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TECHNICAL MANUAL FOR THE MEASUREMENT OF FUGITIVE EMISSIONS: QUASI-STACK SAMPLING METHOD FOR INDUSTRIAL FUGITIVE EMISSIONS

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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TECHNICAL MANUAL
FOR THE MEASUREMENT OF FUGITIVE EMISSIONS:
QUASI-STACK SAMPLING METHOD
FOR INDUSTRIAL FUGITIVE EMISSIONS

by

H.J. Kolnsberg, P.W. Kalika, R.E. Kenson, and W.A. Marrone

TRC--The Research Corporation of New England
125 Silas Deane Highway
Wethersfield, Connecticut 06109

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Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

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1.0 OBJECTIVE

The objective of this Technical Manual is to present the fundamental considerations required for the utilization of the Quasi-Stack Sampling Method in the measurement of fugitive emissions. Criteria for the selection of the most applicable measurement method and discussions of general information gathering and planning activities are presented. Quasi-stack sampling strategies and equipment are described and sampling system design, sampling techniques, and data reduction are discussed.

Manpower requirements and time estimates for typical applications of the method are presented for programs designed for overall and specific emissions measurements.

The application of the outlined procedures to the measurement of fugitive emissions from a grey-iron foundry is presented as an appendix.

2.0 INTRODUCTION

Pollutants emitted into the ambient air from an industrial plant or other site generally fall into one of two types. The first type is released into the air through stacks or similar devices designed to direct and control the flow of the emissions. These emissions may be readily measured by universally-recognized standard sampling techniques. The second type is released into the air without control of flow or direction. These fugitive emissions usually cannot be measured using existing standard techniques.

The development of reliable, generally applicable measurement procedures is a necessary prerequisite to the development of strategies for the control of fugitive emissions. This document describes some procedures for the measurement of fugitive air emissions using the quasi-stack measurement method described in Section 2.1.1 below.

2.1 Categories of Fugitive Emissions

Fugitive emissions emanate from such a wide variety of circumstances that it is not particularly meaningful to attempt to categorize them either in terms of the processes or mechanisms that generate them or the geometry of the emission points. A more useful approach is to categorize fugitive emissions in terms of the methods for their measurement. Three basic methods exist -- quasi-stack sampling, roof monitor sampling, and upwind-downwind sampling. Each is described in general terms below.

2.1.1 Quasi-stack Sampling Method

In this method, the fugitive emissions are captured in a temporarily installed hood or enclosure and vented to an exhaust duct or stack of regular cross-sectional area. Emissions are then measured in the exhaust duct using standard stack sampling or similar well recognized methods. This approach is necessarily restricted to those sources of emissions that are isolable and physically arranged so as to permit the installation of a temporary hood or enclosure that will not interfere with plant operations or alter the character of the process or the emissions.

Typical industrial sources of fugitive emissions measurable by the quasi-stack method include:

1. Material transfer operations

   Solids - conveyor belts, loading
   Liquids - spray, vapors

2. Process leaks

   Solids - pressurized ducts
   Liquids - pumps, valves

3. Evaporation

   Cleaning fluids - degreasers, wash tanks
   Paint solvent vapors - spray booths, conveyors

4. Fabricating operations

   Solids - grinding, polishing
   Gases - welding, plating

2.1.2 Roof Monitor Sampling Method

This method is used to measure the fugitive emissions entering the ambient air from building or other enclosure openings such as roof monitors, doors, and windows from enclosed sources too numerous or unwieldy to permit the installation of temporary hooding. Sampling is, in general, limited to a mixture of all uncontrolled emission sources within the enclosure and requires the ability to make low air velocity measurements and mass balances of small quantities of materials across the surfaces of the openings.

2.1.3 Upwind-Downwind Sampling Method

This method is utilized to measure the fugitive emissions from sources typically covering large areas that cannot be temporarily hooded and are not enclosed in a structure allowing the use of the roof monitor method. Such sources include material handling and storage operations, waste dumps and industrial processes in which the emissions are spread over large areas or are periodic in nature.

The upwind-downwind method quantifies the emissions from such sources as the difference between the pollutant concentrations measured in the ambient air approaching (upwind) and leaving (downwind) the source site. It may also be utilized in combination with mathematical models and tracer tests to define the contributions to total measured emissions of specific sources among a group of sources.

2.2 Sampling Method Selection

The initial step in the measurement of fugitive emissions at an industrial site is the selection of the most appropriate sampling method to be employed. Although it is impossible to enumerate all the combinations of influencing factors that might be encountered in a specific situation, careful consideration of the following general criteria should result in the selection of the most effective of the three sampling methods described above.

2.2.1 Selection Criteria

The selection criteria listed below are grouped into three general classifications common to all fugitive emissions measurement methods. The criteria are intended to provide only representative examples and should not be considered a complete listing of influencing factors.

2.2.1.1 Site Criteria

Source Isolability. Can the emissions be measured separately from emissions from other sources? Can the source be enclosed?

Source Location. Is the source indoors or out? Does location permit access of measuring equipment?

Meteorological Conditions. What are the conditions representative of typical and critical situations? Will precipitation interfere with measurements? Will rain or snow on ground effect dust levels?

2.2.1.2 Process Criteria

Number and Size of Sources. Are emissions from a single, well defined location or many scattered locations? Is source small enough to hood?

Homogeneity of Emissions. Are emissions the same type everywhere at the site? Are reactive effects between different emissions involved?

Continuity of Process. Will emissions be produced long enough to obtain meaningful samples?

Effects of Measurements. Are special procedures required to prevent the making of measurements from altering the process or emissions or interfering with production? Are such procedures feasible?

2.2.1.3 Pollutant Criteria

Nature of Emissions. Are measurements of particles, gases, liquids required? Are emissions hazardous?

Emission Generation Rate. Are enough emissions produced to provide measurable samples in reasonable sampling time?

Emission Dilution. Will transport air reduce emission concentration below measurable levels?

2.2.2 Application of Criteria

The application of the selection criteria listed in Section 2.2.1 to each of the fugitive emissions measurement methods defined in Section 2.1 is described in general terms in this section.

2.2.2.1 Quasi-Stack Method

Effective use of the quasi-stack method requires that the source of emissions be isolable and that an enclosure can be installed capable of capturing emissions without interference with plant operations. The location of the source alone is not normally a factor. Meteorological conditions usually need be considered only if they directly affect the sampling.

The quasi-stack method is usually restricted to a single source and must be limited to two or three small sources that can be effectively enclosed to duct their total emissions to a single sampling point. Cyclic processes should provide measurable pollutant quantities during a single cycle to avoid sample dilution. The possible effects of the measurement on the process or emissions is of special significance in this method. In many cases, enclosing a portion of a process in order to capture its emissions can alter that portion of the process by changing its temperature profile or affecting flow rates. Emissions may be similarly altered by reaction with components of the ambient air drawn into the sampling ducts. While these effects are not necessarily limiting in the selection of the method, they must be considered in designing the test program and could influence the method selection by increasing complexity and costs.

The quasi-stack method is useful for virtually all types of emissions. It will provide measurable samples in generally short sampling times since it captures essentially all of the emissions. Dilution of the pollutants of concern is of little consequence since it can usually be controlled in the design of the sampling system.

2.2.2.2 Roof Monitor Method

Practical utilization of the roof monitor method demands that the source of emissions be enclosed in a structure with a limited number of openings to the atmosphere. Measurements may usually be made only of the total of all emissions sources within the structure. Meteorological conditions normally need not be considered in selecting this method unless they have a direct effect on the flow of emissions through the enclosure opening.

The number of sources and the mixture of emissions is relatively unimportant since the measurements usually include only the total emissions. The processes involved may be discontinuous as long as a representative combination of the typical or critical groupings may be included in a sampling. Measurements will normally have no effect on the processes or emissions.

The roof monitor method, usually dependent on or at least influenced by gravity in the transmission of emissions, may not be useful for the measurement of larger particulates which may settle within the enclosure being sampled. Emission generation rates must be high enough to provide pollutant concentrations of measurable magnitude after dilution in the enclosed volume of the structure.

2.2.2.3 Upwind-Downwind Method

The upwind-downwind method, generally utilized where neither of the other methods may be successfully employed, is not influenced by the number or location of the emission sources except as they influence the locating of sampling devices. In most cases, only the total contribution to the ambient atmosphere of all sources within a sampling area may be measured. The method is strongly influenced by meteorological conditions, requiring a wind consistent in direction and velocity throughout the sampling period as well as conditions of temperature, humidity and ground moisture representative of normal ambient conditions.

The emissions measured by the upwind-downwind method may be the total contribution from a single source or from a mixture of many sources in a large area. Continuity of the emissions is generally of secondary importance since the magnitude of the ambient air volume into which the emissions are dispersed is large enough to provide a degree of smoothing to cyclic emissions. The measurements have no effect on the emissions or processes involved.

Most airborne pollutants can be measured by the upwind-downwind method. Generation rates must be high enough to provide measurable concentrations at the sampling locations after dilution with the ambient air. Settling rates of the larger particulates require that the sampling system be carefully designed to ensure that representative particulate samples are collected.

2.3 Sampling Strategies

Fugitive emissions measurements may, in general, be separated into two classes or levels depending upon the degree of accuracy desired. Survey measurement systems are designed to screen emissions and provide gross measurements of a number of process influents and effluents at a relatively low level of effort in time and cost. Detailed systems are designed to isolate, identify, and quantify individual contaminant constituents with increased accuracy and higher investments in time and cost.

2.3.1 Survey Measurement Systems

Survey measurement systems employ recognized standard or state-of-the-art measurement techniques to screen the total emissions from a site or source and determine whether any of the emission constituents should be considered for more detailed investigation. They generally utilize the simplest available arrangement of instrumentation and procedures in a relatively brief sampling program, usually without provisions for sample replication, to provide order-of-magnitude type data, embodying a factor of two to five in accuracy range with respect to actual emissions.

2.3.2 Detailed Measurement Systems

Detailed measurement systems are used in instances where survey measurements or equivalent data indicate that a specific emission constituent may be present in a concentration worthy of concern. Detailed systems provides more precise identification and quantification of specific constituents by utilizing the latest state-of-the-art measurement instrumentation and procedures in carefully designed sampling programs. These systems are also utilized to provide emission data over a range of process operating conditions or ambient meteorological influences. Basic accuracy of detailed measurements is in the order of ± 10 to ± 50 percent of actual emissions. Detailed measurement system costs are generally in the order of three to five times the cost of a survey system at a given site.

3.0 TEST STRATEGIES

This section describes the approaches that may be taken to successfully complete a testing program utilizing the quasi-stack sampling method described in Section 2.1. It details the information required to plan the program, describes the organization of the test plan, specifies the types of sampling equipment to be used, establishes criteria for the sampling system design, and outlines basic data reduction methods.

3.1 Pretest Survey

After the measurement method to be utilized in documenting the fugitive emissions at a particular site has been established using the criteria of Section 2.2, a pretest survey of the site should be conducted by the program planners. The pretest survey should result in an informal, internal report containing all the information necessary for the preparation of a test plan and the design of the sampling system by the testing organization.

This section provides guidelines for conducting a pretest survey and preparing a pretest survey report.

3.1.1 Information to be Obtained

In order to design a system effectively and plan for the on-site sampling of fugitive emissions, a good general knowledge is required of the plant layout, process chemistry and flow, surrounding environment, and prevailing meteorological conditions. Particular characteristics of the site relative to the needs of the owner, the products involved, the space and manpower skills available, emission control equipment installed, and the safety and health procedures observed, will also influence the sampling system design and plan. Work flow patterns and schedules that may result in periodic changes in the nature or quantity of emissions or that indicate periods for the most effective and least disruptive sampling must also be considered. Most of this information can only be obtained by a survey at the site. Table 3-1 outlines some of the specific information to be obtained. Additional information will be suggested by considerations of the particular on-site situation.

3.1.2 Report Organization

The informal, internal pretest survey report must contain all the pertinent information gathered during and prior to the site study. A summary of all communications relative to the test program should be included in the report along with detailed descriptions of the plant layout, process, and operations as outlined in Table 3-1. The report should also incorporate drawings, diagrams, maps, photographs, meteorological records, and literature references that will be helpful in planning the test program.

3.2 Test Plan

3.2.1 Purpose of a Test Plan

Measurement programs are very demanding in terms of the scheduling and completion of many preparatory tasks, observations at sometimes widely separated locations, instrument checks to verify measurement validity, etc. It is therefore essential that all of the experiment design and planning be done prior to the start of the measurement pro-

TABLE 3-1

PRE-TEST SURVEY INFORMATION TO BE OBTAINED
FOR APPLICATION OF FUGITIVE EMISSION SAMPLING METHODS

Plant Layout	Drawings: Building Layout and Plan View of Potential Study Areas Building Side Elevations to Identify Obstructions and Structure Available to Support Test Setup Work Flow Diagrams Locations of Suitable Sampling Sites Physical Layout Measurements to Supplement Drawings Work Space Required at Potential Sampling Sites
Process	Process Flow Diagram with Fugitive Emission Points Identified General Description of Process Chemistry General Description of Process Operations Including Initial Estimate of Fugitive Emissions Drawings of Equipment or Segments of Processes Where Fugitive Emissions are to be Measured Photographs (if permitted) of Process Area Where Fugitive Emissions are to be Measured Names, Extensions, Locations of Process Foremen and Supervisors Where Tests are to be Conducted
Operations	Location of Available Services (Power Outlets, Maintenance and Plant Engineering Personnel, Laboratories, etc.) Local Vendors Who Can Fabricate and Supply Test System Components Shift Schedules Location of Operations Records (combine with process operation information) Health and Safety Considerations
Other	Access routes to the areas Where Test Equipment/Instrumentation Will Be Located Names, Extensions, Locations of Plant Security and Safety Supervisors

gram in the form of a detailed test plan. The preparation of such a plan enables the investigator to "pre-think" effectively and cross-check all of the details of the design and operation of a measurement program prior to the commitment of manpower and resources. The plan then also serves as the guide for the actual performance of the work. The test plan provides a formal specification of the equipment and procedures required to satisfy the objectives of the measurement program. It is based on the information collected in the informal pretest survey report and describes the most effective sampling equipment, procedures, and timetables consistent with the program objectives and site characteristics.

3.2.2 Test Plan Organization

The test plan should contain specific information in each of the topical areas indicated below:

Background

The introductory paragraph containing the pertinent information leading to the need to conduct the measurement program and a short description of the information required to answer that need.

Objective

A concise statement of the problem addressed by the test program and a brief description of the program's planned method for its solution.

Approach

A description of the measurement scheme and data reduction methodology employed in the program with a discussion of how each will answer the needs identified in the background statement.

Instrumentation/Equipment/Facilities

A description of the instrumentation arrays to be used to collect the samples and meteorological data identified in the approach description. The number and frequency of samples to be taken and the sampling array resolution should be described.

A detailed description of the equipment to be employed and its purpose.

A description of the facilities required to operate the measurement program, including work space, electrical power, support from plant personnel, special construction, etc.

Schedule

A detailed chronology of a typical set of measurements or a test, and the overall schedule of events from the planning stage through the completion of the test program report.

Limitations

A definition of the conditions under which the measurement project is to be conducted. If, for example, successful tests can be conducted only during occurrences of certain wind directions, those favorable limits should be stated.

Analysis Method

A description of the methods which will be used to analyze the samples collected and the resultant data, e.g., statistical or case analysis, and critical aspects of that method.

Report Requirements

A draft outline of the report on the analysis of the data to be collected along with definitions indicating the purpose of the report and the audience for which it is intended.

Quality Assurance

The test plan should address the development of a quality assurance program as outlined in Section 3.7. This QA program should be an integral part of the measurement program and be incorporated as a portion of the test plan either directly or by reference.

Responsibilities

A list of persons who are responsible for each phase of the measurement program, as defined in the schedule, both for the testing organization and for the plant site.

3.3 Quasi-Stack Sampling Strategies

The quasi-stack sampling method, as described in Section 2.1.1, is used to quantify the emissions from a source by capturing the emissions, entrained in the ambient air, in a temporary hood or enclosure built over or around the source and directing the captured stream through a duct of regular cross section for measurement, sampling and analysis using standard stack techniques. The concentration of the pollutants in a sampled volume of the captured stream is determined in terms of micrograms per cubic meter or parts per million and used to determine the source strength of the pollutants by extrapolation to the total volume of the captured stream.

Sections 3.4 and 3.5 describe the strategies, sampling equipment, criteria for sampling system design, sampling techniques and data reduction procedures for respectively, survey and detailed quasi-stack sampling programs.

3.4 Survey Quasi-Stack Sampling Strategy

A survey measurement system, as defined in Section 2.3, is designed to provide gross measurements of emissions to determine quickly and inexpensively whether any pollutant constituents should be considered for more detailed investigation. A quasi-stack measurement system consists basically of a hood or other enclosure to capture the emissions at the source, an exhaust duct or stack in which the emissions are measured, a fan or blower to direct the emissions through the measurement duct, and the emissions sampling equipment. A survey system capture hood utilizes the simplest design possible, consistent with the requirement to capture all of the emissions from the source. Its measurement duct is the minimum diameter and length required to convey the suspected pollutants to their measurement points in sufficient quantity for efficient operation of the sampling equipment; and the sampling equipment is the simplest combination that will provide overall measurements of the suspected pollutants.

3.4.1 Sampling Equipment

Particulate pollutants may be grossly measured most conveniently using any of a large variety of filter impaction devices. A typical arrangement consists of an in-duct probe with a collection orifice angled into the flowing stream, a micro-porous filter in a flow-through holder, a positive-displacement suction pump and a flow measurement device such as a rotameter, all connected by small-diameter tubing.

Gaseous pollutants may be grab-sampled for laboratory analysis into suitably-sized vessels added to the particulate sampling train or separate sampling ports elsewhere in the measurement duct. On-line measurements may be made for specific gaseous compounds with bubbler trains designed for the pollutant of concern.

The total of pollutant-carrying air in the measurement duct is determined using a pitot tube - draft gage velocity measurement device in the known, regular cross-section duct area. Air pressure and temperature are determined using simple menometers and thermometers suitably located in the duct.

An alternative method for the measurement of particulates and volatile matter utilizes the recently developed source assessment sampling system (SASS) train. This train consists of a stainless steel probe that delivers the sample to an oven module containing three cyclone separators in series to provide measurable quantities of particulate matter in three size ranges: >10 micro meters, 3 to 10 micro meters, and 1 to 3 micro meters. A standard Method 5 type filter, also in series, provides a fourth size range of <1 micro meter. Organic vapors are collected on a parous polymer absorber after the sample is cooled by a gas conditioner on the outlet of the oven. An oxidative impinger entraps the remaining volatile trace elements to complete the sampling train. Used in combination with a gas-sampling assembly, the train can provide all the information required as to the native and composition of the pollutants in the sampled stream.

3.4.2 Sampling System Design

The primary concern in the design of a survey quasi-stack sampling system is insuring that measurable concentrations of the pollutants of concern are transported intact from the source to the sampling points. This is accomplished by carefully designing the pollutant-capturing enclosure, measurement duct and air-moving blower to provide sufficient air flow to entrain and transport the pollutants.

The size and shape of the pollutant-capturing hood will be dictated by the size, shape and location of the pollutant source. In general, it must be large enough to capture all of the pollutants, but not so large that the pollutants are diluted below measurable concentrations by an excessive volume of ambient air.

Hemeon[(1)] notes that the specific gravity of dusts, vapors or gases has no bearing on the design of an exhaust system so long as a basic control velocity is achieved and proposes some basic control velocities

(1) Hemeon, W.C.L., Plant and Process Ventilation, Industrial Press, Inc., New York. 1963.

for various ambient draft conditions for dusts and fumes. These are summarized in Table 3-2.

The air velocity at the open face of a hood is related to the air flow rate and the face area by

$$Q = VA, \qquad \text{[Equation 3-1]}$$

where Q = air volume flow rate, cubic feet per minute
V = air velocity, feet per minute
A = hood face area, square feet

The minimum air flow rate required to control the emissions is calculated as the product of the hood face area and the control velocity indicated in Table 3-2.

Since the calculated air flow rate is sufficient to provide capture velocity of the emissions at the largest opening of the hood, the transport of the emissions through the smaller cross-sectional area measurement duct is assured. In order to effectively measure the velocity, temperature and pressure of the flowing stream to determine the total flow rate, and to provide the most efficient sample flows, flow in the measurement duct should be in the turbulent range with a Reynold's number of 2×10^5 for a typical smooth-walled duct. The Reynolds number for air is roughly calculated as

$$Re = dV \times 110$$

where Re = Reynolds number, dimensionless
d = duct diameter, feet
V = air velocity, feet per minute

Since $V = Q/A$

and $A = \Pi d^2/4$

by substitution, $Re = \frac{140Q}{d}$

and $d = \frac{140Q}{Re} = \frac{140Q}{2 \times 10^5} = 7 \times 10^{-4}Q.$ [Equation 3-2]

TABLE 3-2

CONTROL VELOCITIES FOR DUSTS AND FUMES

Ambient Draft Characteristics	Control Velocities, feet per minute	
	Small dust quantities	Large dust quantities
Nearly draftless	40 - 50	50 - 60
Medium drafts	50 - 60	60 - 70
Very drafty	70 - 80	75 - 100

(Dust quantities may be roughly estimated in terms of their effect on visibility. A quantity of dust sufficient to obscure visibility of major details should be considered a large quantity.)

The blower or fan used to provide the required air flow rate should, in general, be selected to provide about twice the calculated rate to allow for adjustments for inaccuracies in estimates or assumptions. The actual flow rate may be controlled by providing a variable bypass air duct downstream of the measurement duct. A typical survey sampling system arrangement is illustrated schematically in Figure 3-1. Actual system layouts will, of course, be governed by space requirements at the source site. The minimum straight duct runs of 3 duct diameters upstream and downstream of the measurement and sampling ports must be provided to ensure that the sampled flow reaches and remains in the laminar region.

3.4.3 Sampling Techniques

Sampling must be scheduled and carefully designed to ensure that data representative of the emission conditions of concern are obtained. Effective scheduling demands that sufficient knowledge of operations and process conditions be obtained to determine proper starting times and durations for samplings. The primary concern of the sampling design is that sufficient amounts of the various pollutants are collected to provide meaningful measurements.

Each of the various sample collection and analysis methods has an associated lower limit of detection, typically expressed in terms of micrograms of captured solid material and either micrograms per cubic meter or parts per million in air of gases. Samples taken must provide at least these minimum amounts of the pollutants to be quantified. The amount (M) of a pollutant collected is the product of the concentration

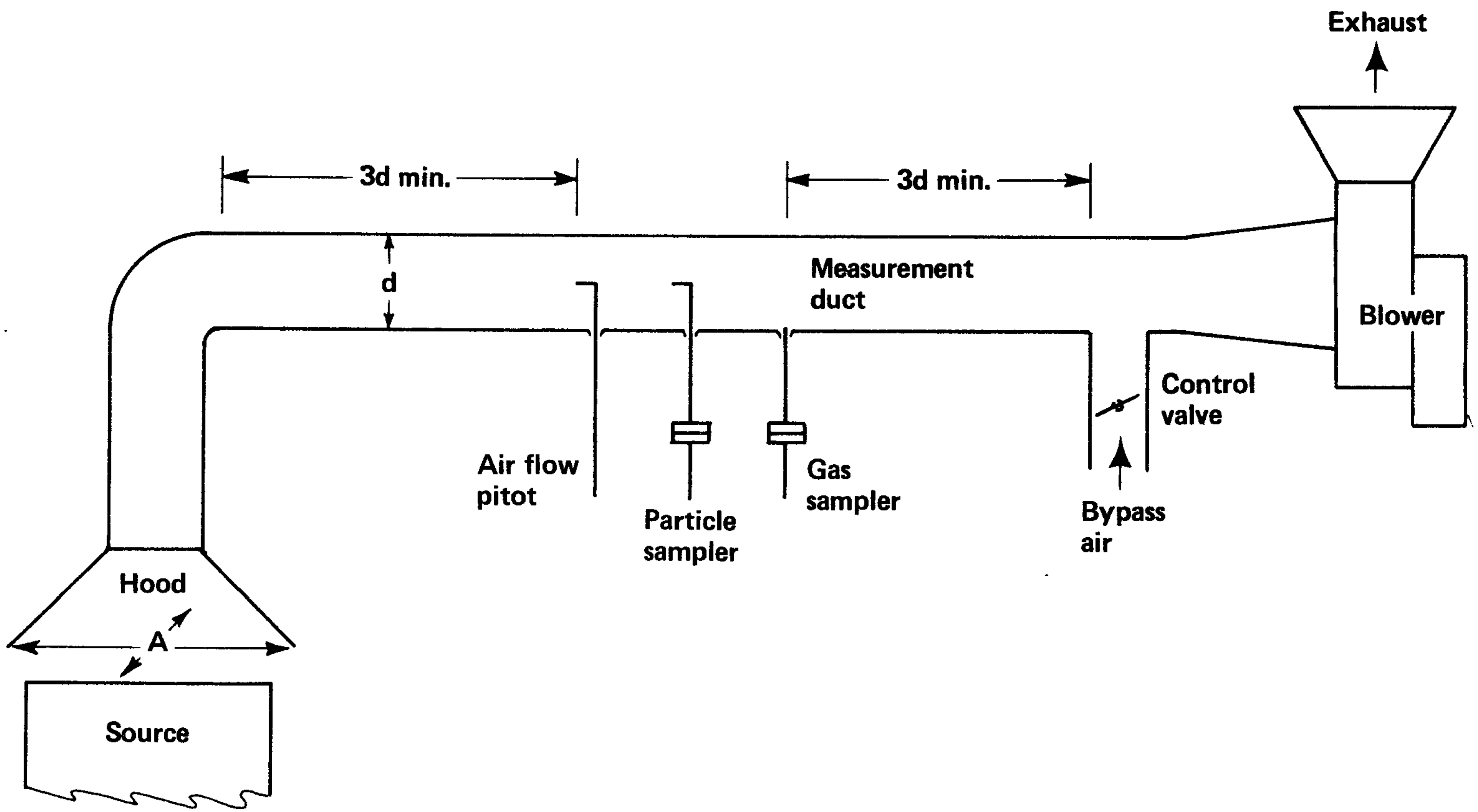

Fig. 3-1. Typical survey program sampling system.

of the pollutant in the air (χ) and the volume of air sampled (W), thus,

$$M \text{ (micrograms)} = \chi \text{ (micrograms/cubic feet)} \times V \text{ (cubic feet)}.$$

To ensure that a sufficient amount of pollutant is collected, an adequately large volume of air must be passed through such samplers as particle filters or gas absorbing trains for a specific but uncontrollable concentration. The volume of air (W) is the product of its flow rate (F) and the sampling time (T), or,

$$W \text{ (cubic feet)} = F \text{ (cubic feet/minute)} \times T \text{ (minutes)}.$$

Since the sampling time is most often dictated by the test conditions, the only control available to an experimenter is the sampling flow rate. A preliminary estimate of the required flow rate for any sample may be made if an estimate or rough measurement of the concentration expected is available. The substitution and rearrangement of terms in the above equations yields:

$$F \text{ (cubic feet/minute)} = M \text{ (micrograms)}/\chi \text{ (micrograms/cubic feet)} \times T \text{ (minutes)}. \quad \text{[Equation 3-3]}$$

This equation permits the calculation of the minimum acceptable flow rate for a required sample size. Flow rates should generally be adjusted upward by a factor of at least 1.5 to compensate for likely inaccuracies in estimates of concentration. The upper limit of the sampling flow rate is determined by the velocity of the measurement stream. To minimize the possibility of creating disturbances in the measurement stream that will permit entrained particulates to escape the entraining air flow and thus measurement by downstream samplers, the sample stream velocity at inlet must not exceed the measurement stream velocity. Thus,

$$F\ max = Q \frac{d_s^2}{d^2} \qquad \text{[Equation 3-4)}$$

where $F\ max$ = maximum sampler flow rate, cubic feet per minute
Q = air volume flow rate, cubic feet per minute
d_s = sampling line inlet diameter, feet
d = measurement duct diameter, feet

Grab samples of gaseous pollutants provide for no means of pollutant sample quantity control except in terms of the volume of the sample. Care should be taken, therefore, to correlate the sample size with the requirements of the selected analysis method.

3.4.4 Data Reduction

When the sampling program has been completed and the samples analyzed to yield pollutant concentrations in micrograms per cubic meter or parts per million per unit volume in the captured stream, the values are then multiplied by the flow rate of the captured stream which is assumed to contain all the pollutants omitted by the source, to yield the source strength in terms of grams per unit time.

In cases where the background pollutant level in the ambient air used as the source pollutant transport medium is known or suspected to be of a magnitude sufficient to mask the source pollutant emission level, a sampling run of the ambient air may be required for better quantification of the source strength. This may be accomplished using the sampling system either with the source inoperative or with the hood directed so as to avoid capturing any source emissions. The samples from such a sampling run are analyzed in the same manner as the source samples to yield the pollutant concentrations in the ambient air. These are then subtracted from the source sample values before calculating the source strengths.

3.5 Detailed Quasi-Stack Sampling Strategy

A detailed measurement system is designed to more precisely identify and quantify pollutants that a survey measurement or equivalent data indicate as possible problem areas. A detailed system is necessarily more complex than a survey system in terms of equipment, system design, sampling techniques and data reduction. It requires a much larger investment in equipment, time and manpower to yield data detailed and dependable enough for direct action toward achieving emissions control. The basic configuration of a detailed quasi-stack sampling system is the same as that of a survey system -- an emissions capturing enclosure, a measurement duct and an air mover plus the sampling and measuring equipment. Its capturing enclosure may, depending on the characteristics of the source, be considerably more complex, providing more of the functions of a permanent system. The measurement duct is usually longer, providing space for the installation of a greater number of sampling devices or more complex, on-line specific pollutant measuring arrangements.

3.5.1 Sampling Equipment

The pollutants to be characterized by a detailed quasi-stack sampling system fall into the same two basic classes -- airborne particulates and gases -- as those measured by survey systems. Detailed system sampling and analysis equipment is generally selected to obtain continuous or semi-continuous measurements of specific pollutants rather than grab-sampled overall measurement.

Particulate samples are collected using the SASS train described in Section 3.4.1, filter impaction, piezo-electric, particle charge transfer, light or radiation scattering, electrostatic, and size selective or adhesive impaction techniques. Gases are sampled and analyzed using flame ionization detectors, bubbler/impinger trains, non-dispersive infrared or ultraviolet monitors, flame photometry, and other techniques specific to individual gaseous pollutants.

The selection of suitable sampling equipment should be influenced by such considerations as portability, power requirements, detection limits and ease of control.

3.5.2 Sampling System Design

The basic criteria and methods reviewed in Section 3.4.2 for the design of a survey system are generally applicable to the design of a detailed system. In cases where the capturing enclosure actually covers all or part of the source, however, a minor adjustment is required in the calculation of the required air flow rate. In such cases, the source serves to block some of the free air flow area and reduces the air flow required to achieve capture velocity. The elements of Equation 3-1 must therefore be redefined in

$$Q = VA$$

where Q = air volume flow rate, cubic feet per minute
V = air velocity, feet per minute
A = free flow area, square feet

The free flow area is defined as the maximum area between the hood and the enclosed source in any plant parallel to the open hood face.

The calculation of the minimum measurement duct diameter by Equation 3-2, $d = 4.45 \times 10^{-4} Q$ remains unchanged. Straight duct run requirements of at least 3d upstream and downstream of measurement parts are required.

3.5.3 Sampling Techniques

Detailed system sampling, like survey system sampling, must be scheduled and designed to obtain data representative of the emission conditions of concern. Since a greater number of samples are likely to be required in a detailed system, care must be taken to ensure that the total flow rate to the samplers does not exceed the air flow required for capture velocity at the source enclosure.

A detailed system may be utilized to make comparative measurements of emissions at different process conditions. It is possible, especially in cases where the source enclosure closely follows the contours of the source, that the flow of air induced by the sampling system over the surface of the source could alter the process from that occurring under normal operating conditions. While no general method to verify the existence of this alteration can be defined, it is suggested that an appropriate analysis be conducted to investigate the possibility and corrective actions, such as a modification to the enclsoure design, be taken as required.

3.5.4 Data Reduction

Data obtained in detailed programs is reduced in the same manner as that obtained in survey programs, relating pollutant concentrations in the sample volumes to sources strengths. The results are generally more accurate than those of a survey program, due to the combined effects of the increase in the emissions capture effectiveness of the source enclosure, the performance of inherently more accurate samplings and analyses, and the replication of sampling.

3.6 Quality Assurance

The basic reason for quality assurance on a measurement program is to insure that the validity of the data collected can be verified. This requires that a quality assurance program be an integral part of the measurement program from beginning to end. This section outlines the quality assurance requirements of a sampling program in terms of several basic criteria points. The criteria are listed below with a brief explanation of the requirements in each area. Not all of the criteria will be applicable in all fugitive emission measurement cases.

1. Introduction

   Describe the project organization, giving details of the lines of management and quality assurance responsibility.

2. Quality Assurance Program

   Describe the objective and scope of the quality assurance program.

3. Design Control

   Document regulatory design requirements and standards applicable to the measurement program as procedures and specifications.

4. Procurement Document Control

   Verify that all regulatory and program design specifications accompany procurement documents (such as purchase orders).

5. Instructions, Procedures, Drawings

   Prescribe all activities that affect the quality of the work performed by written procedures. These procedures must include acceptance criteria for determining that these activities are accomplished.

6. Document Control

Ensure that the writing, issuance, and revision of procedures which prescribe measurement program activities affecting quality are documented and that these procedures are distributed to and used at the location where the measurement program is carried out.

7. Control of Purchase Material, Equipment, and Services

Establish procedures to ensure that purchased material conforms to the procurement specifications and provide verification of conformance.

8. Identification and Control of Materials, Parts, and Components

Uniquely identify all materials, parts, and components that significantly contribute to program quality for traceability and to prevent the use of incorrect or defective materials, parts, or components.

9. Control of Special Processes

Ensure that special processes are controlled and accomplished by qualified personnel using qualified procedures.

10. Inspection

Perform periodic inspections where necessary on activities affecting the quality of work. These inspections must be organized and conducted to assure detailed acceptability of program components.

11. Test Control

Specify all testing required to demonstrate that applicable systems and components perform satisfactorily. Specify that the testing be done and documented according to written procedures, by qualified personnel, with adequate test equipment according to acceptance criteria.

12. Control of Measuring and Test Equipment

Ensure that all testing equipment is controlled to avoid unauthorized use and that test equipment is calibrated and adjusted at stated frequencies. An inventory of all test equipment must be maintained and each piece of test equipment labeled with the date of calibration and date of next calibration.

13. Handling, Storage, and Shipping

Ensure that equipment and material receiving, handling, storage, and shipping follow manufacturer's recommendations to prevent damage and deterioration. Verification and documentation that established procedures are followed is required.

14. Inspection, Test, and Operating Status

Label all equipment subject to required inspections and tests so that the status of inspection and test is readily apparent. Maintain an inventory of such inspections and operating status.

15. Non-conforming Parts and Materials

Establish a system that will prevent the inadvertent use of equipment or materials that do not conform to requirements.

16. Corrective Action

Establish a system to ensure that conditions adversely affecting the quality of program operations are identified, corrected, and commented on; and that preventive actions are taken to preclude recurrence.

17. Quality Assurance Records

Maintain program records necessary to provide proof of accomplishment of quality affecting activities of the measurement program. Records include operating logs, test and inspection results, and personnel qualifications.

18. Audits

Conduct audits to evaluate the effectiveness of the measurement program and quality assurance program to assure that performance criteria are being met.

4.0 ESTIMATED COSTS AND TIME REQUIREMENTS

Table 4-1 presents a listing of the conditions assumed for estimating the costs and time requirements of quasi-stack fugitive emissions sampling programs using the methodology described in this document. Four programs are listed, representing simple and more complex levels of effort for each of the survey and detailed programs defined in Section 3.3. The combinations of conditions for each program are generally representative of ideal and more realistic cases for each level and will seldom be encountered in actual practice. They do, however, illustrate the range of effort and costs that may be expected in the application of the quasi-stack technique except in very special instances.

4.1 Manpower

Table 4-2 presents estimates of manpower requirements for each of the sampling programs listed in Table 4-1. Man-hours for each of the three general levels of Senior Engineer/Scientist, Engineer/Scientist, and Junior Engineer/Scientist are estimated for the general task areas outlined in this document and for additional separable tasks. Clerical man-hours are estimated as a total for each program. Total man-hour requirements are approximately 500 man-hours for a simple survey program and 1000 man-hours for a more complex survey program and 1400 man-hours for a simple detailed program and 2600 man-hours for a more comples detailed program.

4.2 Other Direct Costs

Table 4-3 presents estimates for equipment purchases, rentals, cal-

TABLE 4-1

CONDITIONS ASSUMED FOR COST ESTIMATION
OF QUASI-STACK SAMPLING PROGRAM

Parameter	Level 1 Program		Level 2 Program	
	Simple	Complex	Simple	Complex
Source accessibility	Open	Congested	Open	Congested
Source geometry	Small, simple shape	Large, complex shape	Small, simple shape	Large, complex shape
Emissions	Constant rate, continuous flow	Variable rate, interrupted flow	Constant rate, continuous flow	Variable rate, interrupted flow
Particulate Samplers	Filter	Filter	Cascade impactor	Impactor, light scatter
Gas Samplers	Grab	Bubblers	EID	FID, infrared
Experiments	1	1	4	12
Estimated basic accuracy	± 500%	± 200%	± 100%	± 50%

TABLE 4-2

ESTIMATED MANPOWER REQUIREMENTS FOR QUASI STACK
FUGITIVE EMISSIONS SAMPLING PROGRAMS

Estimates in Man-Hours

Task	Level 1 Programs						Level 2 Programs					
	Simple			Complex			Simple			Complex		
	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech
Pretest Survey	4	12	0	8	24	0	8	24	0	12	36	16
Test Plan	8	12	0	12	16	4	12	24	12	16	32	12
Equipment Acquisition	4	4	12	4	8	28	8	24	48	12	36	52
Field Set-Up	16	32	80	16	72	120	16	64	120	32	128	240
Field Study	16	56	120	32	128	280	32	128	240	64	240	480
Sample Analysis	8	8	16	8	12	24	20	80	120	40	180	240
Data Analysis	8	8	16	8	12	24	20	120	40	40	240	80
Report Preparation	16	16	8	32	32	16	40	80	40	60	160	80
Totals	80	140	252	120	304	496	156	544	620	276	1052	1200
Engineer/Scientist Total		480			920			1320			2528	
Clerical		40			60			100			120	
Grand Total		520			980			1420			2648	

TABLE 4-3

ESTIMATED COSTS OTHER THAN MANPOWER FOR QUASI-STACK FUGITIVE EMISSIONS SAMPLING PROGRAMS

Cost Item	Level 1 Programs		Level 2 Programs	
	Simple	Complex	Simple	Complex
Equipment				
Sampler Purchases	$1000	$1200	$8000	$12000
Calibration	0	50	300	500
Repairs/Maintenance	50	50	200	300
Blower/Fan	200	200	300	300
Construction				
Enclosure	500	800	1200	1800
Ducting	300	500	300	800
Shipping	200	400	800	1200
Trailer Rental	0	0	500	500
Vehicle Rentals	280	560	900	1200
On-Site Communications	100	100	300	300
TOTAL	$2630	$3860	$12800	$19100

ibration and repairs; on-site construction of enclosures and ducts; shipping and on-site communications for each of the listed programs. Total costs are approximately $2,600 for a simple survey program and $4,000 for a more complex survey program, and $13,000 for a simple detailed program and $19,000 for a more complex detailed program.

4.3 Elapsed-Time Requirements

Figure 4-1 presents elapsed-time estimates for each of the listed programs broken down into the task areas indicated in the manpower estimates of Table 4-2. Total program durations are approximately 12 weeks for a simple survey program and 16 weeks for a more complex survey program, and 29 weeks for a simple detailed program and 38 weeks for a more complex detailed program.

4.4 Cost Effectiveness

Figure 4-2 presents curves of the estimated cost effectiveness of the quasi-stack technique, drawn through points calculated for the four listed programs. Costs for each program were calculated at $30 per labor hour, $40 per man day subsistence for field work for the manpower estimates of Table 4-2, plus the other direct costs estimated in Table 4-3.

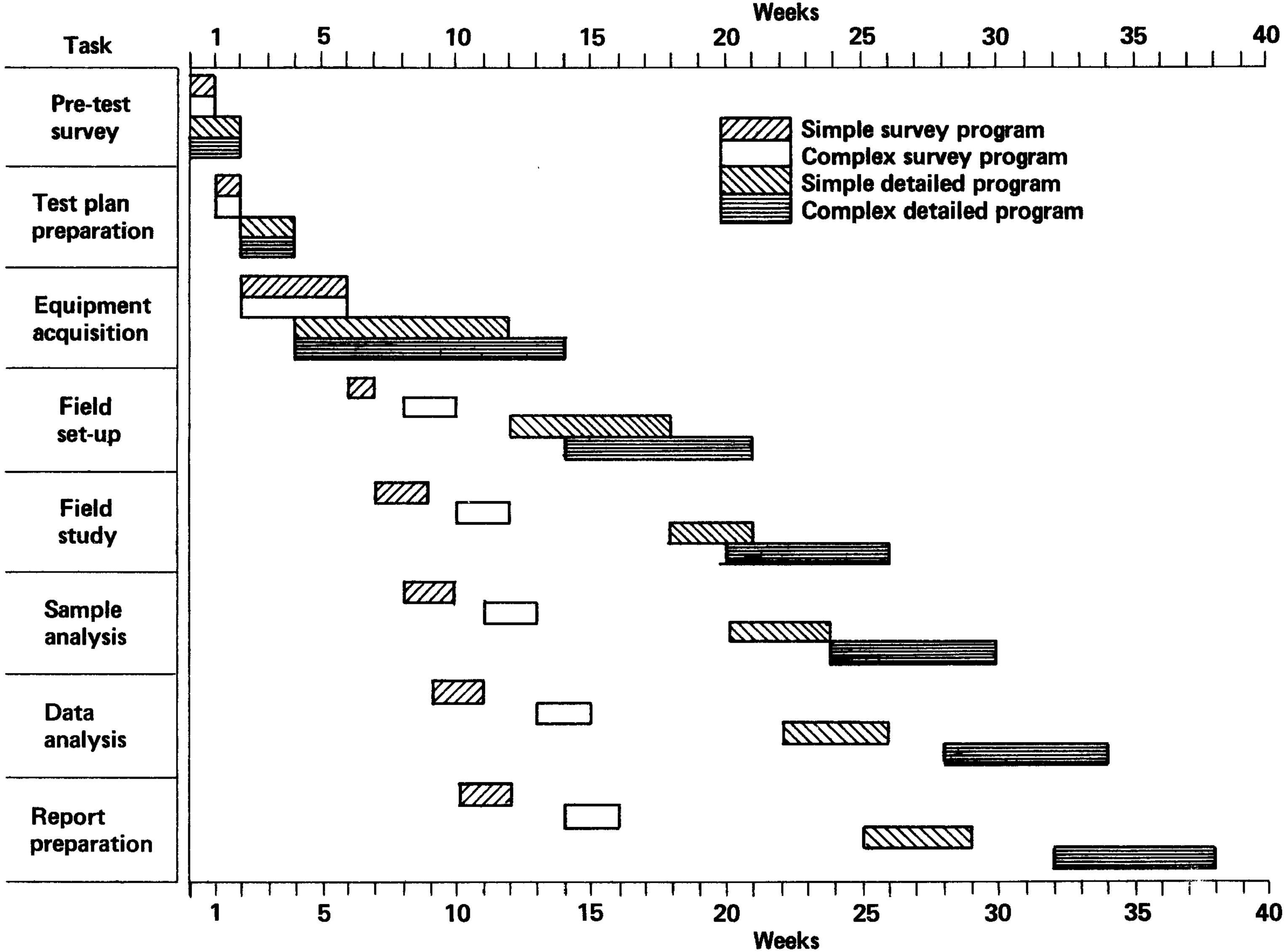

Fig. 4-1. Elapsed-time estimates for quasi-stack fugitive emissions sampling programs.

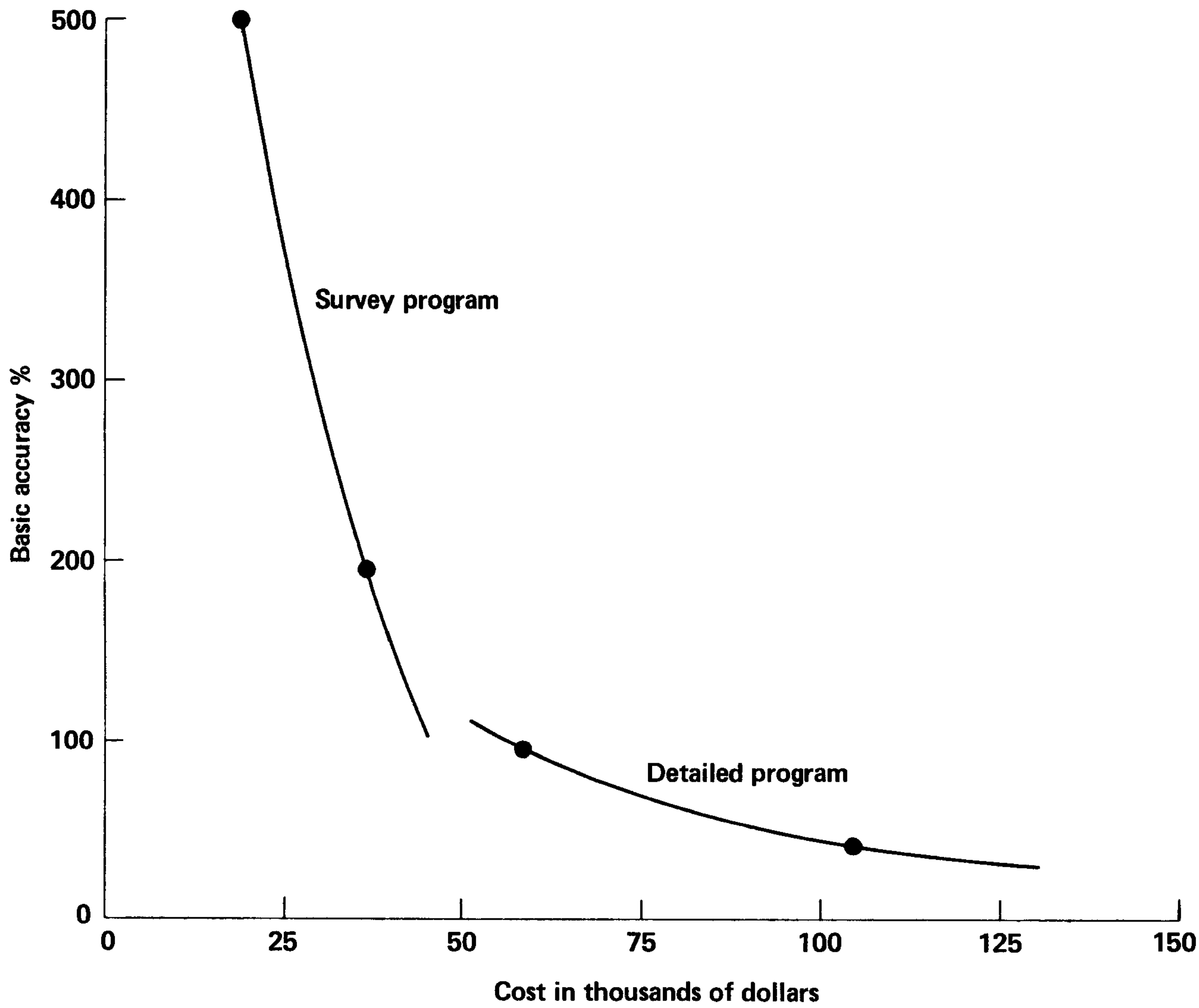

Fig. 4-2. Cost effectiveness of quasi-stack fugitive emissions sampling programs.

APPENDIX A

APPLICATION OF THE QUASI-STACK MEASUREMENT METHOD TO A GREY-IRON FOUNDRY

A.1.0 INTRODUCTION

This appendix presents an application of the quasi-stack fugitive emissions measurement system selection and design criteria to a grey-iron foundry mold pouring operation. The criteria for the selection of the method and the design procedures for both survey and detailed sampling systems as presented in Sections 3.4 and 3.5 of this document are discussed.

A.2.0 BACKGROUND INFORMATION

The following information relative to the pouring operation of the subject grey-iron foundry would ordinarily be compiled from interviews and observations during a visit to the plant for a pre-test survey:

Mold pouring operations are conducted at many locations over the foundry floor, with the molten iron carried from the melting furnace in a pouring ladle by means of an overhead crane. Ladles are selected to provide at least enough melt to completely fill a mold in a single pouring. As many as six smaller molds, with flasks up to about 8 cubic feet in volume, may be filled from a single small ladle; while the largest ladle can carry enough melt to fill one mold in a flask up to 300 cubic feet. Actual pouring of the melt takes from about 30 seconds for the smallest molds to nearly 6 minutes for the largest molds. The emission character is the same for any size pouring, consisting mostly of grey-iron fume and a variety of gaseous compounds, principally hydrocarbons and carbon oxides. Emission character immediately after the pouring, while there is still a gas-producing reaction between the melt and the binder material in the mold, is different from that during the pour, with almost no fume and more gaseous compounds being generated. Emissions during this venting period are highest immediately after the pour and lessen with time, becoming negligible after about 4 minutes for small molds and about 10 minutes for the largest molds. Molds are spaced to provide working room around all four sides, so that pouring operations, at least for the larger molds, may be readily isolated and emissions from other operations excluded. Pouring is always accomplished from above the mold, with mold sprues generally located near one edge. Mold gas vents are located over the entire top surface of the mold. Though foundry operations are continuous, the pouring of a single mold may be scheduled at any time without seriously disturbing normal operations.

A.3.0 METHOD SELECTION

Selecting the most practical method to quantify the pollutants emitted during the pouring operation involves the evaluation of the site, process and pollutant information gathered during the pre-test survey in terms of the criteria of Section 2.2 as follows:

> Site Criteria - the typical mold is located within the foundry building with enough room around the mold to provide complete isolation from other operations and installation of an enclosure and measuring equipment.

> Process Criteria - emissions are from locations small enough to totally enclose. No reactive effects will occur with other emissions. Emission duration is only 10-15 minutes. Measurement equipment installation and application will not alter emissions, process or production schedules.

> Pollutant Criteria - emissions to be measured are particulates and gases, neither of which is hazardous. Generation rate should produce measurable concentrations in reasonable transport air flows.

The criteria in this case satisfy the requirements for the quasi-stack method. Measurements made of a single pouring can provide information relative to the emission rate for a given volume or mass of melt, and, by extrapolation, for the entire foundry. A survey program may be utilized to roughly determine the overall emissions rate and establish whether the concentrations of particulates or gases that may reach the ambient air will result in the creation of an objectionable condition. If such a condition is indicated, a detailed program will identify and quantify specific pollutants to assist in the selection and design of control equipment to reduce emissions to alleviate the condition. The design of both survey and detailed systems is described in following sections.

A.4.0 SURVEY MEASUREMENT SYSTEM

To measure the contribution of a single pouring's emission to the ambient air, emissions from the mold and ladle during the pouring and from the mold alone during the post-pouring venting must be captured and transported to sampling equipment. Samples must be taken at a high rate to ensure that measurable pollutant quantities are isolated during the short process duration. In order to keep the required hood structure to a manageable size and still obtain a reasonable sampling time, a medium-sized mold, 3 x 4 x 4 feet is selected, representative of the average-sized casting produced in the foundry. This size casting requires about 4 minutes to pour and has a venting period of 7 to 8 minutes. Consultations with foundry engineers indicating that a clearance of 3 feet above the front pouring edge of the mold will leave sufficient room for handling the pouring ladle, a hood is designed as shown in Figure A-1, providing this clearance and a 3 inch overlap over each edge of the mold.

The face area of this hood is about 16 square feet. The control velocity for a large quantity of fume in a medium drafty ambient atmosphere, as indicated in Table 3-2, is 60-70 feet per minute. Using the higher velocity value for V and the calculated area for A in Equation 3-1,

$$Q = VA = 70 \times 16 = 1120 \text{ cubic feet per minute.}$$

For this flow rate, the minimum measurement duct diameter is calculated from Equation 3-2,

$$d = 7 \times 10^{-4} Q = .78 \text{ feet}$$

$$d = 9.4 \text{ inches}$$

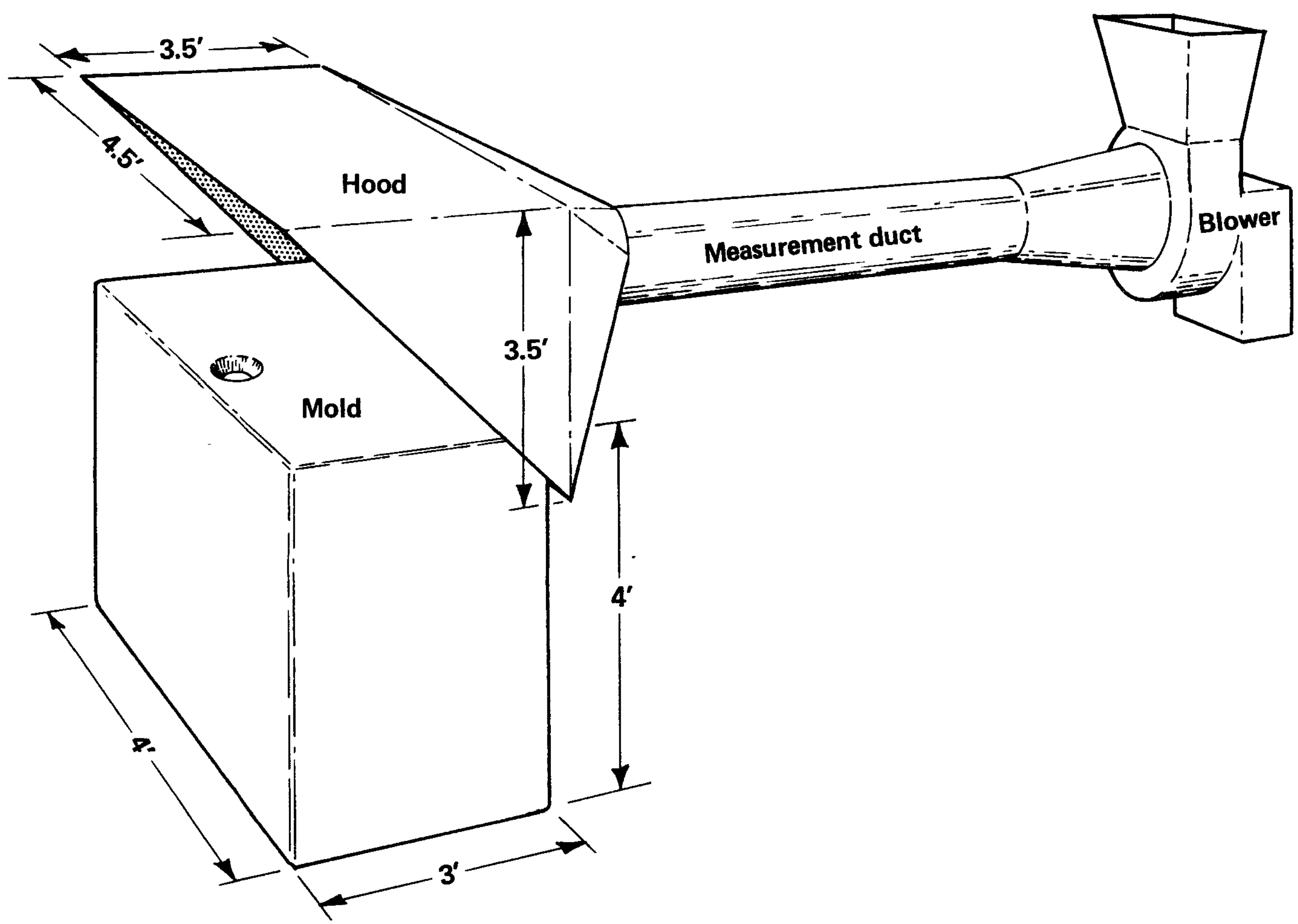

Fig. A-1. Survey program sampling hood design.

A standard 10 inch diameter duct will provide for the proper flow and require only 8 to 10 feet of length to provide the required flow straightening upstream and downstream of the measurement and sampling probes.

The flow measuring instruments located in the duct consist of a pitot pressure tube, a static pressure port and a mercury thermometer inserted to the duct centerline about 40 inches (4d) from the hood transition section.

The particulate sampling tube is located about 20 inches downstream of the flow measuring instruments and consists of a 1/2 inch diameter right-angled probe, this diameter chosen to provide as much sample as possible during the rather short emission duration. The sampling flow rate is calculated from Equation 3-4 as

$$F\ max = Q\ \frac{d_s^2}{d^2} = 2.8 \text{ cubic feet per minute.}$$

At 2.8 cubic feet per minute, the particulate filter will be exposed to about 11 cubic feet during the pouring and about 20 cubic feet during the venting period. Grab-sampling 4 cubic foot bags valved into the sampling line will be readily filled during the pour and venting to provide separate measurements of gaseous emission.

A.5.0 DETAILED MEASUREMENT SYSTEM

Assuming that the survey system measurements indicate emission rates resulting in pollutant concentrations in a range possibly hazardous to the health of the foundry personnel, further identification of the specific pollutant components and their concentrations by means of a detailed measurement system will either establish the need for emission controls or eliminate the cause for concern.

The detailed system will utilize three separate on-line particulate measurement devices to determine size distribution, mass, composition and organic characteristics. These are:

1. Particle charge transfer monitor
2. Cascade impactor
3. EPA isokinetic sampling train

The combination will provide positive identification of all particulates and readily separate fume from background particles.

Alternatively, the SASS train described in Section 3.4.1 may be utilized to provide data on the particulates and the volatile matter in the sampled stream.

Gaseous emissions will be identified and quantified by on-line measurements using a flame ionization detector for hydrocarbons and a non-dispersive infrared monitor for carbon monoxide.

The 3 x 4 x 4 foot mold used in the survey program is again utilized, with the capture hood modified to provide almost total enclosure of the mold and pouring ladle by extending the hood to the floor and providing flexible shrouds across the open front face. The sampling system is shown with shrouds in place in Figure A-2.

In this configuration, the free flow area of the hood is maintained at about the same size as in the Level 1 system and the air flow rate calculation remains the same, yielding Q = 1120 cubic feet per minute and d = 10 inches. The sampling probes may be reduced in size since the on-line samplers flow requirements are significantly less than those required for overall measurements. Equation 3-4 shows, for example, that a 1/16 inch line will provide about 30 times the required 200 milliliter per minute flow rate required by the FID monitor without exceeding measurement duct velocity restrictions.

All measurement devices for this system are shown within a laboratory trailer, since most foundry floors will not allow the installation of sensitive devices without a strong possibility of either external contamination or interference with normal work patterns.

In use, the floor area within the hood/shroud enclosure is carefully swept to remove any non-pouring particles. A "dry" run, without the ladle of melt in position, is conducted before the pour to measure the background pollutant concentrations. These are subtracted from the concentrations measured during the pour before source strength calculations are performed.

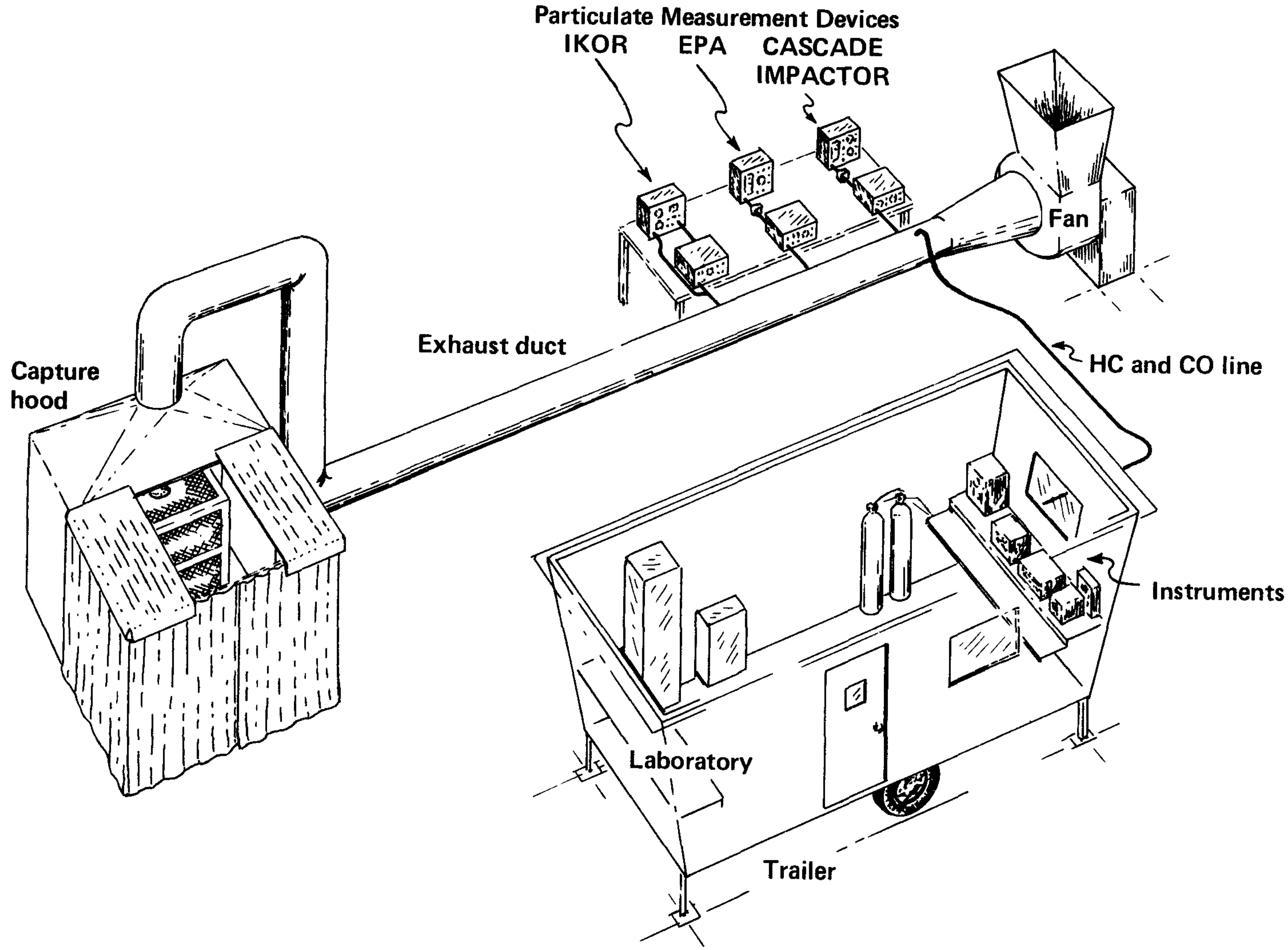

Fig. A-2. Detailed program sampling system.

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16. ABSTRACT The technical manual presents fundamental considerations that are required in using the Quasi-Stack Sampling Method to measure fugitive emissions. Criteria for selecting the most applicable measurement method and discussions of general information-gathering and planning activities are presented. Quasi-Stack sampling strategies and equipment are described, and sampling system design, sampling techniques, and data reduction are discussed. Manpower requirements and time estimates for typical applications of the method are presented for programs designed for overall and specific emissions measurements. The application of the outlined procedures to the measurement of fugitive emissions from a gray-iron foundry is presented as an appendix.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution, Foundries	Air Pollution Control	13B
Industrial Processes	Stationary Sources	13H
Measurement	Fugitive Emissions	14B
Sampling	Quasi-Stack Sampling	
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