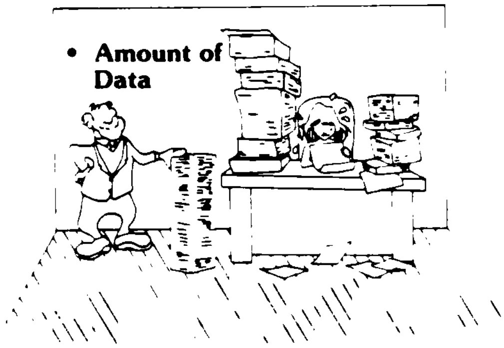
• Intended Uses of Data



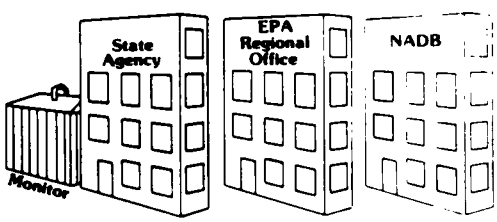


• Intended Uses of Data (continued)

• Amount of Data



LEVELS OF DATA VALIDATION



Validation should be performed by originating organization because it has more information concerning:

- **local meteorology**
- **local emissions sources**
- **unusual events**
- **site/instrument logbooks**

- personnel
- equipment/supplies
- operating procedures
- calibration materials

Validation should be performed by someone other than the person who collected or reported the data.

QUALITY ASSURANCE AND DATA VALIDATION FOR THE REGIONAL AIR MONITORING SYSTEM OF THE ST. LOUIS REGIONAL AIR POLLUTION STUDY

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The success of model development and evaluation from a body of monitoring data depends heavily upon the quality of that data. The quality of the monitoring data in turn is dependent upon the various quality assurance (QA) activities which have been implemented for the entire system, commencing with the design, procurement, and installation of the system and ending with validation of monitoring data prior to archiving. Of the many sources of aerometric and emissions data that exist, the St. Louis Regional Air Pollution Study (RAPS) is the only known study specifically designed for model development and evaluation on an urban/rural scale.[1,2]

The prime objective of RAPS is to develop and evaluate mathematical models which will be useful in predicting air pollution concentrations from information of source emissions and meteorology. In addition to detailed emissions and meteorological data, an extensive base of high quality pollutant monitoring data is required to verify and to refine the models.

The Regional Air Monitoring System (RAMS) is the ground-based aerometric measurement system of RAPS and consists of 25 automated data acquisition sites situated in and about the St. Louis metropolitan area. Data from these 25 stations are transmitted over telephone lines to a central computer facility for processing and then sent to Research Triangle Park for archival. Details of RAMS have been described by Meyers and Reagan.[3] The complex air pollution, meteorological, and solar radiation measurements that are made at RAMS sites are shown in Table 1. Also shown are the recording intervals and the number of recording stations for each instrument.

Two main challenges exist for an effort of the magnitude of the St. Louis study:

1. To efficiently and effectively handle the large quantity of monitoring data; and

2. To obtain high quality monitoring data.

In general, data validity results from: (1) A quality assurance system aimed at acquiring acceptable data, and (2) A screening process to detect spurious values which exist in spite of the quality control process.

*On assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Table 1. RAMS NETWORK MEASURE:'ENTS

		MEASUREMENT INTERVAL (mm)	NUM STAT
AIR QUALITY:	SULFUR DIOXIDE	5	1
	TOTAL SULFUR	1	1.
		5	1
	HYDROGEN SULFIDE	5	1
	OZONE	1	2
	NITRIC OXIDE	1	2
	OXIDES OF NITROGEN	1	2
	NITROGEN DIOXIDE	1	2
	CARBON MONOXIDE	5	2
	METHANE	5	2
	TOTAL HYDROCARBONS	5	2
METEOROLOGICAL:	WIND SPEED	1	2
	WIND DIRECTION	1	2
	TEMPERATURE	1	2
	TEMPERATURE GRADIENT	1	
	PRESSURE	1	
	DEW POINT	1	2
	AEROSOL SCATTER	1	2
SOLAR RADIATION:	PYRANOMETER	1	
	PYRHELIOMETER	1	
	PYRGEOMETER	1	

QUALITY ASSURANCE SYSTEM

The following list includes the elements of total quality assurance system for aerometric monitoring:

Quality policy
*Quality objectives
*Quality organization and responsibility
QA manual
*QA plans
Training
*Procurement control
  Ordering
  Receiving
  Feedback and corrective action
*Calibration
  Standards
  Procedures
Internal QC checks
Operations
  Sampling
  Sample handling
  Analysis

Data
  Transmission
  Computation
  Recording
* Validation
*Preventive maintenanc
*Reliability records a analysis
*Document control
*Configuration control
*Audits
  On-site system
  Performance
Corrective action
Statistical analysis
Quality reporting
Quality investigation
Interlab testing
Quality costs

Detailed definition and discussion of the elements of quality assurance for air pollution measurement systems have recently been published.

The elements of particular concern to RAMS[5] fall into three general categories:

1. Procurement and management, those activi which need to be established or accomplished earl in the program;

2. Operation and maintenance, those activit which need to be performed routinely to assure continued operation of the system; and

*These particular elements, of major concern to d screening, are discussed herein.

3. Specific data quality control activities, those activities which involve the calibration and data output from the meteorological and pollutant measurement instruments and are explicitly involved in acquiring quality data.

Procurement and Management

Data Quality Objectives. A requirement of the initial contract stated that 90% valid data were to be achieved. Valid data for pollutant measurements were defined as the data obtained during periods when the daily zero and span drifts were less than 2 per cent, with an allowance for the time required to perform daily zero/span checks and periodic multi-point calibrations.

Procurement. In planning to achieve the objectives very stringent requirements were placed on the suppliers of the various instruments of the system and extensive performance tests (with numerous rejections) were conducted prior to final acceptance.

First Article Configuration Inspection (FACI). The first remote station was installed and performance tested by the contractor under EPA review. Various indicated corrections were made before proceeding with the installation of the entire network.

System Acceptance Test (SAT). After installation of the entire network, a one-month system performance demonstration was required to assure satisfactory operation with respect to obtaining data of adequate quantity and quality. The SAT was completed in December 1974.

Incentive Contract. The current contract has introduced award fee performance incentives for management, schedule, and for quality. The quality portion of the award fee provides a continual motivation for obtaining and improving data quality.

Quality Assurance Plans. An extensive QA plan has been developed by the contractor. A point of emphasis is that the QA plan (and its implementation) is dynamic --continually being revised and improved based upon experience with the system. The QA plan outlines in detail the activities of the various QA elements previously mentioned.

Organization. To implement the QA plan, one full-time employee is assigned to overall QA responsibilities reporting directly to the Program Manager. In addition, two persons are assigned for QA on a half-time basis, one for the remote monitoring stations, and the other for the central computer facility.

Operation and Maintenance

Document Control. Detailed operation and maintenance manuals have been prepared for the remote stations and for the central computer facility. These manuals are issued in a loose-leaf revisable and document-control format so that needed additions and/or revisions can be made. Also, a complete history of changes are kept so that traceability to the procedures in effect for any past period of time can be made. A document control system also exists for the computer programs.

Preventive Maintenance. Record-keeping and appropriate analysis of the equipment failure records by instrument type and mode of failure have enabled more efficient and effective scheduling of maintenance and optimum spare parts inventory with resultant improvement in instrument performance. RAMS station preventive maintenance is completed twice each week. Normally, the remote stations are unattended except for the weekly checks, for other scheduled maintenance, or for special corrective maintenance.

Central Computer Monitors. Central computer personnel, using a CRT display, periodically monitor the output from all stations to detect problems as soon as possible. To maximize the satisfactory operation of the network equipment, the assigned QA personnel review the following activities associated with preventive maintenance:

1. remote station logbook entries,

2. remote station corrective maintenance reports,

3. laboratory corrective maintenance reports, and

4. central computer operator log.

Additionally, the QA individuals are in frequent verbal communication with field and laboratory supervisors to discuss quality aspects of the operations.

Reliability Records and Analysis

Telecommunications Status Summaries. Each day, a summary of telecommunications operations is prepared to determine which stations and/or telephone lines are experiencing significant problems that might require corrective action.

Daily Analog/Status Check Summaries. Each day, the central computer prepares a summary of analog/status checks by station so that major problems can be corrected as soon as possible by available field technicians. These analog/status checks are explained in the section on data validation.

Configuration Control. Histories are kept of the station assignment of specific instruments, by serial number, so that possible future problems with specific instruments can be traced back to the stations. A logbook for each instrument is maintained for recording in a systematic manner the nature and date of any changes or modifications to the hardware design of the instruments.

Specific Data Quality Control Activities

Calibration

Calibration References for Gaseous Pollutants NBS standard reference materials are used for calibration standards if available. Otherwise, commercial gases are procured and certified at NBS for use as standards.

Multipoint Calibrations. As a check on the linearity of instrument response, an on-site, 5-point calibration is scheduled at each station at 8-week intervals. Originally, acceptability was determined by visual evaluation of the calibration data plots; more recently, quantitative criteria are being established for linearity.

Measurement Audits. Independent measurement audits for pollutant instruments are performed by the contractor using a portable calibration unit and independent calibration sources at each station once each calendar quarter. Similar audits are performed on the same frequency for temperature, radiation, and mass flowmeters; and independent checks are made on relative humidity, windspeed, and wind direction instruments. In addition to the internal audits performed by the contractor on his own operation, a number of external audits have been performed by EPA and other contractors[5] to check the entire measurement system.

On-Site System Audit. A thorough, on-site quality system audit of RAMS was performed for EPA by an independent contractor.[6] The results of this audit pointed out several areas of weakness for which corrective actions have been implemented.

Data Validation. As a part of the overall QA system, a number of data validation steps are implemented. Several data validation criteria and actions are built into the computer data acquisition system:

Status Checks. About 35 electrical checks are made to sense the condition of certain critical portions of the monitoring system and record an on-off status. For example, checks are made on power on/off, valve open/shut, instrument flame-out, air flow. When these checks are unacceptable, the corresponding monitoring data are automatically invalidated.

Analog Checks. Several conditions including reference voltage, permeation tube bath temperature, and calibration dilution gas flow are sensed and recorded as analog values. Acceptable limits for these checks have been determined, and, if exceeded, the corresponding affected monitoring are invalidated.

Zero/Span Checks. Each day, between 8-12 pm, each of the gaseous pollutant instruments in each station are zeroed and spanned by automatic, sequenced commands from the central computer. The results of the zero/span checks provide the basis for a two-point calibration equation, which is automatically computed by the central computer and is used for converting voltage outputs to pollutant concentrations for the following calendar day's data. In addition, the instrument drift at zero and span conditions between successive daily checks are computed by the central computer and used as a basis for validating the previous day's monitoring data. Originally, zero and span drifts were considered as acceptable if less than 2 per cent, but the span drift criterion has recently been increased to 5 per cent, a more realistic level. If the criteria are not met, the minute data for the previous day are flagged. Hourly averages are computed during routine data processing only with data which have not been flagged as invalid.

DATA SCREENING IN RAMS

The tests which are used to screen RAMS data are summarized in Table 2. Specific tests and associated data base flags are listed. The types of screens that have been employed or tested will be detailed, the mechanisms for flagging will be reviewed, and then the implementation of screening within RAMS will be discussed.

Table 2. SCREENING CATEGORIES AND ASSOCIATED FLAGS FOR RAMS DATA

Category	Flag
I. Modus Operandi	
No instrument	10^{37}
Missing measurement	10^{37}
Status	Value * 10^{-25}
Calibration	10^{35}
II. Continuity and Relational	
A. Intrastation	
Gaseous analyzer drift	- Value
Gross limits	10^{36}
Aggregate frequency distributions	Being implement
Relationships	Value * 10^{32}
Temporal continuity	
Constant output	Value * 10^{23}
Successive difference	Being implement
B. Interstation	
Meteorological network uniformity	Value * 10^{16}
Statistical outliers	
Dixon Ratio	Value * 10^{-20}
III. A Posteriori	
Review of station log	Invalidate 10^{38}
Unusual events or conditions	Validate - Remo flag
Visual inspection of data	

For descriptive purposes, the tests are divided into three categories. The first category, "Modus Operandi," contains checks which document the networ instrument configuration and operating mode of the recording system. Included are checks for station instrumentation, missing data, system analog and status sense bits, and instrument calibration mode. These checks, which have been described above, are part of the quality control program incorporated in the data acquisition system and central facility dat processing, and are an important data management function used to document system performance.

The second category, "Continuity and Relationa contains temporal and spatial continuity checks and relational checks between parameters which are base on physical and instrumental considerations or on statistical patterns of the data. A natural subdivision can be made between intrastation checks, those checks which apply only to data from one stat and interstation checks, which test the measured parameters for uniformity across the RAMS network.

Intrastation checks include tests for gaseous analyzer drift, gross limits, aggregate frequency distributions, relationships, and temporal continui The drift calculations, which are part of the quali control program, have been discussed above.

Gross limits, which are used to screen impossi values, are based on the ranges of the recording instruments. These, together with the parametric relationships which check for internal consistency between values, are listed in Table 3. Setting lim for relationship tests requires a working knowledge noise levels of the individual instruments. The relationships used are based on meteorology, atmospheric chemistry, or on the principle of chemical m balance. For example, at a station for any given minute, TS cannot be less than SO_2 + H_2S with allowances for noise limits of the instruments.

Table 3. GROSS LIMITS AND RELATIONAL CHECKS

PARAMETER	INSTRUMENTAL OR NATURAL LIMITS: LOWER	INSTRUMENTAL OR NATURAL LIMITS: UPPER	INTERPARAMETER CONDITION
Ozone	0 ppm	5 ppm	$NO*O_3 \leq 0.04$
Nitric Oxide	0 ppm	5 ppm	$NO - NO_X \leq$ Noise (NO)
Oxides of Nitrogen	0 ppm	5 ppm	$NO - NO_X \leq$ Noise (NO_X)
Carbon Monoxide	0 ppm	50 ppm	
Methane	0 ppm	50 ppm	CH_4 - THC $\leq$ Noise (CH_4)
Total Hydrocarbons	0 ppm	50 ppm	CH_4 - THC $\leq$ Noise (THC)
Sulfur Dioxide	0 ppm	1 ppm	SO_2 - TS $\leq$ Noise (SO_2)
Total Sulfur	0 ppm	1 ppm	SO_2 - TS $\leq$ Noise (TS)
Hydrogen Sulfide	0 ppm	1 ppm	H_2S - TS $\leq$ Noise (H_2S)
Aerosol Scatter	$0.000001m^{-1}$	$0.00099m^{-1}$	
Wind Speed	0 m/s	22.2 m/s	
Wind Direction	0°	360°	
Temperature	-20°C	45°C	
Dew Point	-30°C	45°C	DP - 0.5 $\leq$ T
Temperature Gradient	- 5°C	5°C	
Barometric Pressure	950 mb	1050 mb	
Pyranometers	- 0.50	2.50 Langleys/min	
Pyrgeometers	0.30	0.75 Langleys/min	
Pyrheliometers	-0.50	2.50 Langleys/min	

A refinement of the gross limit checks can be made using aggregàte frequency distributions. With a knowledge of the underlying distribution, statistical limits can be found which have narrower bounds than the gross limits and which represent measurement levels that are rarely exceeded. A method for fitting a parametric probability model to the underlying distribution has been developed by Dr. Wayne Ott of EPA's Office of Research and Development.[7]. B.E. Suta and G.V. Lucha[8] have extended Dr. Ott's program to estimate parameters, perform goodness-of-fit tests, and calculate quality control limits for the normal distribution, 2- and 3-parameter lognormal distribution, the gamma distribution, and the Weibull distribution. These programs have been implemented on the OSI computer in Washington and tested on water quality data from STORET. This technique is being studied for possible use in RAMS as a test for potential recording irregularities as well as a refinement of the gross limit check currently employed.

Under intrastation checks are specific tests which examine the temporal continuity of the data as output from each sensor. It is useful to consider, in general, the types of atypical or erratic responses that can occur from sensors and data acquisition systems. Figure 1 illustrates graphically examples of such behavior, all of which have occurred to some extent within RAMS. Physical causes for these reactions include sudden discrete changes in component operating characterisitcs, component failure, noise, telecommunication errors and outages, and errors in software associated with the data acquisition system or data processing. For example, it was recognized early in the RAMS program that a constant voltage output from a sensor indicated mechanical or electrical failures in the sensor instrumentation. One of the first screens that was implemented was to check for 10 minutes of constant output from each sensor. Barometric pressure is not among the parameters tested since it can remain constant (to the number of digits recorded) for periods much longer than 10 minutes. The test was modified for other parameters which reach a low constant background level during night-time hours.

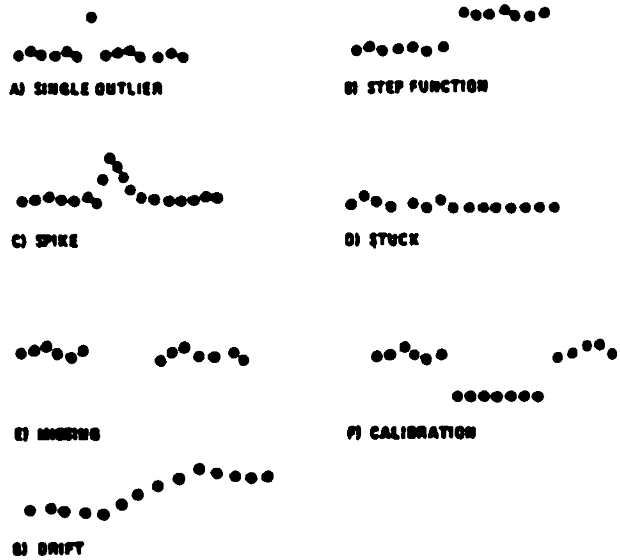


Figure 1. Irregular instrument response.

A technique which can detect any sudden jump in the response of an instrument, whether it is from an individual outlier, step function or spike, is the comparison of minute successive differences with predetermined control limits. These limits are determined for each parameter from the distribution of successive differences for that parameter. These differences will be approximately normally distributed with mean zero (and computed variance) when taken over a sufficiently long time series of measurements.

Exploratory application of successive differences, using 4 standard deviation limits which will flag 6 values in 100,000 if the differences are truly normally distributed, indicate that there are abnormal occurrences of "jumps" within certain parameters. Successive difference screening will be implemented after further testing to examine the sensitivity of successive difference distributions to varying computational time-periods and to station location.

The type of "jump" can easily be identified. A single outlier will have a large successive difference followed by another about the same magnitude but of opposite sign. A step function will not have a return, and a spike will have a succession of large successive differences of one sign followed by those of opposite sign.

The interstation or network uniformity screening tests that have been implemented in RAMS will now be described. Meteorological network tests are performed on hourly average data and are based on the principle that meteorological parameters should show limited differences between stations under certain definable conditions typically found in winds of at least moderate speeds (>4 m/sec). Each station value is compared with the network mean. The network mean is defined as the average value for a given parameter from all stations having reported valid data. (If more than 50% are missing, a network mean is not computed and the test is not made.) Values exceeding prescribed limits are flagged. The limits have been set on the advice of experienced meteorologists. The tested parameters and flagging limits are listed below.

Maximum allowable deviations from network mean
under moderate winds (network mean > 4 m/sec)

Wind speed	2 m/sec or MEAN/3 (whichever is larger)
Wind direction	30°
Temperature	$3^{\circ}C$
Temperature difference	$.5^{\circ}C$
Dew point	$3^{\circ}C$
Adjusted pressure	5.0 millibars

In addition to network screening techniques which are based on knowledge of underlying physical processes, methods from statistical outlier theory[9,10] were also examined. Specifically, the Dixon ratio test[11] was implemented to determine extreme observations of a parameter across the RAMS network. The Dixon ratio test is based entirely on ratios of differences between observations from an assumed normal distribution and is easy to calculate. The Dixon criteria for testing a low suspect value from a sample size of n, $n \leq 25$, are shown in Figure 2. Though the entire sample is shown as ranked, only the extreme 2 or 3 values need to be ordered. Associated with each value of n are tabulated ratios for statistical significance at various probability levels. For example, if n=25, X_1 would be considered as an outlier at the 1% level of significance when $r_{22} \geq .489$. Since the underlying distribution may not be normal, the calculated probabilities may not be exact, but are used as indicators of heterogeneity of the network observations at a given time.

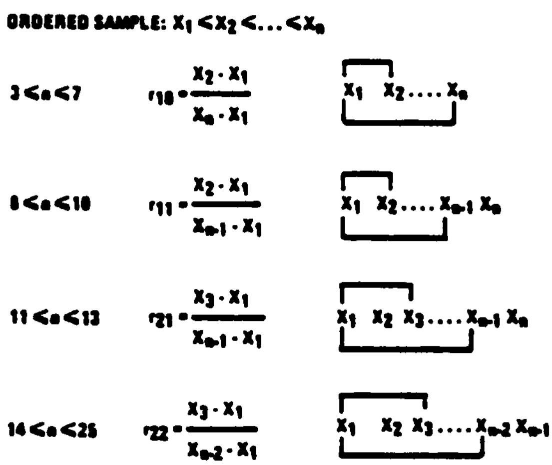


Figure 2. Dixon ratio test for suspected low value.

The third screening category, a Posteriori, was established to provide a mechanism for overriding the automated flagging schemes which have been implemented in the instrumentation at the remote sites and in the data screening module. From a review of station logs and preventive maintenance records, a knowledge of unusual events, or through visual inspection of data, it may be determined that previously valid data should be flagged as questionable. Conversely, it may be determined that previously invalid data should be validated by removing existing flags. An example of when data would be invalidated is when an instrument, such as a wind direction indicator, becom misaligned or uncalibrated because of some non-linear or unknown reason. Removal of flags or revalidation can occur, for example, when the recording instrument function properly, but the sense bit or analog status circuity is known to have malfunctioned.

Implementation of à posteriori changes of RAMS data requires special software, inserted in the data flow during data processing, screening and archiving, or during a special pass through the data after archival.

Data Flagging

Embedded in the data base structure must be a flagging mechanism which can distinguish the variou data screens. In general, data which have been filtered by the various screens must be either removed from the data base or qualified by attaching a uniquely identifying flag.

Two details of the RAMS archival data base are important to understanding the implementation of the RAMS data flagging. First, all data are stored in integer floating point numbers in Univac internal binary representation. Floating point notation is a natural representation of numerical data and can readily accommodate a variety of flagging schemes. Second, each potential measurement has a reserved location in the data base. Thus, substitutions must be made for missing and removed data. For instance, RAMS data rejected by the gross limit checks are removed and replaced by a value of 10^{34}.

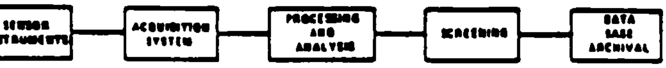
Data which have been screened and which are not obviously impossible may have limited application and should not be eliminated from the data base. If each screening test can be associated with a unique flag, then modelers and other users can establish their own criteria for accepting or rejecting the flagged data.

Three flagging mechanisms suggest themselve when the value of the measurement is to be retained: (1) exponent offset, (2) range offset, and (3) binary bit encoding. These techniques are listed for reference only. A full description and comparison of these techniques is being prepared.

Exponent offsetting which is used for RAMS data is accomplished by multiplying the value by a power of 10. Special considerations must be given to the dynamic range of the data and to values which are identically zero. The flags which are associated with each of the individual screens are listed in Table 2.

Implementing the Screening Module Into the Data Flow

We emphasize the importance of considering the sequence in which screening is integrated into the data flow by considering a generalized data flow diagram, or basic system design, which is applicable to any environmental measurement system. This flow diagram is illustrated in Figure 3.



gure 3. Generalized data flow for environmental measurement systems.

Data screening should take place as near to ta acquisition as possible either in data processing ich is traditionally concerned with laboratory alysis, conversion to engineering units, transcribing termediate results, etc., or in a separate module, illustrated, designed specifically for the screening rocess. Screening data soon after data acquisition ermits system feedback in the form of corrective aintenance, changes to control processes, and even changes in system design. This feedback is ssential to minimize the amount of lost or marginally cceptable data.

The RAMS screening tests, which have been eveloped at Research Triangle Park (RTP), are now art of the data processing carried out at the RAPS entral facility in St. Louis. Slow computation peeds of the St. Louis PDP 11/40 computer required estricting the intrastation screening tests to hourly verage data. RAMS data is still passed through the TP screening module before archiving.

UMMARY

The experiences gained in RAMS and applicable to ther monitoring systems are:

1. Data validity is a function of quality ssurance and data screening.

2. A QA plan and data screening rules should e established initially and maintained throughout he program.

3. The QA plan and screening rules are dynamic, eing improved as additional knowledge and experience s gained.

4. Applied during data acquisition or shortly thereafter, quality control and screening checks onstitute an important feedback mechanism, indicating requirement for corrective action.

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Section 16

Quality Costs

Lesson Goal

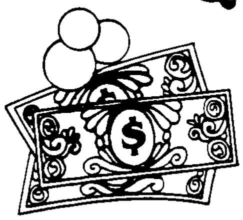
To familiarize you with the concept of quality costs and with considerations when establishing a quality cost system.

Lesson Objectives

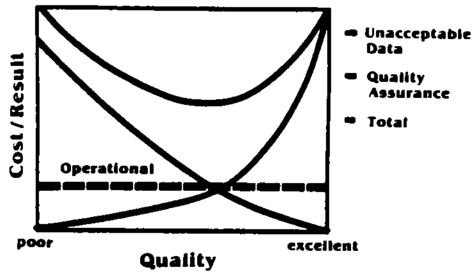
At the end of this lesson, you should be able to—

1. recall the three types of cost that compose the total cost per measurement result of an air quality measurement system,
2. describe the relationship between unacceptable data cost and quality assurance cost,
3. explain the purpose of a quality cost system,
4. list and define the three cost categories of a quality cost system,
5. identify at least two groups of activities that are related to each of the three cost categories, and
6. describe a procedure for establishing a quality cost system.

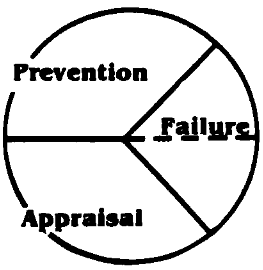
QUALITY COSTS



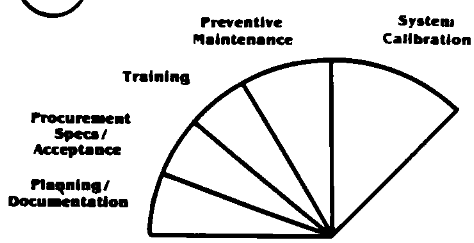
QUALITY ~~COSTS~~ PAYS



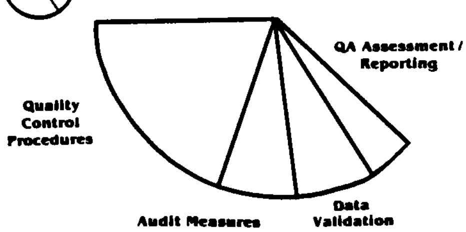
QUALITY RELATED COSTS

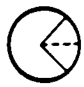


Prevention Cost Groups

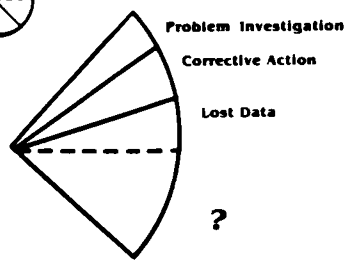


Appraisal Cost Groups



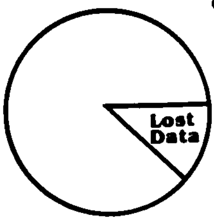


Failure Cost Groups



ACCUMULATION OF COSTS

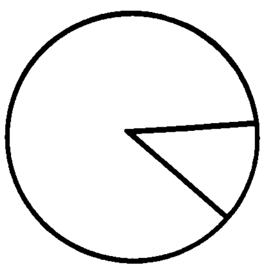
- **lost data costs**
- **other costs**



- $F_d = f \times B$

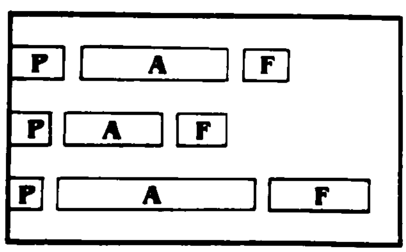
Where:

F_d = lost data cost
f = % lost data
B = part of network budget associated with lost data



- **Prorate Personnel Salaries**

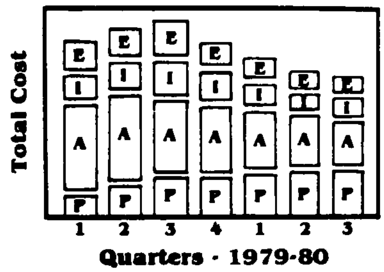
COST EFFECTIVENESS



QUALITY COST REPORTING

- data obtained from source documents
- reports understandable at a glance
  - data summarized
  - graphs preferred

QUALITY COST TREND CHART



GUIDELINES FOR IMPLEMENTING A QUALITY COST SYSTEM FOR ENVIRONMENTAL MONITORING PROGRAMS

Presented at 73rd APCA Annual Meeting
and Exhibition in Montreal, Quebec,
Canada, June 1980

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GUIDELINES FOR IMPLEMENTING A QUALITY COST SYSTEM FOR ENVIRONMENTAL MONITORING PROGRAMS

Introduction

Program managers with Governmental agencies and industrial organizations involved in environmental measurement programs are concerned with overall program cost-effectiveness including total cost, data quality and timeliness. There are several costing techniques designed to aid the manager in monitoring and controlling program costs. One particular technique specifically applicable to the operational phase of a program is a quality cost system.

The objective of a quality cost system for an environmental monitoring program is to minimize the cost of those operational activities directed toward controlling data quality while maintaining an acceptable level of data quality. The basic concept of the quality cost system is to minimize total quality costs through proper allocation of planned expenditures for the prevention and appraisal efforts in order to control the unplanned correction costs. That is, the system is predicated on the idea that prevention is cheaper than correction.

There is no pre-set formula for determining the optimum mode of operation. Rather, the cost effectiveness of quality costs is optimized through an iterative process requiring a continuing analysis and evaluation effort. Maximum benefits are realized when the system is applied to a specific measurement method in a stable long term monitoring program. For example, a monitoring program with a fixed number of monitoring sites, scheduled to operate for a year or more, would be a desirable candidate for a quality cost system.

Quality costs for environmental monitoring systems have been treated by Rhodes and Hochheiser[1]. The purpose of this paper is to present guidelines for the implementation of a quality cost system. The contents of this paper are based on work performed by the Research Triangle Institute under contract to the U.S. Environmental Protection Agency[2].

Structuring of Quality Costs

The first step in developing a quality cost system is identifying the cost of quality-related activities, including all operational activities that affect data quality, and dividing them into the major cost categories.

Costs are divided into category, group, and activity. Category, the most general classification, refers to the standard cost subdivisions of prevention, appraisal, and failure. The category subdivision of costs provides the basic format of the quality cost system. Activity is the most specific classification and refers to the discrete operations for which costs should be determined. Similar types of activities are summarized in groups for purposes of discussion and reporting.

Cost Categories

The quality cost system structure provides a means for identification of quality-related activities and for organization of these activities into prevention, appraisal, and failure cost categories. These categories are defined as follows:

- Prevention Costs—Costs associated with planned activities whose purpose is to ensure the collection of data of acceptable quality and to prevent the generation of data of unacceptable quality.
- Appraisal Costs—Costs associated with measurement and evaluation of data quality. This includes the measurement and evaluation of materials, equipment, and processes used to obtain quality data.
- Failure Costs—Costs incurred directly by the monitoring agency or organization producing the failure (unacceptable data).

Cost Groups

Quality cost groups provide a means for subdividing the costs within each category into a small number of subcategories which eliminates the need for reporting quality costs on a specific activity basis. Although the groups listed below are common to all environmental measurement methods, the specific activities included in each group may differ between methods.

Groups within prevention costs. Prevention costs are subdivided into five groups:

- Planning and Documentation—Planning and documentation of procedures for all phases of the measurement process that may have an effect on data quality.
- Procurement Specification and Acceptance—Testing of equipment parts, materials, and services necessary for system operation. This includes the initial on-site review and performance test, if any.
- Training—Preparing or attending formal training programs, evaluation of training status of personnel, and informed on-the-job training.
- Preventive Maintenance—Equipment cleaning, lubrication, and parts replacement performed to prevent (rather than correct) failures.
- System Calibration—Calibration of the monitoring system, the frequency of which could be adjusted to improve the accuracy of the data being generated. This includes initial calibration and routine calibration checks and a protocol for tracing the calibration standards to primary standards.

Groups within appraisal costs. Appraisal costs are subdivided into four groups:

- Quality Control (QC) Measures—QC-related checks to evaluate measurement equipment performance and procedures.
- Audit Measures—Audit of measurement system performance by persons outside the normal operating personnel.
- Data Validation—Tests performed on processed data to assess its correctness.
- Quality Assurance (QA) Assessment and Reporting—Review, assessment, and reporting of QA activities.

Groups within failure costs. Under most quality cost systems, the failure category is subdivided into internal and external failure costs. Internal failure costs are those costs incurred directly by the agency or organization producing the failure.

Internal failure costs are subdivided into three groups:

- Problem Investigation—Efforts to determine the cause of poor data quality.
- Corrective Action—Cost of efforts to correct the cause of poor data quality, implementing solutions, and measures to prevent problem reoccurrence.
- Lost Data—The cost of efforts expended for data which was either invalidated or not captured (unacquired and/or unacceptable data). This cost is usually prorated from the total operational budget of the monitoring organization for the percentage of data lost.

External failure costs are associated with the use of poor quality data external to the monitoring organization or agency collecting the data. In air monitoring work these costs are significant but are difficult to systematically quantize. Therefore, this paper will only address failure costs internal to the monitoring agency. However, external failure costs are important and should be considered when making decisions on additional efforts necessary for increasing data quality or for the allocation of funds for resampling and/or reanalysis.

Examples of failure cost groups are:

- Enforcement actions—Cost of attempted enforcement actions lost due to questionable monitoring data.
- Industry—Expenditures by industry as a result of inappropriate or inadequate standards established with questionable data.
- Historical Data—Loss of data base used to determine trends and effectiveness of control measures.

Cost Activities

Examples of specific quality-related activities which affect data quality are presented in Table I. These activities are provided as a guide for implementation of a quality cost system for an air quality program utilizing continuous monitors. Uniformity across agencies and organizations in the selection of activities is desirable and encouraged, however, there are variations which may exist, particularly between monitoring agencies and industrial/research projects.

Agencies should make an effort to maintain uniformity regarding the placement of activities in the appropriate cost group and cost category. This will provide a basis for future "between agency" comparison and evaluation of quality cost systems.

Development and Implementation of the Quality Cost System

Guidelines are presented in this section for the development and implementation of a quality cost system. These cover planning the system, selecting applicable cost activities, identifying sources of quality cost data, tabulating, and reporting the cost data.

Planning

Implementation of a quality cost system need not be expensive and time consuming. It can be kept simple if existing data sources are used wherever possible. The importance of planning cannot be overemphasized. For example, implementation of the quality cost system will require close cooperation between the quality cost system manager and other managers or supervisors. Supervisors should be thoroughly briefed on quality cost system concepts, benefits, and goals.

System planning should include the following activities:

- Determining scope of the initial quality cost program.
- Setting objectives for the quality cost program.
- Evaluating existing cost data.
- Determining sources to be utilized for the cost data.
- Deciding on the report formats, distribution, and schedule.

To gain experience with quality cost system techniques, an initial pilot program could be developed for a single measurement method or project within the agency. The unit selected should be representative, i.e., exhibit expenditure for each cost category: prevention, appraisal, and failure. Once a working system for the initial effort has been established, a full-scale quality cost system can then be implemented.

Activity Selection

The first step for a given agency to implement a quality cost system is to prepare a detailed list of the quality-related activities most representative of the agencies monitoring operation and to assign these activities to the appropriate cost groups and cost categories. Worksheets and cost summaries for collecting and tabulating cost data for specific measurement methods will then need to be assigned and methods developed to accumulate the costs as easily as possible. Ultimately and most important is the analysis of the accumulated costs, discussed in the next section.

The general definitions of the cost groups and cost categories, presented in the previous section, are applicable to any measurement system. Specific activities contributing to these cost groups and categories, however, may vary significantly between agencies, depending on the scope of the cost system, magnitude of the monitoring network, parameters measured, and duration of the monitoring operation. The activities listed in Table I are provided as a guide only, and they are not considered to be inclusive of all quality-related activities. An agency may elect to add or delete certain activities from this list. It is important, however, for an agency to maintain uniformity regarding the cost groups and categories the activities are listed under. As indicated previously, this will provide a basis for future cost system comparison and evaluation.

Quality Cost Data Sources

Most accounting records do not contain cost data detailed enough to be directly useful to the operating quality cost system. Some further calculation is usually necessary to determine actual costs which may be entered on the worksheets. The cost of a given activity is usually estimated by prorating the person's charge rate by the percentage of time spent on that activity. A slightly rougher estimate can be made by using average charge rates for each position instead of the actual rates.

Failure costs are more difficult to quantize than either prevention or appraisal costs. The internal failure cost of lost data (unacquired and/or unacceptable data), for example, must be estimated from the total budget.

Cost Accumulation and Tabulation

Cost collection and tabulation methods should be kept simple and conducted within the framework of the agency's normal reporting format whenever possible. During initial system development, a manual approach will allow needed flexibility, whereas, automatic quality cost data tabulation would be complicated, since many of the quality-related activities are not typical in existing accounting systems. Automatic tabulation of costs may be practical after the basic quality cost system has been developed.

Also, an effective cost system does not require precise cost accounting. Reasonable cost estimates are adequate when actual cost records are not available.

Worksheets and summaries used to collect and tabulate the cost data should be designed to represent expenditures by activity.

Quality Cost Worksheets

Worksheets for collecting and tabulating quality cost data should be prepared for each specific measurement method. The worksheet should be designed to allow cost tabulation for each quality-related activity performed and to accomodate more than one personnel level per activity. In addition, activities should be organized into appropriate cost groups and cost categories so that when total costs are computed, they can be transferred directly to cost summaries later.

Quality Cost Analysis Techniques

Techniques for analyzing and evaluating cost data range from simple charts comparing the major cost categories to sophisticated mathematical models of the total program. Common techniques include trend analysis and Pareto analysis.

Trend analysis. Trend analysis compares present to past quality expenditures by category. A history of quality cost data, typically a minimum of 1-year, is required for trend evaluation. (An example is given in Figure 1 of the next section).

Cost categories are plotted within the time frame of the reporting period (usually quarterly). Costs are plotted either as total dollars (if the scope of the monitoring program is relatively constant) or as "normalized" dollars/data unit (if the scope may change). Groups and activities within the cost categories contributing the highest cost proportions are plotted separately.

Pareto analysis. Pareto analysis identifies the areas with greatest potential for quality improvement by:

- Listing factors and/or cost segments contributing to a problem area.
- Ranking factors according to magnitude of their contribution.
- Directing corrective action toward the largest contributor.

Pareto techniques may be used to analyze prevention, appraisal, or failure costs. They are most logically applied to the failure cost category, since the relative costs associated with activities in the failure category indicate the major source of data quality problems. Typically, relatively few contributors will account for most of the failure costs.[3,4] (An example is given in Figure 3 of the next section.)

Quality Cost Reports

Quality cost reports prepared and distributed at regular intervals should be brief and factual, consisting primarily of a summary discussion, a tabulated data summary, and a graphic representation of cost category relationships, trends, and data analysis. The summary discussion should emphasize new or continuing problem areas and progress achieved during the reporting period.

Written reports should be directed toward specific levels of management. Managers and supervisors receiving reports should be thoroughly briefed on the concepts, purpose, and potential benefits of a quality cost system, i.e., identification of quality-related problems, potential input into problem solution, and quality cost budgeting.

Quality Cost System Example

A hypothetical case history of a quality cost system is presented in this section. In this example, a cost system is developed for an agency operating sixteen sulfur dioxide monitoring stations. The stations are located within a 50-mile radius and each is equipped with a continuous sulfur dioxide monitor. The monitoring network has been in operation for 2 years.

The QA Coordinator is given the responsibility for implementing the quality cost system. The QA Coordinator plans the implementation of the pilot cost system. Planning for the system includes selecting cost activities, determining cost methods, and establishing procedures for maintaining the system.

To establish an historical basis quality costs are estimated for the past year. This allows for trend observation over an adequate period of time. These costs are shown (see Figure 1) and discussed in the following paragraphs.

Unacceptable data costs are a major cost group in the failure category. In order to establish the value of "lost data", the overall monitoring budget is determined from contracts, accounting documents, and other source documents. Table II summarizes total monitoring costs for the criteria pollutants and the sulfur dioxide costs are used in this example quality cost system. The cost data includes the maximum possible number of data units and cost per data unit.[5]

Quality-related costs are estimated for each quarter over the preceding year. The estimated costs are subject to the following considerations:

- Estimates of time spent by an operator performing a specific activity takes into account the capability of the operator to perform several activities simultaneously. For example, an operator performing daily analyzer zero/span will have time to simultaneously perform other duties while the analyzers stabilize to the zero/span inputs.
- The activities are performed by three personnel types: manager, supervisor, and operator. The cost per hour for each level is consistent with "Cost of Monitoring Air Quality in the United States."[5]

Analysis and evaluation of the collected cost data will determine several facts about the example agency's quality effort. The cost data should reflect the present status of the quality program, where major problem areas exist, and what immediate goals should be established.

A graph of the expenditures for each cost category is shown in Figure 2. Throughout the preceding year prevention costs were relatively small, appraisal costs were moderate, and failure costs were significant. Also, failure costs showed an increasing trend throughout the year.

A Pareto distribution of the failure costs (Figure 3) shows that the major cost contributor is "lost" data. The "lost" data cost represents over 80 percent of the total failure costs. Although the "lost" data cost represents less than 20 percent of the total data possible, the cost of this loss is significant.

An investigation determines the major cause of the problem to be a shortage of station operators. The workload of the one fulltime operator does not allow adequate time for an effective preventive maintenance program. The lack of proper preventive maintenance increases the frequency of analyzer/equipment failure resulting in an additional workload for the station operator, i.e., equipment repair.

The quality manager prepares a quality cost report covering the initial study results. The report presents several recommendations, including:

- Hire and train an additional operator.
- Increase prevention efforts for the monitoring operation.
- Reduce failure costs 50% by the end of the next reporting period.

During the following quarter, an additional operator was hired and trained. Preventive maintenance procedures were reviewed and modified as required. At the end of this reporting period, quality costs were collected, analyzed, and evaluated. The quality cost report covering this reporting period shows that failure costs were reduced 37%, prevention costs were increased 81% and appraisal costs increased 32%. A net decrease in total quality cost, amounting to $2,584 (11%) was experienced for the quarter as seen in Figure 1 when comparing the first quarter of 1979 with the fourth quarter of 1978.

The changes in category expenditures (Figure 2) reflect specific corrective measures initiated during the reporting period. These measures included hiring and training an additional operator and increasing the preventive maintenance effort.

Although the unacceptable data costs were decreased significantly, these costs are still excessive and a preliminary analysis of the last sulfur dioxide data indicates that additional effort in preventive maintenance is necessary to further reduce the networks operating costs.

TOTAL QUALITY COST SUMMARY
(Combined network costs, 1978-79)

COST GROUP	2nd Quarter	3rd Quarter	4th Quarter	1st Quarter
PREVENTION				
Planning & documentation	—	—	—	179
Procurement	—	—	—	179
Training	—	—	—	459
Preventive maintenance	588	559	587	1,046
System calibration and operation	1,254	1,317	1,386	1,713
TOTAL PREVENTION COSTS	1,842	1,876	1,973	3,576
APPRAISAL				
QC measures	768	806	742	1,631
Audits	1,308	1,508	1,470	1,913
Data validation	1,468	1,668	1,868	1,887
QA assessment & reporting	1,748	1,839	1,686	2,179
TOTAL APPRAISAL COSTS	5,292	5,821	5,766	7,610
FAILURE				
Problem investigation	1,579	1,886	1,760	704
Corrective action	1,361	1,334	1,365	546
Lost data (unacquired data)	12,430	13,893	13,162	9,506
TOTAL FAILURE COSTS	15,370	17,113	16,287	10,256
TOTAL QUALITY COSTS	22,504	24,810	24,026	21,442

MEASUREMENT BASES
Total program cost per quarter 48,304
Total data units per quarter 33,792

Figure 1. Total quality cost summary.

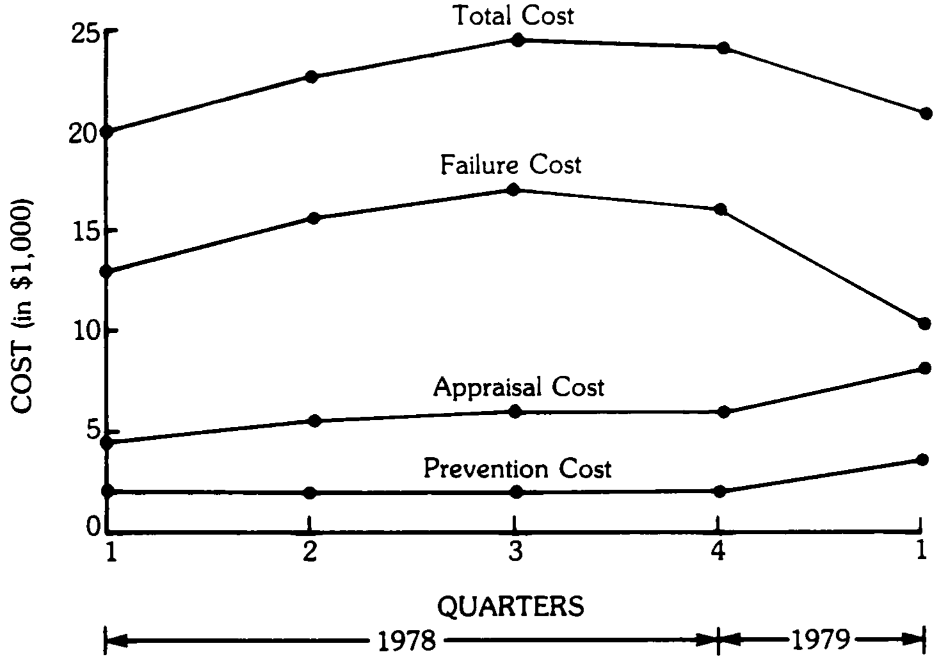

Figure 2. Quality cost trends.

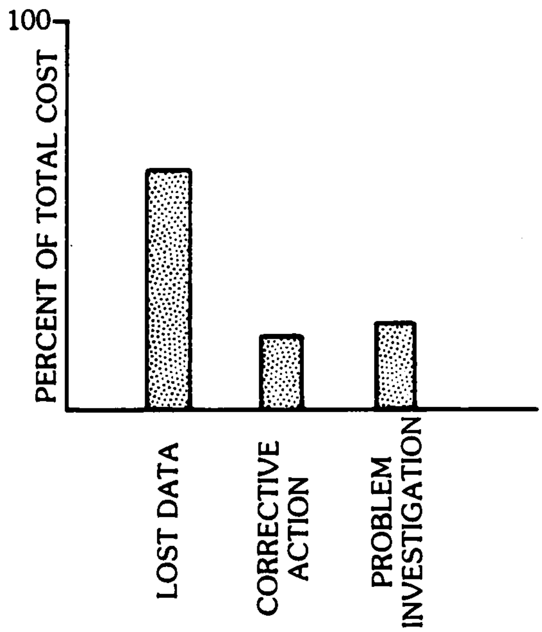

Figure 3. Failure cost distribution.

TABLE 1. EXAMPLE COST ACTIVITIES GUIDE FOR AMBIENT AIR MEASUREMENT METHODS

APPRAISAL COST CATEGORY	ACTIVITY	PREVENTION COST CATEGORY	ACTIVITY	FAILURE COST CATEGORY	ACTIVITY
QC Measures	Intercomparison of calibration teams. Operation of collocated samplers. Special activities performed by station operator strictly for obtaining data to evaluate accuracy and precision.	Planning and Documentation	Planning and preparation of: • Audit schedules and procedures • Operating standards • Apparatus configuration • Control procedures • Special tests • Operating procedures • Preventive maintenance procedures	Problem Investigation	Special tests and information collection to detect source and characteristics of problem Data and procedure review to identify problem area
				Corrective Action	Cost of correcting data Cost of changing established procedures to prevent reoccurrence of problems
Audits	Independent performance and system audits.	Procurement	Specification and acceptance testing of: • Calibration gases/devices • Equipment	Lost Data (unacquired and/or unacceptable data)	Estimated value of data which was lost or invalidated
Data Validation	• Statistical evaluation of data • Review of data handling procedures • Comparison of data with historical data and data from nearby stations Review and evaluation of: • Control tests • Audit schemes • Audit results • Special interference tests	Training	Operator training/proficiency evaluation. Certification of calibration personnel and equipment.		
		Preventive Maintenance	Maintenance of records, logs operation, calibration, and maintenance). Performance of preventive maintenance procedures.		
QA Assessment and Reporting	Assessment of overall data quality. Generation of data quality reports. Maintenance of quality cost system records.	System Calibration	Routine multipoint calibration of analyzers. Zero/span checks. Special checks on calibration system (voltage, temperature, variation, etc.)		

TABLE II. Total monitoring cost (dollars).

Pollutant	Annualized Total Cost Per Station	Maximum Data Units Per Station*	Cost Per Data Unit
CO	9,969	8448	1.18
SO_2	12,076	8448	1.43
O_3	8,713	8448	1.03
TSP	1,535	61	25.10
NO_2	8,757	8448	1.04
THC	9,231	8448	1.09
TOTAL FOR SO_2 = $12,076 × 16 = $193,216			

*Maximum data units for continuous analyzers based on total possible hourly averages per year.

Summary

The first step in implementing a quality cost system for an environmental monitoring program is to categorize quality-related activities into prevention, appraisal, and correction categories. An example listing for measurement methods involving continuous gaseous analyzers is given in this paper. Major items to be considered when implementing a system have been discussed along with an example quality cost system. Emphasis should be placed by management on preventive activities to decrease total cost of quality related activities.

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA 450/2-81-016		

4. TITLE AND SUBTITLE	5. REPORT DATE
APTI Course 470 Quality Assurance for Air Pollution Measurement Systems Student Workbook, Second Edition	May 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) B. Michael Ray	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Northrop Services, Inc. P.O. Box 12313 Research Triangle Park, NC 27709	10. PROGRAM ELEMENT NO. B18A2C 11. CONTRACT/GRANT NO. 68-02-3573
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Manpower and Technical Information Branch Air Pollution Training Institute Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Student Workbook 14. SPONSORING AGENCY CODE EPA-OAR-OAQPS

15. SUPPLEMENTARY NOTES

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16. ABSTRACT

This workbook is designed for use in APTI Course 470, "Quality Assurance for Air Pollution Measurement Systems." The workbook contains course and lesson objectives, selected reading material, representations of course visuals, and problem exercises covering the following topics:

- Basic Areas of QA Activities
- Managerial QA Elements
- Statistical Control Charts
- Calibration
- Regression Analysis
- Data Validation
- Outliers
- Intralaboratory/Interlaboratory Testing
- Procurement Quality Control
- Performance/System Audits
- QA Requirements for SLAMS/PSD
- Quality Costs

This workbook is designed for use with APTI Course 470 Instructor's Guide, Second Edition (EPA 450/2-81-015) and Volumes I and II of the Quality Assurance Handbook for Air Pollution Measurement Systems (EPA 600/9-76-005, EPA 600/4-77-027a).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Training Quality Assurance Quality Control Air Pollution Measurement	Training Course Air Pollution Monitoring Data Validation Control Charts Calibration	13 B 5 I 68 A

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Unlimited, available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.	Unclassified	165
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)