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A REVIEW OF METHODS FOR MEASURING FUGITIVE PM-10 EMISSION RATES



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Abstract

The purpose of this report is to serve as a guide for the measurement of fugitive dust. To that end, the methods of measuring fugitive particulate emissions are reviewed. The methods included are the quasi-stack method, the roof monitor method, the upwind-downwind method, the exposure profiling method, the portable wind tunnel method, the scale model wind tunnel method, the tracer method and the balloon method. Each measurement method is explained, along with its advantages and disadvantages. Sources of error are discussed, as are sampling protocols. The literature on each method is reviewed. A section of the report is devoted to the issues of error, accuracy and precision of the methods.

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Introduction

Fugitive dust may be defined as dust emitted from sources other than stacks or tail pipes. EPA now regulates emissions of dust particles which have an aerodynamic diameter of ten microns or less, because this dust causes respiratory health effects. Such dust is referred to as PM-10.

Emission factors published in EPA document AP-42 describe fugitive dust emission rates for a variety of sources. Most of the time these emission factors suffice for calculation of industrial or other fugitive emissions. But sometimes people in the private sector or state or local government disagree with the published emission factors for a given process or situation, or they think that the published emission factors do not apply. They wish to calculate specific emission factors themselves. In that event, the rate of fugitive dust emission must be measured. The purpose of this report is to provide information and guidance about the measurement of PM-10 from fugitive sources. To that end, a review of the literature concerning methods for measuring fugitive PM-10 emissions has been performed.

Several such methods exist. The quasi-stack method, the roof monitor method and the upwind-downwind method have relatively long histories, and have been used to measure various kinds of fugitive emissions including dust. The exposure profiling method was developed specifically for measuring fugitive particulate emissions. The portable wind tunnel method was first used by soil scientists before being used in an air pollution context. The balloon method is a little-used offshoot of the exposure profiling method. The scale model wind tunnel method and tracer method have also been comparatively little-used.

The selection of a measurement method depends upon such factors as source geometry, presence or absence of an enclosing structure, feasibility of hooding or enclosing the source, size of the dust plume, distance between plume generation and feasible sampling sites, and type of process causing the plume. For example, the quasi-stack method requires the (usually temporary) enclosure or hooding of a source. The roof monitor method involves monitoring of air flow and particle concentration leaving all major exit points in a building. The portable wind tunnel is used only to study emissions from wind erosion. Exposure profiling is an excellent method for studying "point" sources such as loading or unloading operations, or "line" sources such as traffic on a road, but the sampling equipment must be placed within a few meters of the emission source. The upwind-downwind method is nearly universally applicable, but may be the least accurate of the methods. Appendix K (TRC, 1980) contains excellent information on the selection of a measurement method.

Quasi-stack method

Richards and Brozell (1992), Richards and Kirk (1992), and Brozell and Richards (1993) describe recent applications of the quasi-stack method at stone crushing plants. The quasi-stack method is especially well suited to small materials-handling operations and small components of industrial processes. Essentially, this method consists of enclosing or hooding (often temporarily) the fugitive dust source to be measured. The dust plume is ducted away from the source at a known air velocity, by using a fan, and the exhaust is sampled isokinetically in the duct.

The intake velocity must be lower than the velocity in the sampling duct. For typical ducts with smooth walls the Reynolds number should be in the neighborhood of 200,000 (turbulent region). There should be a minimum straight duct run of three duct diameters upstream and downstream of the sampling port (Kolnsberg et al., 1976).

Standard stack sampling trains (EPA Methods 201 or 201A) may be used to measure concentrations of PM-10, using standard sampling protocols (EPA Method 1, where applicable). The product of the concentration, the mean velocity of the exhaust and the cross-sectional area of the duct gives the emission rate.

The quasi-stack method is potentially the most accurate means of measuring a fugitive dust plume because the entire plume is captured and measured close to the source, and because it uses well established and well validated sampling protocols. However, the air velocity in the vicinity of the hood or enclosure must be sufficient to entrain the entire PM-10 plume without being fast enough to cause excess emissions.

For example, excess emissions might emit from a stone crusher if the air speed inside the temporary enclosure is higher than the normal ambient air speed. In that case, the higher air speed in the enclosure might cause more dust to enter the air from stone crushing, thus causing an overestimation of the emission rate.

Also, there must not be significant deposition of PM-10 within the duct-work or enclosure. Furthermore, if the space enclosed is normally subjected to turbulence from ambient winds, the emission rate calculated after enclosure may underpredict the true emissions. Finally, the sampling protocol must represent the average dust levels encountered in cyclic or uneven dust-producing processes (Cowherd and Kinsey, 1986).

Appendix A is an excerpt from 40 CFR 51 containing descriptions of Methods 201 and 201A. Appendix A also contains excerpts from 40 CFR 60, with descriptions of Methods 1 and 5D. Appendix B is

an excerpt from Richards and Brozell (1992) describing recent applications of the quasi-stack method.

EPA published a series of technical manuals on measuring fugitive emissions in 1976. One manual was on the quasi-stack method (Kolnsberg et al.), one was on the roof monitor method (Kenson and Bartlett) and one was on the upwind-downwind method (Kolnsberg). From the point of view of measuring PM-10, these manuals have several problems: they are old, the equipment in them has largely been superseded, the manuals were written from the perspective of measuring all fugitive emissions, not just dust, and at that time EPA was concerned with measuring total suspended particulate, not PM-10. Nevertheless, they provide significant useful information and are being included in this report as appendices. However, it must be reiterated that much of the equipment in these manuals has been superseded. Appendix C contains the text of Kolnsberg et al., (1976), the manual on the quasi-stack method. Appendix K (TRC, 1980) also contains very detailed information on this method, although the equipment described is out of date.

Some specific work has been done on hood capture of process fugitive particulate by PEDCo Environmental, Inc. (1984) and by Kashdan et al. (1986). The former study describes the capture of fugitive particulate from a primary copper convertor by use of an air curtain, and the use of quasi-stack measurements to quantify emission rates. There is very good documentation of adequate capture efficiency of this arrangement, but no documentation that the fugitive emissions are unaffected by the air curtain. Nevertheless, the air curtain is quite far from the process, and it seems likely that the very small negative pressure involved would be too small to cause increased emissions. The air curtain seems useful only for heated, buoyant plumes.

Kashdan et al. comprehensively describe a series of hood designs for capture of process fugitive particulate emissions. Capture efficiencies are included. Again, however, there is no information available on the extent of influence of these hood systems on the processes themselves. To what extent do they induce increased emissions? Could they reduce emissions by decreasing turbulence around the source? Obtaining answers to these questions is not necessarily a trivial problem.

Richards and Brozell (personal communication, 1993) have used a smoke tracer method to visually determine the minimum air velocity required for PM-10 plume capture. This issue is further complicated if ambient winds or drafts must be dealt with, because the hood air velocity needs to be higher in draftier environments (Kolnsberg et al., 1976). Also, it must be ascertained that the behavior of the visible smoke plume resembles that of the actual PM-10 plume. Furthermore, it would be preferable to have mass measurements of emitted and captured

tracer as well as the visual evidence that the hood is effective at capturing emissions without inducing or decreasing them.

In any case, several hood designs may be appropriate for use with quasi-stack measurements. The user must demonstrate, however, that the hood does not cause underestimation or overestimation of source emissions.

Roof monitor method

When processes are located within a building, the roof monitor method may be the best means of measuring fugitive particulate emissions. In this method, measurements of particulate concentration and air velocity must be made at each opening from which dust may issue from the building. The cross-sectional area of each opening is also required. The product of the cross-sectional area of the opening, the exit velocity, and the concentration of PM-10 gives the fugitive PM-10 emission rate from an opening. The sum of the emission rates from all openings gives the emission rate for the building as a whole.

In most cases, the building as a whole is considered to be the "source." When considering the ambient impact of processes within a building, we are only interested in dust which escapes from the building, rather than in the "true" emissions from each process inside.

Air velocity in openings to buildings may be quite variable. Even flow direction may shift. Consequently, isokinetic sampling may be difficult, and it may not be feasible to use stack testing methods. In that event, ambient PM-10 sampling devices may be used. These devices may pump a measured flow of air past a filter. The weight of particulate deposited divided by the total air flow during the time the device was in operation gives the average concentration of dust in the sampled air. The product of the average concentration, the cross-sectional area of an opening, and the average exit velocity will give an average emission rate for a given opening over the period of time sampled. Appendix D contains a list of ambient samplers which have met EPA criteria published in 40 CFR 50, as of July, 1993. Table I (from Muleski et al., 1991) provides a list of advantages and disadvantages of various types of PM-10 ambient samplers.

Another issue when using the roof monitor method is that concentrations of dust may vary in unknown ways across various openings. Consequently, it is important to sample, as in stack testing, at a number of sites along the cross section of each opening.

In cases where ducts lead to openings, it is important to ascertain that there is not significant PM-10 deposition in the

duct-work downstream from the sampling site before the exit from the building is reached. Otherwise one will make significant overestimations of PM-10 emissions.

On the other hand, it is critical to sample during times which are representative of normal and peak dust emissions. Otherwise, the calculated emission rates will have little meaning.

Without the use of additional testing, it will not be possible to separate and quantify the individual sources within a building; the different plumes will be measured as one intermingled plume leaving the various openings of the building. To discriminate between sources under one roof, tracer tests are required (see Appendix E, and also see Vanderborght et al. 1982), or else one process at a time may be operated to obtain an emission rate for each process.

The roof monitor method should have the potential to give accurate emission rates. It has been thought to be somewhat less accurate than the quasi-stack method, however (Kolnsberg, 1982).

Another issue that may arise in sampling via the roof monitor method is that the building openings may be difficult to access, difficult or hazardous to lead electrical lines to, and precarious to work around. Trozzo and Turnage (1981) developed a protocol for using battery powered personal samplers as surrogates for the large hi-vol ambient samplers which were then the EPA reference method for measuring ambient dust concentrations. No subsequent studies using this technique were found in the literature. Newer battery powered devices called saturation monitors could be adequate under some conditions for the roof monitor method, but this has not been studied. Generally, if stack sampling methods cannot be used, it is recommended that EPA approved ambient sampling devices be used whenever possible (See Appendix D).

However, it is EPA's recommendation that whenever feasible, stack sampling trains be used, specifically Method 201 or 201A. It may be desirable to build temporary duct-work around openings in order to use these methods, provided that the duct-work does not alter the dust outflow.

In the case where emissions are sampled in ducts, EPA Method 1 should be used when the ducts are of the appropriate type. In cases where sampling is attempted in an actual roof monitor, the sampling should be done according to EPA Method 5D. (See Appendix A.)

Appendix E contains the 1976 technical manual on the roof monitor method by Kenson and Bartlett. As noted above, there is substantial obsolete material in this manual; we include it nevertheless because there is also substantial valuable

information. Appendix K (TRC,1980) also has detailed information on the roof monitor method (but dated information on equipment).

Upwind-downwind method

In the upwind-downwind method, at least one ambient PM-10 concentration is obtained upwind of a dust source and several PM-10 concentrations are obtained downwind as well. Wind speed and direction and other meteorological variables are monitored during the sampling procedure. The downwind concentration minus the upwind concentration is considered to be the concentration due to the PM-10 source (or net concentration). Using a dispersion model and the meteorological information, the net concentration is used to solve for the emission rate in the dispersion model. Each downwind sampler will yield an emission rate estimate; these may be averaged to obtain the best estimate of the emission rate.

The upwind-downwind method may be applied to many different situations. It cannot, however, distinguish between plumes which mix, unless one of the plumes is distinctly upwind of the other.

While the upwind-downwind method is the most versatile of the generally applied methods, it is also been considered the least accurate. This is partly because only a tiny fraction of the greatly diluted plume is sampled, and this sampling is usually done many meters from the source. While plumes are thought to behave in a Gaussian fashion, that behavior occurs only on average over a period of time. A great many samples over a long time would have to be obtained for the actual plume distribution to approach that of a Gaussian curve. Such a sampling strategy is usually impractical. Consequently, random plume irregularities will give rise to uncertain emission estimates.

Even if sampling is done at many sites (an expensive proposition), inaccuracies still result from using average meteorological values to represent the instantaneous vagaries of real weather. For example, the dispersion models are particularly unable to cope with a situation in which the wind direction at the source is different from the wind direction at the receptor.

Despite these problems, it seems possible to obtain reasonable accuracy with this method. Hu Gengxin et al. (1992) found that their results were within a factor of two, 80 percent of the time, apparently using the quasi-stack method as a reference.

In any case, there is an important reason for using the upwind-downwind method: there are times when this is the only method which suits the situation. Obtaining an emission rate from an area source such as a large parking lot is an example.

Regarding basic sampling protocol, the arrangement of sampling devices will vary depending upon the geometry of the source. The number of upwind samplers will depend upon the proximity of interfering upwind plumes--a more heterogeneous upwind dust profile will require more upwind samplers. Downwind of the source to be measured, for "point" or area sources, at least five ambient particulate samplers are required, at two different downwind distances and three different crosswind distances (Cowherd and Kinsey, 1986). The greater the number of downwind samplers, the better the characterization of the plume. Refer to Appendix D for a list of acceptable ambient sampling equipment, and for an excerpt from the statute which defines the reference method for measuring PM-10 in ambient air.

Kinsey and Englehart (1984), Russell and Caruso (1983), Maxwell et al. (1982), and Larson et al. (1981) have done upwind-downwind studies on "line" sources (roads). However the exposure profiling technique is well suited to roads, and is thought to be more accurate than the upwind-downwind method (Kolnsberg, 1982; Fitzpatrick, 1987).

Looking at sampling arrangements in more detail, a study by Carnes et al. (1982) suggested that 10 or 11 downwind samplers was the optimum number for measuring emissions from a coal storage pile, based upon a cost-benefit analysis. They claimed that using ten downwind samplers will provide estimates of emission strength within 25 percent of estimates obtained using 30 or more samplers. Hesketh and Cross (1983) make no specific recommendations on total number of samplers, but do suggest two sampling heights for each sampling site, one at ground level and one at three meters. Axetell and Cowherd (1984) did an exhaustive study on surface coal mines; they wrote in detail on most of the measurement methods described in this report, including the upwind-downwind method. Excerpts of their report are included as Appendix F. The reader should keep in mind, however, that the equipment in that study was used primarily to measure total suspended particulate, not PM-10. Appendix K (TRC, 1980) also contains a good deal of information on the upwind-downwind method. Kolnsberg (1976) wrote a technical manual on the method. That report is included as Appendix G because of its valuable detail, despite the obsolescence of much of the equipment described.

Regarding equipment, some studies (Kinsey and Englehart, 1984; Russell and Caruso, 1983; and Larson et al., 1981) have used devices which turn off the ambient samplers automatically if the wind direction deviates more than a certain number of degrees from the source. This is done because the sampler may be essentially out of the plume if the wind deviates enough. Shut-off angles for these devices have typically been in the range of 22.5 - 65 degrees to either side of the original plume centerline. The desirable shut off angle will vary with the

distance the samplers are from the source. Other studies (Maxwell et al., 1982; Carnes et al., 1982; Larson, 1982; and Wells et al., 1980) have not used such a device. Current thought is that using an automatic shut-off is a good idea (Cowherd, C., 1993, personal communication). Hesketh and Cross (1983) suggest using two ambient samplers at each sampling position, one operating continuously and the other operating only when the wind is within 22.5 degrees from the source. Any sampler with a directional shut-off should have a timer to count the elapsed time the sampler is in operation.

Factors other than wind direction changes may make the data from a particular test run unusable. For example, if the wind is very slight, a recognizable plume might not form. A typical response has been to initiate testing only if wind speeds exceed 1 meter per second (2.2 m.p.h.).

Another important issue relevant to the upwind-downwind method is the choice of a dispersion model. Which model should one use? EPA uses the Industrial Source Complex (ISC) model, particularly for gaseous emissions. This is a Gaussian plume model for flat terrain. It has no deposition term specifically for particles under 30 microns in aerodynamic diameter (as of July, 1993), meaning that it does not accurately account for deposition of these particles downwind of the source. PM-10 will have some degree of downwind deposition. The ISC model is known to always underestimate deposition of particles smaller than five microns (Irwin, John, U.S. EPA Source Receptor Analysis Branch, personal communication, 1993). On the other hand, the direction and magnitude of bias for deposition of particles between five and ten microns in diameter will depend upon release height, source configuration, particle size and downwind distance.

The rate of downwind deposition will depend upon air convection and turbulence which bring particles into contact with the ground, and upon the gravitational settling velocity of the particles. The gravitational settling flux and ground deposition flux are both thought to be proportional to the local air concentration of particles (Ermak, 1977). EPA is nearing completion on work to add an improved deposition term to the ISC model, which should make it more accurate for use with dust.

There are other dispersion models available which have deposition terms. Ermak (1977) developed a model based upon the solution of an atmospheric diffusion equation. Several later models are based upon his work. These include models developed by Wings (1990 and 1982), and by Becker and Takle (1979). Wings's Fugitive Dust Model (1990) has computer software which allows non-scientists to perform the data entry.

Hu Gengxin and Yang Xu (1992) reported on the development of a model by Hu Gengxin and Xia Liguo. Hu Gengxin et al. (1992)

briefly reviewed the applicability of various dispersion models to fugitive dust problems, and compared a model developed by them to two previously developed by Hu Gengxin. They used known emission rates to evaluate the models, and found that their new model performed somewhat better overall than Hu Gengxin's older ones. They also found that each model had optimal distances and angles from the plume centerline where it performed better than the other models .

Generally, when using dispersion models, at a minimum the following information will be required: Distance from each ambient sampler to dust source, wind speed, wind direction, and Pasquill-Gifford stability class. Other parameters, such as roughness length or deposition velocity, may be required for a given model. The elucidation of these other parameters may not be trivial.

Furthermore, if the model was created for unobstructed flat terrain, but the real terrain is not flat, inaccuracies will result unless the model is altered to suit the real situation. A meteorologist or other mathematical modeler is required for making such alterations.

Another modeling issue is the source geometry. Some models are better than others for a particular source geometry. A model which treats point and volume sources well might not be as good for area sources, for example. Furthermore, the use of a point source approximation for an area source will cause an underestimate of emissions for a measured downwind concentration. The closer the downwind receptor is to the area source, the greater will be the error. A rule of thumb sometimes used by the EPA for square area sources is that the receptor must be a minimum of ten site lengths from the source for the point source approximation to be reasonable.

Some information on dispersion models is available on an EPA computer bulletin board called TTN (Technology Transfer Network). The number to call for modem connections is 919-541-5742. Upon reaching the main menu, choose the "SCRAM" (Support Center for Regulatory Air Models) option for model information.

If one does use a model which accounts for deposition, the model will typically require the sizing of the particles emitted from the dust source. This is because particles of different aerodynamic diameter will deposit on the ground between the source and the sampler at different rates. To model the deposition rate of the dust requires knowledge of the size distribution of the dust. This has often been obtained aerodynamically with cascade impactors, but may also be obtained using other methods.

Exposure profiling method

The exposure profiling method was developed by Midwest Research Institute, under an EPA contract, as a tool for deriving emission factors (Cowherd et al., 1974). The exposure profiler consists of a number of ambient samplers (typically four or five) at several heights along a vertical tower, typically four to ten meters in height (Figure 1). The samplers are provided with a means to sample nearly isokinetically: typically this consists of either interchangeable nozzles of various sizes or variable flow-rate control. Wind speed is monitored by anemometers, usually at two to five heights along the tower (McCain et al., 1985). Wind speeds for unmonitored heights are often calculated using a logarithmic algorithm (Muleski et al., 1993; Axetell and Cowherd, 1984). Wind direction is monitored by a wind vane.

One or more towers of this type is placed downwind of the source, with the sampler intakes pointed into the wind. The profiling tower is placed close to the source, often approximately five meters away (Muleski et al., 1993; Cowherd and Kinsey, 1986; Cuscino et al., 1983;). Ambient samplers (typically between one and four of them) are placed upwind of the source at one or more heights (Pyle and McCain, 1985). The upwind samplers are also placed close to the source, often ten to fifteen meters away (Muleski et al., 1993; Cowherd and Kinsey, 1986; Cuscino et al., 1983). Sampling at the upwind samplers is not necessarily isokinetic (Bohn, 1982).

Exposure (Garman and Muleski, 1993a) may be defined as the net passage of mass through a unit area perpendicular to the plume transport direction (wind direction):

$$E = (10^{-7}) C U t$$

where: E = dust exposure (mg/cm²)
C = net concentration (ug/m³)
U = approaching wind speed (m/s)
t = sampling duration (s)

Values of exposure will vary at different sites within the plume. The integral of exposure evaluated over the cross section of the plume should equal the total mass flux of dust emitted from the source (Garman and Muleski, 1993a; Axetell and Cowherd, 1984; Bohn et al., 1978). The integration may be accomplished via Simpson's rule. Simpson's rule necessitates an odd number of data points at equal intervals; if additional data points are required to obtain an odd number or equal spacing, they are obtained by extrapolation (Muleski et al., 1993).

Mathematically, for a uniformly emitting "line" source (really a "point" source moving along a line), such as a car moving along a relatively uniform dirt road, a single vertical integration may

suffice to characterize the emissions (Bohn et al., 1978). In the case of "point" or small area sources, a two dimensional integration will be required (Garman and Muleski, 1993a; Bohn et al., 1978).

Similarly, from the point of view of physical measurement, for a point source moving along a line and emitting uniformly, one profiling tower may suffice to characterize the plume. In the case of "point" or small area sources, a number of profiling towers must be used.

The samplers should be symmetrically placed in the body of the dust plume so that approximately 90 percent of the mass flux of the dust cloud passes between the outermost edges of the array. As an example, for a Gaussian dust plume, the exposure values measured by the samplers at the edge of the sampling array should be about 25 percent of those measured at the center of the array (Bohn et al., 1978).

Exposure profiling has been used primarily for measuring emissions from sources whose plumes will not have significant mass passing above the highest sampler on a profiling tower. This has largely constrained this method to sampling close to the source. Axetell and Cowherd (1984) for example, write that it is preferable for the profiling towers to be approximately five meters from the source. However, Clayton et al. (1984) report the use of sectional aluminum masts to raise the heights of their highest samplers well above 20 meters. This kind of tower height would permit sampling farther from the source. Sampling farther from a point or area source, however, also requires a more horizontally widespread tower array, because of horizontal plume dispersion.

The exposure profiling method may not be practical for sampling large area sources. The bigger the distance between the upwind side of the area source and the profiling tower, the higher the tower will need to be. The longer the dimension of the area source perpendicular to the wind, the wider the profiling array must be.

Exposure profiling uses a mass conservation approach (Garman and Muleski, 1993a) to calculate emission rates from mass fluxes measured downwind. But some PM-10 may deposit on the ground between the source and the profiling tower. This "lost mass" of PM-10 could be significant, particularly if the source is close to the ground. Any deposition occurring between the source and the profiling tower will lead to inaccuracies (under-predictions) in calculating emission rates. The significance of these inaccuracies is unknown.

However, perhaps a distinction should be drawn between the actual emission rate and the relevant emission rate. What we are

normally concerned about is entry of dust into the ambient environment. The dust that is immediately deposited is not usually of great concern. Hence, it may be reasonable to acknowledge this source of inaccuracy in the exposure profiling method in terms of measuring the actual emission rate, while realizing that this inaccuracy may not pertain to the "relevant" emission rate.

This inaccuracy could become problematic if the calculated emission rate is to be used with a dispersion model to predict downwind ambient impact. If a dispersion model with a deposition algorithm is used, there will be under-prediction of the ambient impact. "Lost mass" deposited between the source and the profiler will lead to a lower-than-actual calculated emission rate, and then the deposition algorithm will further decrease the predicted downwind concentration.

Nor would it necessarily be correct to use a dispersion model without a deposition algorithm to calculate the ambient impact of a source. Again, in this case, missing mass deposited between the source and the profiler will lead to underestimates of the actual emission rate. The application of a dispersion model without a deposition term tends to lead to overestimates of PM-10 downwind impacts. The result of combining an underestimated emission rate with an ambient impact overestimation is unclear. Possibly the errors would essentially cancel. Perhaps comparing the resulting ambient impact predictions with predictions derived from receptor models provides a clue, but receptor models for dust generally have their own problems with conservation of mass issues.

In any case, the magnitude of the mass lost to deposition between the source and the profiler is unknown. It will vary with source height, meteorological conditions and source-profiler distance. This mass may not be significant at many emission heights and under certain meteorological conditions, but it could be important for sources emitting close to the ground. This mass should be quantified. We would then be more sure of actual emission rates.

Exposure profiling has another source of inaccuracy in the necessity of extrapolating mass fluxes from the outermost samplers in the array to the fluxes outside of the array. The more widespread the sampling array, the more this source of error can be minimized. As an example of the potential magnitude of this source of error, Muleski et al. (1983) found between a ten and seventeen percent discrepancy from using a six-meter profiling tower compared to their results using a ten-meter tower, for measuring dust emissions five meters from an unpaved road.

Exposure profiling is considered significantly more accurate than

the upwind-downwind method (Kolnsberg, 1982; Fitzpatrick, 1987). This is because exposure profiling samples quasi-isokinetically, typically samples a much larger portion of the dust plume, and does not depend on dispersion modeling for determining emission rates. Kolnsberg (1982) writes that the accuracy of the exposure profiling method is comparable to that of the roof monitor method.

The report of Axetell and Cowherd (1984), which has been included as Appendix F, contains a description of the exposure profiling method and step by step calculations for measuring emission rates from line-sources. Garman and Muleski (1993b) has a less detailed but more current plan for measuring line-source emission rates; this is Appendix H. Another report by Garman and Muleski (1993a) includes information on the calculation of emission rates from area sources, sampling configuration diagrams, and information on sample handling and analysis, and is included as Appendix I.

Portable wind tunnel method

The portable wind tunnel was used in the 1970's to study the effects of wind-blown sand on vegetation, and to quantify the determinants of wind erosion (Fryrear, 1971; Gillette, 1978). It has since been used to quantify wind-generated emissions from exposed soil and from coal storage piles (Axetell and Cowherd, 1984; Cowherd, 1983; Cuscino et al., 1983). It should be reiterated that this method is used only to quantify wind-generated emissions.

The portable wind tunnel is diagrammed in Figure 2 (from Cuscino et al., 1983). The "working" part of the wind tunnel has an open floor and is placed directly on the surface to be tested. An airtight seal is maintained between the tunnel sides and the tested surface (Axetell and Cowherd, 1984). A fan draws air through the tunnel from an intake "upwind" of the test area. At a threshold speed, dust will be picked up or eroded from the test surface by the passing air stream. The quantity of eroded material (neglecting deposition) is the net amount of dust leaving the tunnel, or the total amount leaving minus the amount entering.

As shown in Figure 2, the emissions sampling in the portable wind tunnel is done in a raised, fully enclosed duct, downstream from the working section. In the past, emissions have been measured isokinetically by ambient sampling equipment. The Emissions Measurement Branch of EPA prefers the use of standard stack sampling trains whenever feasible. This would mean using Method 201 or 201A. An ambient sampler could, however, be used to obtain the concentration of dust in the ambient intake air for the tunnel.

The emission rate calculation is like a stack problem: The emission rate from the tested area equals the net particle concentration times the tunnel flow rate. The calculation of the tunnel flow rate is complicated, however, by boundary layer considerations, including shear stress at the tunnel floor and walls. Axetell and Cowherd (1984) present a calculation procedure for determining flow rate (See pages 82-86 of Appendix F).

Cowherd (1983) stated that the wind speed profile near the tunnel floor followed a logarithmic pattern and was related to friction velocity, roughness height and the distance from the tunnel floor. Friction velocity is related to shear stress at the tunnel sides and floor (White, 1986). Roughness height has been obtained via an extrapolation of the measured wind speed profile; the distance from the tunnel floor at which the wind speed extrapolates to zero is considered to be the mean roughness height (Axetell and Cowherd, 1984). According to Cowherd (1983), knowing the roughness height allows the use of the tunnel centerline wind speed to extrapolate the probable wind speed at 10 meters height via a logarithmic wind profile which describes wind speeds in the atmospheric boundary layer. In practice, this extrapolation is done graphically by plotting height versus wind speed using semi-log paper (Cowherd, C., personal communication, 1993). The measured wind speeds are extrapolated "back" to the y-axis to obtain the roughness height, and they are extrapolated "forward" to 10 meters to obtain the wind speed at that altitude. The slope of the graph will be the friction velocity.

Thus, over flat ground, the tunnel centerline wind speed can apparently be related to a corresponding wind speed at 10 meters altitude. Since the tunnel centerline wind speed can also be related to a PM-10 emission rate, the wind speed at 10 meters can presumably be related to that emission rate.

For storage piles, the procedure is as above, except that one must also consult EPA publication AP-42, section 11.2.7 in order to obtain the relationship between the unobstructed atmospheric wind speed profile and the wind speed profile at various sites across a storage pile. Section 11.2.7 of AP-42 is included as Appendix J. For a description of the use of the portable wind tunnel see Appendix F (Axetell and Cowherd, 1984).

A basic assumption made in using the portable wind tunnel method concerns the relating of emission rates in the tunnel to those out of the tunnel. Consider a wind speed measured in the open air at a height of 15 cm. That wind moving over a particular segment of open ground at a certain time causes a specific emission rate. Now consider the same wind speed measured at the same height, but moving through a tunnel placed next to the same spot at the same time. It is assumed that if the ground is similar in and out of the tunnel, the emissions will be the same

in and out of the tunnel. In other words, the physical presence of the tunnel is assumed not to affect the emission rate.

The portable wind tunnel method, like the exposure profile method employs a mass conservation approach (Axetell and Cowherd, 1984). Therefore any deposition which occurs between the point of emission and the point of measurement will lead to an underestimation of total emissions. However, one must ask whether such deposition is relevant. Are we concerned with the total flux of PM-10 up from a source, regardless of whether some of it is deposited before it leaves the source, or are we concerned with the net flux leaving the source and entering the ambient environment?

Let us look at the situation in which a dispersion model is used to determine downwind ambient impact of the source. If the source is treated as a point source in a dispersion model with a deposition algorithm, the deposition occurring in the tunnel might not be relevant. This is because the source is actually an area, but is being treated as a point. Deposition occurring within the area of the source but unaccounted for in the tunnel may be accounted for by the deposition algorithm of the dispersion model. (However, one must make sure to consider ambient impact far enough downwind so that the use of a point source model for an area source will not distort the predicted downwind impact--one must be far enough downwind so that the source "looks like" a point.)

Wind erosion of soil or other materials is a complicated process. For example, Cowherd (1982) has suggested that wind gusts rather than mean wind speed cause most particle uptake. Another complication is that wind erosion is not a steady state process, but changes as a function of the amount of erodible material exposed to the wind, which itself is partly a function of the length of time a surface has been exposed to a particular wind speed. The amount of erodible material will also depend upon the frequency, extent, timing and effect of disturbances caused by outside forces acting on a surface to be tested. An example of such outside forces might be the driving of a vehicle on a material storage pile. Cowherd (1983) has dealt with the issue of erosion potential and describes a means to quantify it (Also see Appendix F, pages 85-86). The issue of disturbance will presumably need to be dealt with by having a sampling strategy which fairly represents the normal conditions of the surface to be tested.

However, there are other complications of wind erosion. For example, fetch is defined as the length of exposed surface along the axis of the wind. Gillette (1978) found that increasing the fetch in the portable wind tunnel increased the emission rate per unit area for particles smaller than 25 μm . This finding held for all fetches tested, the largest of which was 21.7 cm.

Axetell and Cowherd (1984) use a fetch of 3.5 meters; perhaps this longer fetch obviates this problem, but this is not addressed in the emission measurement literature.

A possibly related issue is that of sandblasting, which is defined as the impaction of saltating particles onto a surface. On open stretches of bare ground, sandblasting causes emissions of particles smaller than 25 μm (Gillette, 1978). But in the wind tunnel, Gillette found that emission of particles smaller than 25 μm was independent of sandblasting. He speculated that this might be due to the short fetch of the test section in his tunnel. Again it is possible that a 3.5 meter fetch would obviate this problem, but this does not appear to be addressed in the literature on emission measurement. On the other hand, most fugitive dust sources have shorter fetches than those encountered by Gillette on the farmlands of Kansas and Texas. Perhaps sand blasting is unimportant for short fetches.

Gillette (1978) also found during field studies that for some soil types, the ratio of fine to coarse particles emitted increased with increasing wind speed. He wasn't able to duplicate this finding in his wind tunnel. He speculated that this was due to the small fetch of his tunnel inhibiting sandblasting effects.

As a benefit of working primarily in rather flat, unforested areas, both Cowherd and Gillette were able to use values of roughness height extrapolated from measured wind tunnel velocities alone. But this could be a problem in forested or rolling areas where a different means of obtaining roughness height may be necessary (Cowherd, C., personal communication, 1993).

In any case, it appears that the portable wind tunnel is superior to other methods of quantifying wind erosion. Nearly the entire plume is captured. Sampling is isokinetic. Flow rate through the tunnel can be accurately determined.

Scale model wind tunnel method

The scale model wind tunnel method involves the construction of a reduced-size re-creation of a process or landscape inside of a wind tunnel. An attempt is usually made to make important parameters in the wind tunnel resemble those occurring in the field. These parameters may include turbulence, wind shear, or other physical quantities.

Specific approaches to ensuring similarity between the wind tunnel environment and the field environment have differed. There does not appear to be a consensus on the correct approach

to take.

Visser (1992) studied the effects of moisture and wind speed on the dust emission rates of three different types of coal. He differentiated emissions occurring from windsift (particles entrained by wind out of a falling stream) from those occurring by impaction (falling and "bouncing"). He determined impaction emissions (dustiness) using a technique described by Lundgren (1986). By dumping the coal into a grille-covered box recessed in the tunnel floor, Visser claimed to minimize re-entrainment of impaction emissions when he was studying windsift.

Emissions were measured isokinetically at nine points downstream from the falling coal. Emission rates were determined by considering the flux at each sampler as representative of the flux of the surrounding area, calculating the flux for each area and then summing the fluxes. The calculated emission factors did not agree well with those from cited field studies, although they were said to be in rough agreement with those from a cited wind tunnel study.

Visser seems to have made the assumption that phenomena observed in his wind tunnel will be indicative of those occurring in the real world. He does not appear to have used any kind of dimensional analysis, which is generally applied to scale model wind tunnel studies, even though he was dumping much smaller quantities of coal than would be dumped in real industrial situations. Not only is the different throughput of coal at issue, but the turbulence inside the tunnel is also important. Does the tunnel turbulence at a given wind speed resemble that encountered in real situations? Does the velocity profile in the tunnel resemble that of the atmospheric boundary layer? Visser does not seem to have addressed these issues.

De Faveri et al. (1990) studied the effects of wind breaks and coating compounds on emissions from coal storage piles. They built a scale model terrain. In the building of their model, they considered the simulation of the atmospheric boundary layer, the simulation of atmospheric turbulence, and the simulation of terrain with the appropriate roughness height. In relating tunnel design to real-world characteristics, their dimensional analysis considered the threshold speed (speed at which eroding particles become airborne), air speed, particle size, space, and time of exposure. Interestingly, they scaled the particle size of the coal they were using.

The actual measurement of emissions was only quantitative relative to baseline emissions, however. No method for measuring the actual mass flux was used. Also, the scaling of particle size may open a formidable can of worms in that such scaling must take into account forces acting on particles which change in importance with differing particle size. Electrostatic force is

one example of a force which has more importance in determining the behavior of smaller particles.

Yocom et al. (1985) dropped sulfur into a hopper in a wind tunnel to study dust emissions at wind speeds up to eight miles per hour. In considering the similarity between the atmosphere and the wind tunnel, they explain that the calculation of the Reynolds number for wind tunnels is related to the dimensions of obstructions in the tunnel. They use the square root of the frontal area of a wind flow obstruction as the characteristic length for calculation of the Reynolds number. Wind tunnel turbulence was compared to atmospheric turbulence via a comparison of Reynolds numbers; it was admitted that, particularly at low wind speeds, the wind tunnel might not accurately represent atmospheric turbulence.

Another feature of the Yocom study was isokinetic sampling at the downwind end of the tunnel using hi-vol samplers with directional nozzles and variable flow rate. Deposition in the tunnel was measured by weighing deposits on removable aluminum plates placed on the tunnel floor downwind of the dropped sulfur.

An emission factor developed in the Yocom et al. study agreed closely with one developed in the field by another group using exposure profiling to measure emissions from the dropping of sulfur. Interestingly, in the Yocom et al. study, particles deposited downwind of the dropped sulfur were not included in the calculation of the emission factor, so the actual mass flux out of the stream of dropping sulfur must have been underestimated.

Billman and Arya (1985) studied the effects of windbreaks on wind speeds across downwind storage piles. While they did not directly study emissions, their report is interesting in that a subsequent field study (Zimmer et al., 1986) was performed to verify the results obtained by Billman and Arya. For piles unscreened by windbreaks, Zimmer et al. found that while the measured field wind speeds agreed well with those predicted from the wind tunnel studies for measurements taken at the front of storage piles, there was poor agreement at the back of the piles. For the case in which the pile was screened by a windbreak, only one test was directly comparable between the two studies; in that case, the wind tunnel values for screen efficiency were approximately forty percent higher than the field results. Zimmer et al. attributed at least part of the discrepancy between field and wind tunnel results to higher turbulence in the atmosphere than in the wind tunnel.

Williams (1982) made the assumption that turbulence in his wind tunnel resembled that at the outdoor site he was modeling. He did not do any dimensional analysis. His study is interesting, however, in that he weighed removable dust trays to determine mass flux. He claimed to differentiate between flux occurring by

saltation and that occurring by suspension. To do this he used a method involving three adjacent dust trays arranged sequentially along the axis of the wind and embedded in the wind tunnel floor. He claimed that the saltation process reaches equilibrium "quickly." Since the upwind tray receives no saltating particles from other trays, the weight loss measured will be due both to suspension of particles into the air and to any outgoing saltation which occurs. By contrast, the downwind tray should, Williams claims, experience incoming saltation flux from the middle tray equal to that lost downwind to the tunnel, and so net saltation flux of the downwind tray should be zero. Any loss of tray weight in the downwind tray should be due, according to Williams, to suspension alone. It may be, however, that the downwind tray is incurring deposition of suspended particles eroded from the upwind trays, as well as saltation flux in and out of the tray. This would complicate Williams' scheme.

Viner et al. (1982) point out that a large wind tunnel cross section is desirable so that boundary layer effects of the walls and ceiling of the tunnel will not complicate the velocity profile around the model. However, a large cross section requires a large fan if high wind speeds are desired.

The Viner study used roughness elements in the tunnel floor to simulate the atmospheric boundary layer. Viner et al. state that "The most important parameter with regard to particle entrainment is the shear stress at the surface of the dust sample." Given the roughness elements used in their tunnel, they calculated that the shear stress in the tunnel was typical of atmospheric conditions.

Viner et al. note that an advantage of scale model wind tunnel tests is that individual parameters affecting dust emissions can be controlled. A disadvantage is that the relationship between the tests and actual field emissions is "uncertain at best."

The Viner study used three methods for studying emission rates. The information in the published report on the first two methods is limited; however, one method measured mass flux by means of a probe and the other method used a probe to collect particles for optical sizing. The third method was judged the most direct and reproducible. This consisted of weighing a removable tray containing the erodible material, before and after a test. This technique was criticized as being subject, however, to error from the handling of the tray.

Tracer method

The tracer method uses either a gas or particles as a tracer for dust. Several gas tracer studies have used sulfur hexafluoride as a tracer. Usually particulate tracers are fluorescent or

phosphorescent or have a dye or other coating which makes them fluoresce or phosphoresce.

The assumption behind the tracer method is that the dispersion of dust will be imitated by the tracer. In other words, the tracer plume will strongly resemble the dust plume if the tracer is released in the same place at the same time as the dust. The validity of this assumption will be discussed later. However, if we assume for the moment that this assumption is correct, then the dust emission rate may be easily determined (Vanderborcht et al., 1982):

$$C_d/C_t = Q_d/Q_t$$

where C_d = downwind net dust concentration
 C_t = downwind net tracer concentration
 Q_d = dust emission rate
 Q_t = tracer emission rate

The concentrations of dust and tracer are measured at the same locations upwind and downwind of the source. The upwind concentrations of dust and tracer are subtracted from the respective downwind concentrations to obtain C_d and C_t . (In practice the upwind tracer concentration will be close to zero.) The tracer emission rate is known. (In the case of a gaseous tracer, the gas cylinder can be weighed before and after the tracer release.) Consequently, the emission rate of the dust will be the only unknown quantity and can be readily calculated using the simple proportion expressed above.

Baxter (1983) used sulfur hexafluoride as a tracer for dust from a mining operation. As previously mentioned, an assumption made in this and other tracer studies is that if the tracer is released in the same area and at the same time as the dust, then the tracer and the dust will disperse in similar ways. Another assumption made in this particular study is that deposition of particles less than 30 μm in diameter will be minimal over distances less than 100 meters. This latter assumption was necessary because Baxter was measuring gaseous tracer and total suspended particulate at distances as far as 100 meters downwind, and any particulate deposition in that distance would mean that the tracer and the dust were dispersing differently, since sulfur hexafluoride does not undergo deposition.

The assumptions of similar dispersion and no particulate deposition are questionable; their veracity should depend upon emission height and meteorological conditions. For example, if the emissions are close to the ground, significant dust deposition might occur over 100 meters, especially under certain weather conditions. Also, significant reflection of the sulfur hexafluoride gas from the ground could occur over 100 meters. By contrast, the dust would not be expected to undergo much

reflection since most dust tends to stick where it impacts.

Baxter visually determined the sites of maximum dust emissions and placed the sulfur hexafluoride cylinders in those areas. He outlined a means of keeping the release rate of the tracer gas constant using a two stage pressure regulator, a fine metering valve and a rotameter. The total amount of gas released was determined by weighing the gas cylinder before and after the tracer gas release.

Baxter used a continuous sulfur hexafluoride analyzer and ambient samplers, all mounted on a van approximately 75 meters downwind of the source. He used the measurements made by the continuous sulfur hexafluoride analyzer to indicate where to move the mobile platform so that he could follow the wind shifts and remain in the main part of the dust plume. Time-integrated samples of sulfur hexafluoride were also obtained using bag samplers.

Vanderborght et al. (1982) point out the advantages of using sulfur hexafluoride as a tracer: it is inert, non-toxic, stable up to approximately 500 degrees Celsius, easily detectable at concentrations as low as 50 nanograms per cubic meter, and normal background levels are below the level of detection. Their study used sulfur hexafluoride as a tracer for antimony (Sb) dust emitted from an Sb metallurgical plant.

The Vanderborght study used bag samples of sulfur hexafluoride and used gas chromatography to analyze the samples. Ambient samples of Sb were obtained, and were analyzed using neutron activation and x-ray fluorescence.

Vanderborght et al. sampled at distances as close as 15 meters and as far as 180 meters from the source. They make the claim that at these distances deposition of Sb aerosol is negligible. They do admit to problems with the tracer study at the close in distances, however. An indication of such problems is that they found different ratios of C_d/C_t at various sampling sites close to the source. But this ratio should be constant over a given time period, even at different locations, since that ratio should equal Q_d/Q_t and the latter ratio will average to a constant over the same time period. Vanderborght et al. attributed this problem to poor mixing of the dust and tracer plumes. This is quite plausible since they were using one point source of sulfur hexafluoride to approximate two separated point sources of dust.

Nevertheless, they found that further downwind, the C_d/C_t ratio remained constant ("within acceptable limits") at various distances and locations. This is evidence both that deposition is negligible at the sampling distances downwind, and that the dust plume and tracer plume disperse in essentially the same way.

Wachter (1980) developed emission factors for stone crushing

operations using sulfur tetrafluoride as a tracer gas. He used a gas chromatograph with an electron capture detector to analyze the gas samples.

Wachter made major errors in his paper. Although he was interested in total suspended particulate rather than PM-10, his errors are instructive. First, in arguing for the validity of the tracer technique, he makes the unsupported assumption that particles under 50 μm in diameter behave in the same way that sulfur tetrafluoride does. Then, in an effort to prove that only small particles emit past the plant boundaries, he attempts to show, using Stokes's Law, that particles larger than 19 μm will settle within 300 meters from the source under average meteorological conditions. Now if particles from 19 μm to 50 μm in diameter settled within 300 meters from the source, they would certainly not be acting like a gas, and the tracer study would probably be invalid.

Furthermore, the use of Stokes Law alone to determine where atmospheric dust will settle is erroneous. Wachter assumes that the terminal settling velocity along with a horizontal wind speed can be used to calculate where particles will deposit. His approach ignores atmospheric turbulence, which is often the most important determinant of where suspended particles will settle. Deposition velocity rather than terminal settling velocity is generally the most important quantity in such a situation.

Reynolds (1980) was concerned with the re-entrainment or resuspension into the air of hazardous materials deposited on surfaces. He seeded various surfaces with known amounts of phosphorescing particulate tracer having a size distribution in the 1 μm to 5 μm diameter range. The tracer particles were composed of "zinc-cadmium sulfide." (The EPA does not recommend the use of cadmium-containing materials as tracers.) Reynolds eroded the labeled surfaces using a hi-vol drawing through a portable wind tunnel, and trapped the eroded particles on a filter. Mass loading of the tracer on the filter was obtained using optical techniques. However, since only the mass of tracer was obtained, and not the mass of eroded dust, C_d could not be obtained. So Q_d could not be directly calculated.

Thus, Reynolds was obliged to determine the mass flux of the dust indirectly. He did this by determining a tracer resuspension rate (fraction of tracer particles resuspended in the air per unit time) with a dimension of time^{-1} . He notes that initial resuspension fluxes are directly proportional to the resuspension rate, and that "Therefore resuspension fluxes and relationships should be nearly equivalent to functional relationships determined for the resuspension rate...". He then calculates the mass flux of dust based upon estimates of the amount of erodible material available and the calculated resuspension rate for the tracer. He claims that his resuspension rates are accurate to

within a factor of three based upon estimations of the magnitudes of the sources of error in the experiment.

The portable wind tunnel method seems to be a much more direct and efficient means of measuring wind erosion than the particulate tracer method described by Reynolds. The mass of eroded dust may be directly calculated with a portable wind tunnel; there is no need to use a tracer as a surrogate for dust.

Sehmel (1973) used zinc sulfide particles as a tracer material in a study on dust emission from a paved road. The zinc sulfide was placed on one lane of the road. An array of non-isokinetic samplers was mounted on towers at various distances downwind of the road. Deposition samplers were also positioned at various downwind distances. A graphical integration of the downwind tracer exposure and ground deposition was performed to calculate the resuspension rate per vehicle pass. The quantity of erodible material per unit area of road must be estimated to permit the calculation of the mass flux of dust from the resuspension rate of tracer. The emission rates thus calculated were said to be accurate within a factor of three, based upon an error analysis.

The exposure profiling method has often been used to calculate dust emissions from roads in the years since Sehmel's study. Exposure profiling appears to be a superior method in that the dust mass flux is measured directly, rather than using a tracer as a dust surrogate.

The use of gaseous tracers, however, appears promising, particularly for PM-10, the dispersion of which should be more like a gas than the dispersion of total suspended particulate would be (since PM-10 will undergo less deposition). However, the distance at which downwind deposition of PM-10 ceases to be negligible remains to be shown. At the distance where deposition ceases to be negligible, the gas and the dust plumes will be acting differently, and the tracer method will be less valid. This distance will vary with source height and with meteorological conditions, and could be predicted using dispersion models.

By contrast, there is also a problem very close to the source: How do we know that the dust and the tracer have adequately mixed and have formed a uniform plume? Perhaps this issue can be minimized by carefully selecting dust source geometry and tracer source location to facilitate plume mixing. Maybe the problem can be solved by sampling both dust and tracer at a number of locations and distances. If the C_d/C_t ratio is constant over a number of locations and distances, perhaps we can assume, as Vanderborcht et al. suggested, that this is adequate evidence of plume homogeneity over those areas.

Balloon method

Balloon sampling is an offshoot of the exposure profiling method. The balloon sampling method consists of ambient samplers sampling quasi-isokinetically, suspended at a number of heights from a balloon. Mass flux is computed in the same way as in the exposure profiling method. The balloon method has been used in attempts to sample large area sources or sources which may not be closely approached. Armstrong and Drehmel (1982) designed one such system. Axetell and Cowherd (1984) used balloon sampling in an attempt at measuring the dust emissions from blasting operations.

The latter study had problems with sampling often being non-isokinetic, as well as encountering a problem of being unable to sample a sufficiently large segment of the plume except under very limited wind conditions. The problem of anisokinesis occurred because nozzles on the ambient sampler intakes could not be changed with the balloons aloft, and the flow rate to the samplers was fixed. In this particular instance, variable flow rate to the samplers might have been a good method of maintaining isokinetic sampling. However, isokinetic sampling is less critical for accurate measurement of PM-10 than it is for total suspended particulate (Davies, 1968). Appendix F has a detailed description of the balloon sampling protocol used by Axetell and Cowherd.

Error, accuracy and precision in the methods

Error may be defined as "the departure of the measured value from the true value" (Taylor, 1990). It is equivalent to the term "inaccuracy."

Rosbury et al. (1984) focus on error in emission factors. However, some of the sources of error which they mention are broadly applicable to several measurement methods. They place error sources into five categories: emissions, activity parameters, source location, meteorological inputs and dispersion model.

A potentially relevant error that Rosbury et al. list in the emissions category is any assumption made about particle size distributions. An example is the common assumption that various types of dust are log-normally distributed.

Errors in defining activity parameters, while not causing inaccuracy in the mass flux measurement itself, can create error in interpreting the meaning of the measurement. Is a given level of activity (which relates to a given mass flux measurement) peak, average or below average activity?

An example of a source location uncertainty may be observed in trying to define source height. For instance, what is the source height for the dust emitted by vehicle traffic on a road?

Uncertainties in meteorological inputs include errors in measurements of wind speed and wind direction. Additional uncertainty comes from estimation of stability class and mixing height. Also, how uniform are the meteorological conditions over the source-measurement area?

Some uncertainties implicit in the use of dispersion models were discussed in the upwind-downwind section of this report. Rosbury et al. used three different emission factors in all combinations with three different dispersion models (while holding other variables constant) and thus calculated nine different predicted downwind concentrations. They found that while the emission factors differed by as much as a factor of 4.7, the predicted downwind concentrations differed by as much as an order of magnitude.

Axetell and Cowherd (1984) performed an error analysis on the exposure profiling method and on the upwind-downwind method (See pages 45-46 and Table 3-6 in Appendix F). An error analysis is an attempt to quantify inaccuracy by listing each perceived source of error, deciding whether it is random or systematic, and making an estimate of its potential magnitude and direction. Their initial results indicated that error in the exposure profiling method for particles less than fifteen microns ranged from -14 percent to +8 percent. Field experience caused them to revise this estimate to plus or minus 30-35 percent. An initial error analysis for the upwind-downwind method estimated inaccuracies of plus or minus 30.5 percent and 50.1 percent for line sources and point/area sources respectively.

Sehmel (1973) and Reynolds (1980) performed error analyses on the different particulate tracer technique each was using, and each claimed that the technique he was using was accurate to within a factor of three.

Error analyses may be useful, but they are essentially an educated guess at the amount of inaccuracy in a method. Even if the estimates of magnitude of known sources of error are good, there is no guarantee that one has considered all sources of inaccuracy. For example, the error analysis of Axetell and Cowherd (1984) for exposure profiling does not appear to take into account the mass balance deficit from deposition that probably occurs with that method.

Turning specifically to the issue of accuracy, this may be defined as the closeness of a method's measurements to the actual value of the measured quantity (Taylor, 1990). To ascertain the level of accuracy of a measurement method, we must know the

actual value of the quantity that is being measured.

There may be only one example in the accessible literature in which experimental releases of known quantities of fugitive dust were measured in order to determine the accuracy of a method. Hu Gengxin et al. (1992) found that their dispersion model used with the upwind-downwind method predicted emissions within a factor of two of measured emissions, 80 percent of the time. They apparently measured emissions with the quasi-stack method as a reference. However, their experimental technique is not described in detail in their paper, no doubt due to space constraints, so their exact procedure, and consequently its validity, is not entirely certain.

While the quasi-stack method may be, from general principles, potentially the most accurate fugitive dust measurement technique, one must demonstrate that the method does not alter the emissions of dust from the source. This may not be a straightforward task. Consequently, the use of the quasi-stack method as a reference method for determining emission rates appears questionable.

However, an adaptation of the quasi-stack method as a means for determining the accuracy of other methods might work very well. In this case, it would only be necessary that the mass flux of the dust emitting out of the quasi-stack duct equal the mass flux measured by the sampling train inside the duct. In other words, one would need to ascertain that there was negligible deposition in the duct downstream of the sampling train. Then one would have a known emission rate with which to assess the accuracy of other methods.

There appears to be at least one other study using known emission rates of dust to determine the accuracy of dust measurement methods. Hu Gengxin et al. cite a book by Li Zhuongkai (1985), presumably written in Chinese, which is said to report on field experiments verifying diffusion models using known releases of glass beads and fog droplets from point sources.

Because so little work has been done comparing known emission rates of dust with measurements made by fugitive dust measuring methods, there is not much to say about the accuracy of these methods, other than what one can deduce or conjecture from general principles. For example, we might expect that methods which sample a large part of a dust plume will be more accurate, on average, than those which sample a small part of the plume. Another generalization is that isokinetic sampling is better than non-isokinetic sampling, although the importance of this decreases as particle size decreases. Dispersion modeling introduces a source of error.

One or more of these generalities might be difficult to quantify.

In any case, that would be a tangential approach to defining accuracy. Much more work needs to be done using known emission rates to evaluate the accuracy of fugitive dust measurement methods.

Similarly, few studies have evaluated the precision of methods. Precision may be defined by considering a series of measurements of a particular quantity. The closer the values of the measurements are to each other, the more precise the measurement method (Taylor, 1990).

Precision may be a difficult parameter to obtain for fugitive dust measurement methods. This is because it is necessary to have multiple measurements of the same quantity to obtain precision. But it may not be easy to emit the same quantity of dust multiple times. So the papers which report values for precision are those which use methods which obtain multiple measurements of the emission rate during each time period when dust is emitted. These methods are the upwind-downwind method and the tracer method.

Carnes et al. (1982) found, in five test runs of the upwind-downwind method, that the coefficients of variation of emission rates (the sample standard deviation divided by the sample mean for each test) ranged from 0.219 to 0.456. There were twelve to fifteen observations in each of the five test runs. Each observation stems from one downwind concentration measurement taken from each ambient sampler in each test run. Carnes et al. found that these observations were normally distributed when they were all grouped together.

Vanderborght (1982), using a gaseous tracer, found relative standard deviations (coefficients of variation multiplied by 100%) of 19, 22, 23 and 33 percent in four test runs. Each test run consisted of seven tracer measurements taken more than fifteen meters downwind of the source.

A number of papers submit emission factors to statistical scrutiny. However, one cannot easily obtain the precision of the measurement method from the emission factor statistics because the emission factors are relationships between emission rates and activity levels (such as the number of grams of dust emitted per kilogram of coal handled). Uncertainty in the relationship between the mass flux measurement and the activity level, as well as uncertainty in measurements of the activity itself would complicate any attempt to obtain precision of the measurement method from statistics about the emission factor.

Conclusions

The quasi-stack method may potentially be very accurate, and is

probably the best method for measuring emissions from enclosable sources, but difficulties arise in trying to demonstrate that the enclosure of a source does not alter its emissions. Many hood configurations exist which might work with this method, but most have not been studied in the context of measurement of mass flux.

The roof monitor method is probably the best method for measuring emissions from buildings. Sampling problems may include difficulties in adequately sampling very large openings, as well as very variable flow through the openings.

The upwind-downwind method may be the least accurate but most generally applicable of the well established methods. The use of dispersion modeling involved with this method is a major source of error; the dispersion model to be used should be carefully chosen and applied to minimize this source of error.

The exposure profiling method seems to be the best method for unenclosable sources which are of relatively small area and which are amenable to having profilers placed within a few meters of them. The method does have a potentially significant mass balance deficit due to deposition; this deficit should be quantified or at least modeled (using a dispersion model, for example).

The portable wind tunnel method may be the best method for determining rates of wind erosion. This method also has a potentially significant mass balance deficit which should be quantified or modeled.

A number of more or less experimental techniques have been used. Balloon sampling has encountered some difficulties outside of very specific meteorological conditions. The scale model wind tunnel method has been used in a number of experiments, but differing protocols, dimensional analyses, and measuring techniques have been used from study to study. The use of the tracer method has been reported in several papers; while particulate tracers do not appear to have been especially accurate, the gas tracer technique seems promising.

Very little work has been done comparing known emission rates with the measurement of those rates. Consequently, almost no conclusions of a quantitative or definitive nature can be drawn about the accuracy of the measurement methods for fugitive dust. Few studies have been done on the precision of the methods. Much work remains to be done in these areas.

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Table 1. PM₁₀ SAMPLING OPTIONS

Type	Representative samplers	Time averaging period	Advantages	Disadvantages
High volume	Wedding, Anderson	6 to 24 h	EPA Reference Method for PM ₁₀ Averaging period comparable to Can operate on portable generator power	Requires AC power Cannot provide fine time resolution of concentrations
Continuous	Beta gauge, TEOM (tapered element oscillating microbalance)	Continuous	Provides very fine time resolution of concentration	Requires "clean" AC power, and does not run well on portable generators Generally requires temperature-controlled enclosure for reliable operation Most expensive option
Saturation	"PRO-2"	6 to 24 h	Battery powered Least expensive option Relatively rugged and easily deployed/moved	Not an equivalent method Cannot provide fine time resolution of concentration

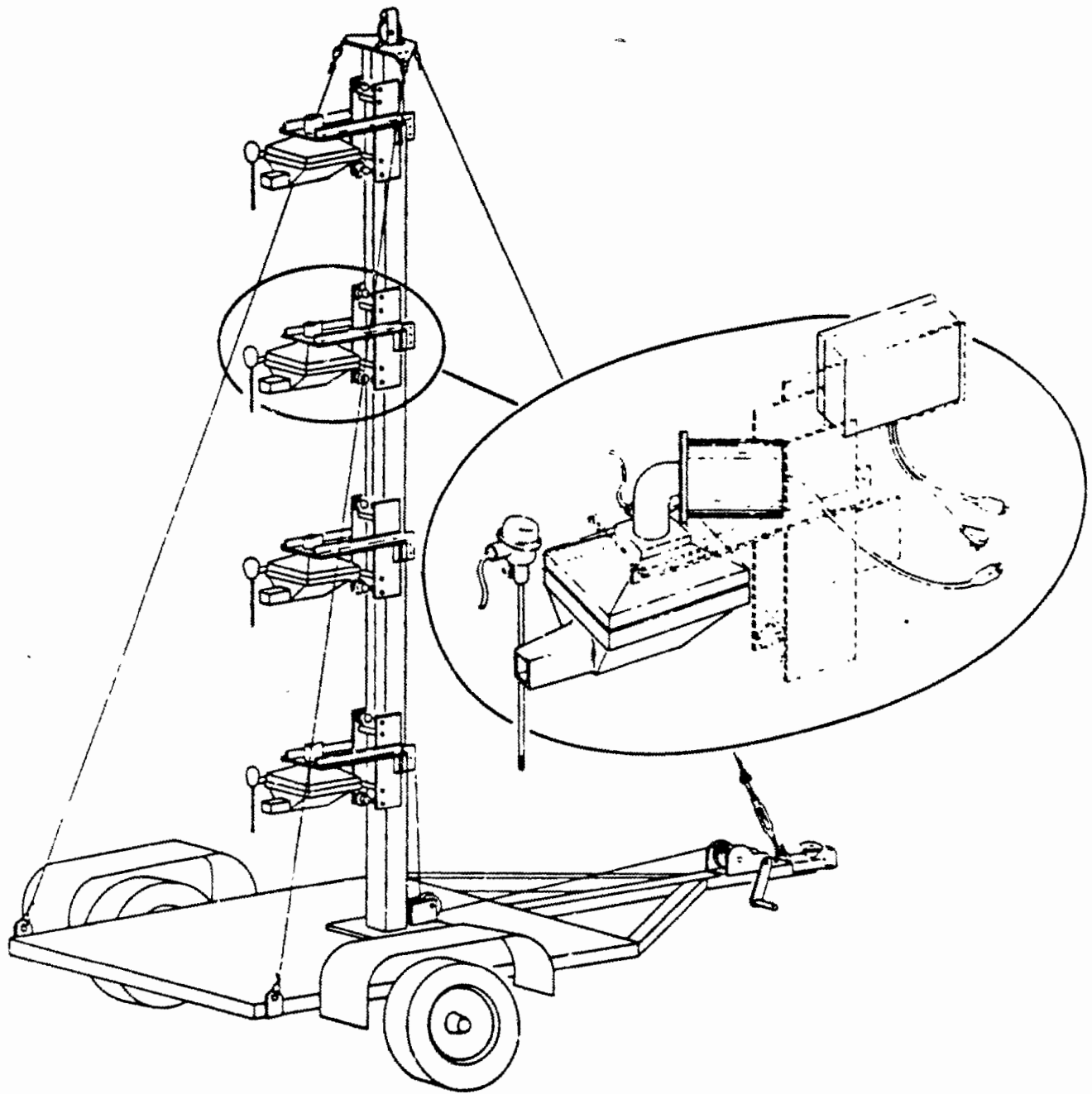


Figure 1. Exposure profiler.

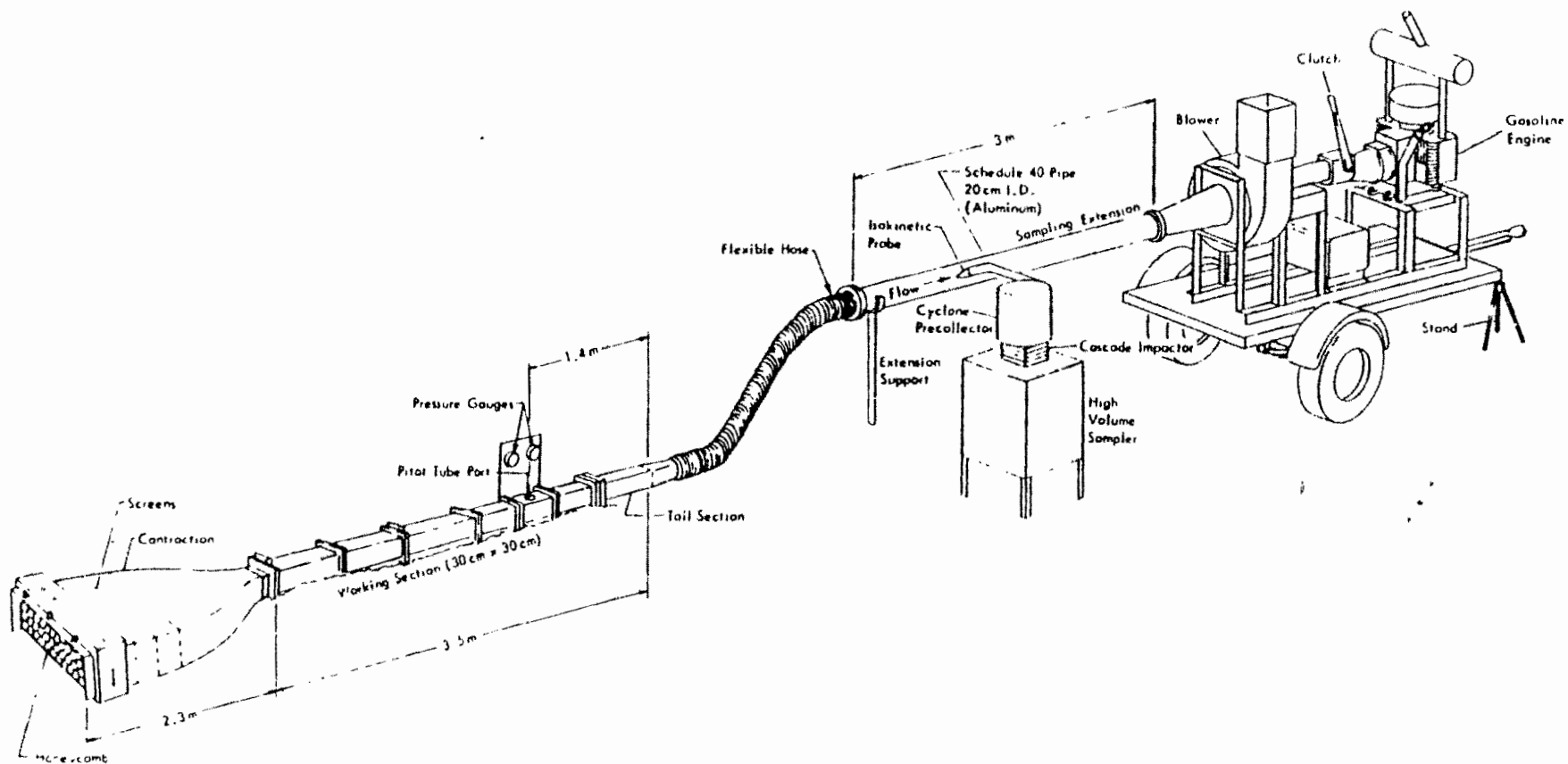


Figure 2. Portable wind tunnel.

Appendix A

4.2.1 Container No. 1 (Filter). Same instructions as Method 5, Section 4.2, "Container No. 1." If it is necessary to fold the filter, do so such that the film of oil is inside the fold.

4.2.2 Container No. 2 (Probe to Filter Holder). Taking care to see that material on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, probe liner, precollector cyclone and collector flask (if used), and front half of the filter holder by washing these components with TCE and placing the wash in a glass container. Carefully measure the total amount of TCE used in the rinses. Perform the TCE rinses as described in Method 5, Section 4.2, "Container No. 2," using TCE instead of acetone.

Brush and rinse the inside of the cyclone, cyclone collection flask, and the front half of the filter holder. Brush and rinse each surface three times or more, if necessary, to remove visible particulate.

4.2.3 Container No. 3 (Silica Gel). Same procedure as in Method 5, Section 4.2, "Container No. 3."

4.2.4 Impinger Water. Treat the impingers as follows: Make a notation of any color or film in the liquid catch. Follow the same procedure as in Method 5, Section 4.2, "Impinger Water."

4.2.5 Blank. Save a portion of the TCE used for cleanup as a blank. Take 200 ml of this TCE directly from the wash bottle being used and place it in a glass sample container labeled "TCE blank."

4.3 Analysis. Record the data required on a sheet such as the one shown in Figure 5A-1. Handle each sample container as follows:

4.3.1 Container No. 1 (Filter). Transfer the filter from the sample container to a tared glass weighing dish and desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Rinse Container No. 1 with a measured amount of TCE and analyze this rinse with the contents of Container No. 2. Weigh the filter to a constant weight. For the purpose of Section 4.3, the term "constant weight" means a difference of no more than 10 percent or 2 mg (whichever is greater) between two consecutive weighings made 24 hours apart. Report the "final weight" to the nearest 0.1 mg as the average of these two values.

4.3.2 Container No. 2 (Probe to Filter Holder). Before adding the rinse from Container No. 1 to Container No. 2, note the level of liquid in the container and confirm in the analysis sheet whether or not leakage occurred during transport. If noticeable leakage occurred, either void the sample or take steps, subject to the approval of the Administrator, to correct the final results.

Measure the liquid in this container either volumetrically to ± 1 ml or gravimetrically

to ± 0.5 g. Check to see if there is any appreciable quantity of condensed water present in the TCE rinse (look for a boundary layer or phase separation). If the volume of condensed water appears larger than 5 ml, separate the oil-TCE fraction from the water fraction using a separatory funnel. Measure the volume of the water phase to the nearest ml; adjust the stack gas moisture content, if necessary (see Sections 6.4 and 6.5). Next, extract the water phase with several 25-ml portions of TCE until, by visual observation, the TCE does not remove any additional organic material. Evaporate the remaining water fraction to dryness at 93°C (200°F), desiccate for 24 hours, and weigh to the nearest 0.1 mg.

Treat the total TCE fraction (including TCE from the filter container rinse and water phase extractions) as follows: Transfer the TCE and oil to a tared beaker and evaporate at ambient temperature and pressure. The evaporation of TCE from the solution may take several days. Do not desiccate the sample until the solution reaches an apparent constant volume or until the odor of TCE is not detected. When it appears that the TCE has evaporated, desiccate the sample and weigh it at 24-hour intervals to obtain a "constant weight" (as defined for Container No. 1 above). The "total weight" for Container No. 2 is the sum of the evaporated particulate weight of the TCE-oil and water phase fractions. Report the results to the nearest 0.1 mg.

4.3.3 Container No. 3 (Silica Gel). This step may be conducted in the field. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance.

4.3.4 "TCE Blank" Container. Measure TCE in this container either volumetrically or gravimetrically. Transfer the TCE to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE: In order to facilitate the evaporation of TCE liquid samples, these samples may be dried in a controlled temperature oven at temperatures up to 38°C (100°F) until the liquid is evaporated.

4.4 Quality Control Procedures. A quality control (QC) check of the volume metering system at the field site is suggested before collecting the sample. Use the procedure defined in Method 5, Section 4.4.

5. Calibration

Calibrate the sampling train components according to the indicated sections of Method 5: Probe Nozzle (5.1), Pitot Tube Assembly (5.2), Metering System (5.3), Probe Heater (5.4), Temperature Gauges (5.5), Leak Check of Metering System (5.6), and Barometer (5.7).

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6. Calculations

6.1 Nomenclature. Same as in Method 5, Section 6.1, with the following additions:

C_1 = TCE blank residue concentration, mg/mg.

m_1 = Mass of residue of TCE after evaporation, mg.

V_w = Volume of water collected in precollector, ml.

V_1 = Volume of TCE blank, ml.

V_2 = Volume of TCE used in wash, ml.

W_1 = Weight of residue in TCE wash, mg.

ρ_1 = Density of TCE, mg/ml (see label on bottle).

6.2 Dry Gas Meter Temperature and Orifice Pressure Drop. Using the data obtained in this test, calculate the average dry gas meter temperature and average orifice pressure drop (see Figure 5-2 of Method 5).

6.3 Dry Gas Volume. Using the data from this test, calculate $V_{m,60}$ by using Equation 5-1 of Method 5. If necessary, adjust the volume for leakages.

6.4 Volume of Water Vapor.

$$V_{w,60} = K_1(V_1 + V_2)$$

Eq. 5A-1

Where:

$K_1 = 0.00133 \text{ m}^3/\text{ml}$ for metric units.

$= 0.04707 \text{ ft}^3/\text{ml}$ for English units.

6.5 Moisture Content.

$$B_m = V_{w,60} / (V_{m,60} + V_{w,60})$$

Eq. 5A-2

NOTE: In saturated or water droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one from the impinger and precollector analysis (Equations 5A-1 and 5A-2) and a second from the assumption of saturated conditions. The lower of the two values of moisture content shall be considered correct. The procedure for determining the moisture content based upon assumption of saturated conditions is given in the note of Section 1.2 of Method 4. For the purpose of this method, the average stack gas temperature from Figure 5-2 of Method 5 may be used to make this determination, provided that the accuracy of the in-stack temperature sensor is within $\pm 1^\circ\text{C}$ (2°F).

6.6 TCE Blank Concentration.

$$C_1 = m_1 / V_1 \rho_1$$

Eq. 5A-3

6.7 TCE Wash Blank.

$$W_1 = C_1 V_2 \rho_1$$

Eq. 5A-4

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from Containers 1, 2, and 3, less the TCE blank.

6.9 Particulate Concentration.

$$C_1 = K_1 m_1 / V_{m,60}$$

Eq. 5A-5

Where:

$K_1 = 0.001 \text{ g/mg}$.

6.10 Isokinetic Variation and Acceptable Results. Method 5, Sections 6.11 and 6.12, respectively.

7. Bibliography

The bibliography for Reference Method 5A is the same as for Method 5, Section 7.

METHOD 5B—DETERMINATION OF NONSULFURIC ACID PARTICULATE MATTER FROM STATIONARY SOURCES

1. Applicability and Principle.

1.1 Applicability. This method is to be used for determining nonsulfuric acid particulate matter from stationary sources. Use of this method must be specified by an applicable subpart, or approved by the Administrator, U.S. Environmental Protection Agency, for a particular application.

1.2 Principle. Particulate matter is withdrawn isokinetically from the source using the Method 5 train at 180°C (320°F). The collected sample is then heated in the oven at 180°C (320°F) for 6 hours to volatilize any condensed sulfuric acid that may have been collected, and the nonsulfuric acid particulate mass is determined gravimetrically.

2. Procedure.

The procedure is identical to EPA Method 5 except for the following:

2.1 Initial Filter Tare. Oven dry the filter at $180 \pm 5^\circ\text{C}$ ($320 \pm 10^\circ\text{F}$) for 2 to 3 hours, cool in a desiccator for 2 hours, and weigh. Desiccate to constant weight to obtain the initial tare. Use the applicable specifications and techniques of Section 4.1.1 of Method 5 for this determination.

2.2 Probe and Filter Temperatures. Maintain the probe outlet and filter temperatures at $180 \pm 14^\circ\text{C}$ ($320 \pm 26^\circ\text{F}$).

2.3 Analysis. Dry the probe sample at ambient temperature. Then oven-dry the probe and filter samples at a temperature of $180 \pm 5^\circ\text{C}$ ($320 \pm 10^\circ\text{F}$) for 6 hours. Cool in a desiccator for 2 hours, and weigh to constant weight. Use the applicable specifications and techniques of Section 4.3 of Method 5 for this determination.

METHOD 5C—[RESERVED]

METHOD 5D—DETERMINATION OF PARTICULATE MATTER EMISSIONS FROM POSITIVE PRESSURE FABRIC FILTERS

1. Applicability and Principle

1.1 Applicability. This method applies to the determination of particulate matter emissions from positive pressure fabric fil-

ters. Emissions are determined in terms of concentration (mg/m³) and emission rate (kg/h).

The General Provisions of 40 CFR Part 60, § 60.8(e), require that the owner or operator of an affected facility shall provide performance testing facilities. Such performance testing facilities include sampling ports, safe sampling platforms, safe access to sampling sites, and utilities for testing. It is intended that affected facilities also provide sampling locations that meet the specification for adequate stack length and minimal flow disturbances as described in Method 1. Provisions for testing are often overlooked factors in designing fabric filters or are extremely costly. The purpose of this procedure is to identify appropriate alternative locations and procedures for sampling the emissions from positive pressure fabric filters. The requirements that the affected facility owner or operator provide adequate access to performance testing facilities remain in effect.

1.2 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at a temperature at or above the exhaust gas temperature up to a nominal 120°C (120 ± 14°C or 248 ± 25°F). The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

2. Apparatus

The equipment requirements for the sampling train, sample recovery, and analysis are the same as specified in Sections 2.1, 2.2, and 2.3, respectively, of Method 5 or Method 17.

3. Reagents

The reagents used in sampling, sample recovery, and analysis are the same as specified in Sections 3.1, 3.2, and 3.3, respectively, of Method 5 or Method 17.

4. Procedure

4.1 Determination of Measurement Site. The configurations of positive pressure fabric filter structures frequently are not amenable to emission testing according to the requirements of Method 1. Following are several alternatives for determining measurement sites for positive pressure fabric filters.

4.1.1 Stacks Meeting Method 1 Criteria. Use a measurement site as specified in Method 1, Section 2.1.

4.1.2 Short Stacks Not Meeting Method 1 Criteria. Use stack extensions and the procedures in Method 1. Alternatively, use flow straightening vanes of the "egg-crate" type (see Figure 5D-1). Locate the measurement site downstream of the straightening vanes at a distance equal to or greater than two times the average equivalent diameter of

the vane openings and at least one-half of the overall stack diameter upstream of the stack outlet.

4.1.3 Roof Monitor or Monovent. (See Figure 5D-2.) For a positive pressure fabric filter equipped with a peaked roof monitor, ridge vent, or other type of monovent, use a measurement site at the base of the monovent. Examples of such locations are shown in Figure 5D-2. The measurement site must be upstream of any exhaust point (e.g., louvered vent).

4.1.4 Compartment Housing. Sample immediately downstream of the filter bags directly above the tops of the bags as shown in the examples in Figure 5D-2. Depending on the housing design, use sampling ports in the housing walls or locate the sampling equipment within the compartment housing.

4.2 Determination of Number and Location of Traverse Points. Locate the traverse points according to Method 1, Section 2.3. Because a performance test consists of at least three test runs and because of the varied configurations of positive pressure fabric filters, there are several schemes by which the number of traverse points can be determined and the three test runs can be conducted.

4.2.1 Single Stacks Meeting Method 1 Criteria. Select the number of traverse points according to Method 1. Sample all traverse points for each test run.

4.2.2 Other Single Measurement Sites. For a roof monitor or monovent, single compartment housing, or other stack not meeting Method 1 criteria, use at least 24 traverse points. For example, for a rectangular measurement site, such as a monovent, use a balanced 5 x 5 traverse point matrix. Sample all traverse points for each test run.

4.2.3 Multiple Measurement Sites. Sampling from two or more stacks or measurement sites may be combined for a test run, provided the following guidelines are met:

(a) All measurement sites up to 12 must be sampled. For more than 12 measurement sites, conduct sampling on at least 12 sites or 50 percent of the sites, whichever is greater. The measurement sites sampled should be evenly, or nearly evenly, distributed among the available sites; if not, all sites are to be sampled.

(b) The same number of measurement sites must be sampled for each test run.

(c) The minimum number of traverse points per test run is 24. An exception to the 24-point minimum would be a test combining the sampling from two stacks meeting Method 1 criteria for acceptable stack length, and Method 1 specifies fewer than 12 points per site.

(d) As long as the 24 traverse points per test run criterion is met, the number of tra-

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verse points per measurement site may be reduced to eight.

Alternatively, conduct a test run for each measurement site individually using the criteria in Section 4.2.1 or 4.2.2 for number of traverse points. Each test run shall count toward the total of three required for a performance test. If more than three measurement sites are sampled, the number of traverse points per measurement site may be reduced to eight as long as at least 72 traverse points are sampled for all the tests.

The following examples demonstrate the procedures for sampling multiple measurement sites.

Example 1: A source with nine circular measurement sites of equal areas may be tested as follows: For each test run, traverse three measurement sites using four points per diameter (eight points per measurement site). In this manner, test run number 1 will include sampling from sites 1, 2, and 3; run 2 will include samples from sites 4, 5, and 6; and run 3 will include sites 7, 8, and 9. Each test area may consist of a separate test of each measurement site using eight points. Use the results from all nine tests in determining the emission average.

Example 2: A source with 30 rectangular measurement sites of equal areas may be tested as follows: For each of three test runs, traverse five measurement sites using a 3 x 3 matrix of traverse points for each site. In order to distribute the sampling evenly over all the available measurement sites while sampling only 50 percent of the sites, number the sites consecutively from 1 to 30 and sample all the even numbered (or odd numbered) sites. Alternatively, conduct a separate test of each of 15 measurement sites using Section 4.2.1 or 4.2.2 to determine the number and location of traverse points, as appropriate.

Example 3: A source with two measurement sites of equal areas may be tested as follows: For each test of three test runs, traverse both measurement sites using Section 4.2.3 in determining number of traverse points. Alternatively, conduct two full emission test runs of each measurement site using the criteria in Section 4.2.1 or 4.2.2 to determine the number of traverse points.

Other test schemes, such as random determination of traverse points for a large number of measurement sites, may be used with prior approval from the Administrator.

4.3 Velocity Determination. The velocities of exhaust gases from positive pressure baghouses are often too low to measure accurately with the type S pitot specified in Method 2 [i.e., velocity head < 1.3 mm H₂O (0.05 in. H₂O)]. For these conditions, measure the gas flow rate at the fabric filter inlet following the procedures in Method 2. Calculate the average gas velocity at the measurement site as follows:

$$v = \frac{Q_i}{A_s} \cdot \frac{T_s}{T_i}$$

Eq. 5D-1

Where:

v = Average gas velocity at the measurement site(s), m/s (ft/s).

Q_i = Inlet gas volume flow rate, m³/s (ft³/s).

A_s = Measurement site(s) total cross-sectional area, m² (ft²).

T_s = Temperature of gas at measurement site, °K (°R)

T_i = Temperature of gas at inlet, °K (°R).

Use the average velocity calculated for the measurement site in determining and maintaining isokinetic sampling rates. Note: All sources of gas leakage, into or out of the fabric filter housing between the inlet measurement site and the outlet measurement site must be blocked and made leak-tight.

Velocity determinations at measurement sites with gas velocities within the range measurable with the type S pitot [i.e., velocity head > 1.3 mm H₂O (0.05 in. H₂O)] shall be conducted according to the procedures in Method 2.

4.4 Sampling. Follow the procedures specified in Section 4.1 of Method 5 or Method 17 with the exceptions as noted above.

4.5 Sample Recovery. Follow the procedures specified in Section 4.2 of Method 5 or Method 17.

4.6 Sample Analysis. Follow the procedures specified in Section 4.3 of Method 5 or Method 17.

4.7 Quality Control Procedures. A (QC) check of the volume metering system at the field site is suggested before collecting the sample. Use the procedure defined in Section 4.4 of Method 5.

5. Calibration

Follow the procedures as specified in Section 5 of Method 5 or Method 17.

6. Calculations

Follow the procedures as specified in Section 6 of Method 5 or Method 17 with the exceptions as follows:

6.1 Total volume flow rate may be determined using inlet velocity measurements and stack dimensions.

6.2 Average Particulate Concentration. For multiple measurement sites, calculate the average particulate concentration as follows:

$$C = \frac{\sum_{i=1}^n m_i}{\sum_{i=1}^n Vol_i}$$

Eq. 5D-2

Where:

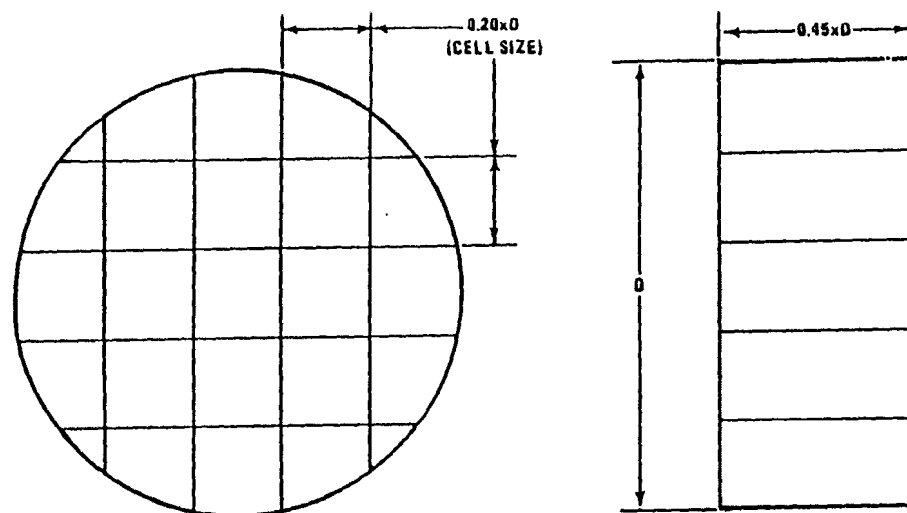
m_i = The mass collected for run i of n , mg(gr).

Vol_i = The sample volume collected for run i of n , sm^3 (scf).

\bar{C} = Average concentration of particulate for all n runs, mg/ sm^3 (gr/scf).

7. Bibliography

The bibliography is the same as for Method 5, Section 7.



NOTE: POSITION STRAIGHTENERS SO THAT CELL SIDES ARE LOCATED APPROX. 45° FROM TRAVERSE DIA'.

Figure 5D-1. Example of flow straightening vanes.

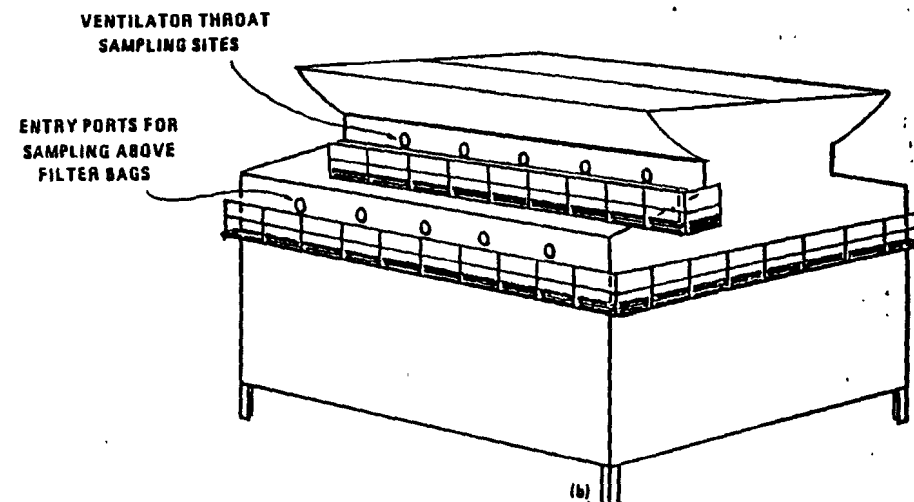
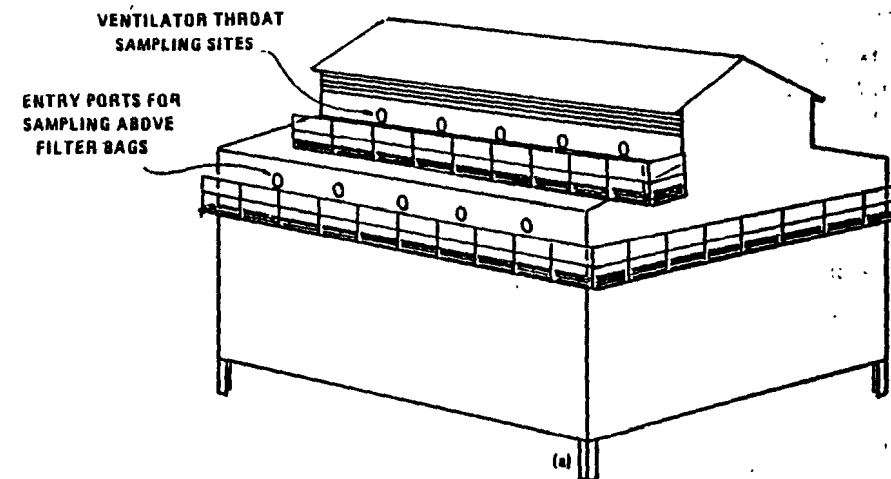


Figure 5D-2. Acceptable sampling site locations for: (a) peaked roof; and (b) ridge vent type fabric filters.

Method 26—Determination of Hydrogen Chloride Emissions From Stationary Sources

Method 27—Determination of vapor tightness of gasoline delivery tank using pressure-vacuum test

Method 28—Certification and auditing of wood heaters

Method 28A—Measurement of air to fuel ratio and minimum achievable burn rates for wood-fired appliances

The test methods in this appendix are referred to in § 60.8 (Performance Tests) and § 60.11 (Compliance With Standards and Maintenance Requirements) of 40 CFR part 60, subpart A (General Provisions). Specific uses of these test methods are described in the standards of performance contained in the subparts, beginning with Subpart D.

Within each standard of performance, a section title "Test Methods and Procedures" is provided to: (1) Identify the test methods to be used as reference methods to the facility subject to the respective standard and (2) identify any special instructions or conditions to be followed when applying a method to the respective facility. Such instructions (for example, establish sampling rates, volumes, or temperatures) are to be used either in addition to, or as a substitute for procedures in a test method. Similarly, for sources subject to emission monitoring requirements, specific instructions pertaining to any use of a test method as a reference method are provided in the subpart or in Appendix B.

Inclusion of methods in this appendix is not intended as an endorsement or denial of their applicability to sources that are not subject to standards of performance. The methods are potentially applicable to other sources; however, applicability should be confirmed by careful and appropriate evaluation of the conditions prevalent at such sources.

The approach followed in the formulation of the test methods involves specifications for equipment, procedures, and performance. In concept, a performance specification approach would be preferable in all methods because this allows the greatest flexibility to the user. In practice, however, this approach is impractical in most cases because performance specifications cannot be established. Most of the methods described herein, therefore, involve specific equipment specifications and procedures, and only a few methods in this appendix rely on performance criteria.

Minor changes in the test methods should not necessarily affect the validity of the results and it is recognized that alternative and equivalent methods exist. Section 60.8 provides authority for the Administrator to specify or approve (1) equivalent methods, (2) alternative methods, and (3) minor

changes in the methodology of the test methods. It should be clearly understood that unless otherwise identified all such methods and changes must have prior approval of the Administrator. An owner employing such methods or deviations from the test methods without obtaining prior approval does so at the risk of subsequent disapproval and retesting with approved methods.

Within the test methods, certain specific equipment or procedures are recognized as being acceptable or potentially acceptable and are specifically identified in the methods. The items identified as acceptable options may be used without approval but must be identified in the test report. The potentially approvable options are cited as "subject to the approval of the Administrator" or as "or equivalent." Such potentially approvable techniques or alternatives may be used at the discretion of the owner without prior approval. However, detailed descriptions for applying these potentially approvable techniques or alternatives are not provided in the test methods. Also, the potentially approvable options are not necessarily acceptable in all applications. Therefore, an owner electing to use such potentially approvable techniques or alternatives is responsible for: (1) assuring that the techniques or alternatives are in fact applicable and are properly executed; (2) including a written description of the alternative method in the test report (the written method must be clear and must be capable of being performed without additional instruction, and the degree of detail should be similar to the detail contained in the test methods); and (3) providing any rationale or supporting data necessary to show the validity of the alternative in the particular application. Failure to meet these requirements can result in the Administrator's disapproval of the alternative.

METHOD 1—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

1. Principle and Applicability

1.1 Principle. To aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source, a measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas.

1.2 Applicability. This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when: (1) flow is cyclonic or swirling (see Section 2.4), (2) a stack is smaller than about 0.30 meter (12 in.) in diameter, or

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0.071 m² (113 in.²) cross-sectional area, or (3) the measurement site is less than two stack or duct diameters downstream or less than a half diameter upstream from a flow disturbance.

The requirements of this method must be considered before construction of a new facility from which emissions will be measured, failure to do so may require subsequent alterations to the stack or deviation from the standard procedure. Cases involving variants are subject to approval by the Administrator, U.S. Environmental Protection Agency.

2 Procedure

2.1 Selection of Measurement Site. Sampling or velocity measurement is performed at a site located at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, or from a visible flame. If necessary, an alternative location may be selected, at a position at least two stack or duct diameters

downstream and a half diameter upstream from any flow disturbance. For a rectangular cross section, an equivalent diameter (D_e) shall be calculated from the following equation, to determine the upstream and downstream distances:

$$D_e = \frac{2LW}{L+W}$$

where L = length and W = width.

An alternative procedure is available for determining the acceptability of a measurement location not meeting the criteria above. This procedure, determination of gas flow angles at the sampling points and comparing the results with acceptability criteria, is described in Section 2.5.

2.2 Determining the Number of Traverse Points.

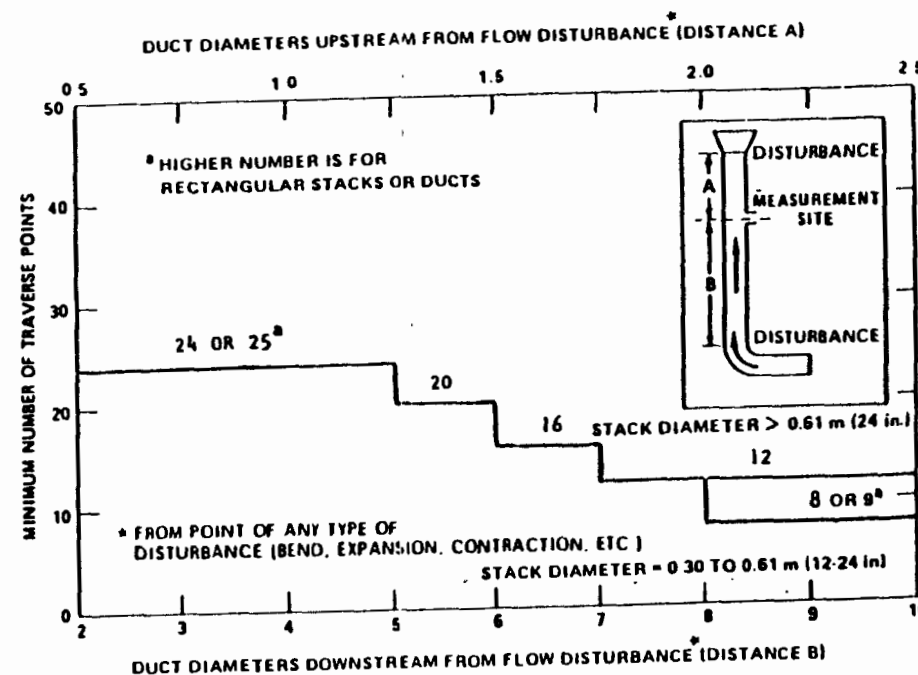


Figure 1-1. Minimum number of traverse points for particulate traverses.

2.2.1 Particulate Traverses. When the eight- and two-diameter criterion can be met, the minimum number of traverse points shall be: (1) twelve, for circular or

rectangular stacks with diameters (or equivalent diameters) greater than 0.61 meter (24 in.); (2) eight, for circular stacks with diameters between 0.30 and 0.61 meter (12-24

in.); (3) nine, for rectangular stacks with equivalent diameters between 0.30 and 0.61 meter (12-24 in.).

When the eight- and two-diameter criterion cannot be met, the minimum number of traverse points is determined from Figure 1-1. Before referring to the figure, however, determine the distances from the chosen measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. Then, determine from Figure 1-1 the minimum number of traverse points that corresponds: (1) to the number of duct diameters upstream; and (2) to the number of diameters downstream. Select the higher of the two minimum numbers of traverse

points, or a greater value, so that for circular stacks the number is a multiple of 4, and for rectangular stacks, the number is one of those shown in Table 1-1.

TABLE 1-1. CROSS-SECTION LAYOUT FOR RECTANGULAR STACKS

Number of traverse points	Matrix layout
9	3x3
12	4x3
16	4x4
20	5x4
25	5x5
30	6x5
36	6x6
42	7x6
49	7x7

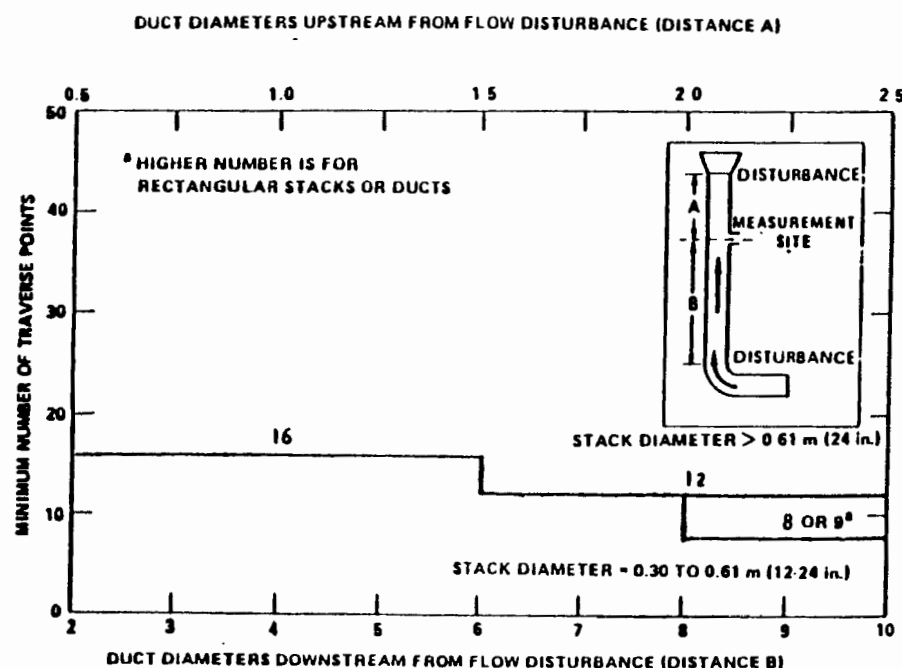


Figure 1-2. Minimum number of traverse points for velocity (nonparticulate) traverses.

2.2.2 Velocity (Non-Particulate) Traverses. When velocity or volumetric flow rate is to be determined (but not particulate matter), the same procedure as that for particulate traverses (Section 2.2.1) is followed, except that Figure 1-2 may be used instead of Figure 1-1.

2.3 Cross-sectional Layout and Location of Traverse Points.

2.3.1 Circular Stacks. Locate the traverse points on two perpendicular diameters according to Table 1-2 and the example shown in Figure 1-3. Any equation (for examples, see Citations 2 and 3 in the Bibliography) that gives the same values as those in Table

For particulate traverses, one of the diameters must be in a plane containing the greatest expected concentration variation, e.g., after bends, one diameter shall be in the plane of the bend. This requirement becomes less critical as the distance from the disturbance increases; therefore, other diameter locations may be used, subject to approval of the Administrator.

In addition for stacks having diameters greater than 0.61 m (24 in.) no traverse points shall be located within 2.5 centimeters (1.00 in.) of the stack walls, and for stack diameters equal to or less than 0.61 m (24 in.), no traverse points shall be located within 1.3 cm (0.50 in.) of the stack walls. To meet these criteria, observe the procedures given below.

2.3.1.1 Stacks With Diameters Greater Than 0.61 m (24 in.). When any of the traverse points as located in Section 2.3.1 fall within 2.5 cm (1.00 in.) of the stack walls, relocate them away from the stack walls to: (1) a distance of 2.5 cm (1.00 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be the "adjusted" traverse points.

Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points, both in the sampling (or velocity measurement) procedure, and in recording the data.

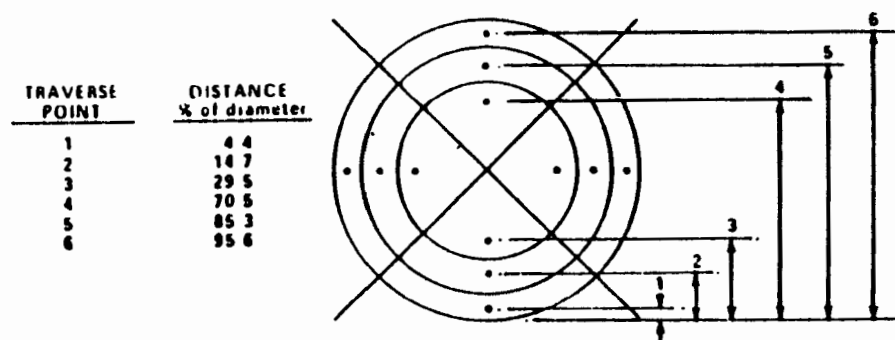


Figure 1-3. Example showing circular stack cross section divided into 12 equal areas, with location of traverse points indicated.

TABLE 1-2 LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

(Percent of stack diameter from inside wall to traverse point)

Traverse point number on a diameter	Number of traverse points on a diameter—											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.8	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8				96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10					97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.8	67.7
15								95.1	89.1	83.5	78.2	72.8
16								92.5	87.1	82.0	77.0	
17								95.6	90.3	85.4	80.6	
18								98.6	93.3	88.4	83.5	

TABLE 1-2. LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS—Continued

Traverse point number on a diameter	Number of traverse points on a diameter— (Percent of stack diameter from inside wall to traverse point)											
	2	4	6	8	10	12	14	16	18	20	22	24
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

2.3.1.2 Stacks With Diameters Equal to or Less Than 0.61 m (24 in.). Follow the procedure in Section 2.3.1.1, noting only that any "adjusted" points should be relocated away from the stack walls to: (1) a distance of 1.3 cm (0.50 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger.

2.3.2 Rectangular Stacks. Determine the number of traverse points as explained in Sections 2.1 and 2.2 of this method. From Table 1-1, determine the grid configuration. Divide the stack cross-section into as many equal rectangular elemental areas as traverse points, and then locate a traverse point at the centroid of each equal area according to the example in Figure 1-4.

If the tester desires to use more than the minimum number of traverse points, expand the "minimum number of traverse points" matrix (see Table 1-1) by adding the extra traverse points along one or the other or both legs of the matrix; the final matrix need not be balanced. For example, if a 4x3 "minimum number of points" matrix were expanded to 36 points, the final matrix could be 9x4 or 12x3, and would not necessarily have to be 6x6. After constructing the final matrix, divide the stack cross-section into as many equal rectangular, elemental areas as traverse points, and locate a traverse point at the centroid of each equal area.

The situation of traverse points being too close to the stack walls is not expected to arise with rectangular stacks. If this problem should ever arise, the Administrator must be contacted for resolution of the matter.

2.4 Verification of Absence of Cyclonic Flow. In most stationary sources, the direction of stack gas flow is essentially parallel to the stack walls. However, cyclonic flow may exist (1) after such devices as cyclones and inertial demisters following venturi scrubbers, or (2) in stacks having tangential inlets or other duct configurations which tend to induce swirling; in these instances, the presence or absence of cyclonic flow at the sampling location must be determined. The following techniques are acceptable for this determination.

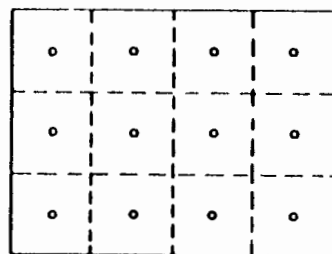


Figure 1-4. Example showing rectangular stack cross section divided into 12 equal areas, with a traverse point at centroid of each area.

Level and zero the manometer. Connect a Type S pitot tube to the manometer. Position the Type S pitot tube at each traverse point, in succession, so that the planes of the face openings of the pitot tube are perpendicular to the stack cross-sectional plane; when the Type S pitot tube is in this position, it is at "0° reference." Note the differential pressure (Δp) reading at each traverse point. If a null (zero) pitot reading is obtained at 0° reference at a given traverse point, an acceptable flow condition exists at that point. If the pitot reading is not zero at 0° reference, rotate the pitot tube (up to $\pm 90^\circ$ yaw angle), until a null reading is obtained. Carefully determine and record the value of the rotation angle (α) to the nearest degree. After the null technique has been applied at each traverse point, calculate the average of the absolute values of α ; assign α values of 0° to those points for which no rotation was required, and include these in the overall average. If the average value of α is greater than 20°, the overall flow condition in the stack is unacceptable and alternative methodology, subject to the approval of the Administrator, must be used to perform accurate sample and velocity traverses.

The alternative procedure described in Section 2.5 may be used to determine the rotation angles in lieu of the procedure described above.

2.5 Alternative Measurement Site Selection Procedure. This alternative applies to

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sources where measurement locations are less than 2 equivalent stack or duct diameters downstream or less than $\frac{1}{2}$ duct diameter upstream from a flow disturbance. The alternative should be limited to ducts larger than 24 in. in diameter where blockage and wall effects are minimal. A directional flow-sensing probe is used to measure pitch and yaw angles of the gas flow at 40 or more traverse points; the resultant angle is calculated and compared with acceptable criteria for mean and standard deviation.

NOTE: Both the pitch and yaw angles are measured from a line passing through the traverse point and parallel to the stack axis. The pitch angle is the angle of the gas flow component in the plane that INCLUDES the traverse line and is parallel to the stack axis. The yaw angle is the angle of the gas flow component in the plane PERPENDICULAR to the traverse line at the traverse point and is measured from the line passing through the traverse point and parallel to the stack axis.

2.5.1 Apparatus.

2.5.1.1 Directional Probe. Any directional probe, such as United Sensor Type DA Three-Dimensional Directional Probe, capable of measuring both the pitch and yaw angles of gas flows is acceptable. (NOTE: Mention of trade name or specific products does not constitute endorsement by the U.S. Environmental Protection Agency.) Assign an identification number to the directional probe, and permanently mark or engrave the number on the body of the probe. The pressure holes of directional probes are susceptible to plugging when used in particulate-laden gas streams. Therefore, a system for cleaning the pressure holes by "back-purging" with pressurized air is required.

2.5.1.2 Differential Pressure Gauges. Inclined manometers, U-tube manometers, or other differential pressure gauges (e.g., magnetic gauges) that meet the specifications described in Method 2, section 2.2.

NOTE: If the differential pressure gauge produces both negative and positive readings, then both negative and positive pressure readings shall be calibrated at a minimum of three points as specified in Method 2, section 2.2.

2.5.2 Traverse Points. Use a minimum of 40 traverse points for circular ducts and 42 points for rectangular ducts for the gas flow angle determinations. Follow section 2.3 and Table 1-1 or 1-2 for the location and layout of the traverse points. If the measurement location is determined to be acceptable according to the criteria in this alternative procedure, use the same traverse point number and locations for sampling and velocity measurements.

2.5.3 Measurement Procedure

2.5.3.1 Prepare the directional probe and differential pressure gauges as recommended

by the manufacturer. Capillary tubing or surge tanks may be used to dampen pressure fluctuations. It is recommended, but not required, that a pretest leak check be conducted. To perform a leak check, pressurize or use suction on the impact opening until a reading of at least 7.6 cm (3 in.) H₂O registers on the differential pressure gauge, then plug the impact opening. The pressure of a leak-free system will remain stable for at least 15 seconds.

2.5.3.2 Level and zero the manometers. Since the manometer level and zero may drift because of vibrations and temperature changes, periodically check the level and zero during the traverse.

2.5.3.3 Position the probe at the appropriate locations in the gas stream, and rotate until zero deflection is indicated for the yaw angle pressure gauge. Determine and record the yaw angle. Record the pressure gauge readings for the pitch angle, and determine the pitch angle from the calibration curve. Repeat this procedure for each traverse point. Complete a "back-purge" of the pressure lines and the impact openings prior to measurements of each traverse point.

A post-test check as described in section 2.5.3.1 is required. If the criteria for a leak-free system are not met, repair the equipment, and repeat the flow angle measurements.

2.5.4 Calculate the resultant angle at each traverse point, the average resultant angle, and the standard deviation using the following equations. Complete the calculations retaining at least one extra significant figure beyond that of the acquired data. Round the values after the final calculations.

2.5.4.1 Calculate the resultant angle at each traverse point:

$$R_i = \arccosine[(\cosine Y_i)(\cosine P_i)]$$

Eq. 1-2

Where:

R_i = Resultant angle at traverse point i , degree.

Y_i = Yaw angle at traverse point i , degree.

P_i = Pitch angle at traverse point i , degree.

2.5.4.2 Calculate the average resultant for the measurements:

$$\bar{R} = \frac{\sum R_i}{n}$$

Eq. 1-3

Where:

\bar{R} = Average resultant angle, degree.

n = Total number of traverse points.

2.5.4.3 Calculate the standard deviations:

$$S_s = \sqrt{\frac{\sum_{i=1}^n (R_i - \bar{R})^2}{(n-1)}}$$

Eq. 1-4

Where:

 S_s = Standard deviation, degree.

2.5.5 The measurement location is acceptable if $R \leq 20^\circ$ and $S_s \leq 10^\circ$.

2.5.6 Calibration. Use a flow system as described in Sections 4.1.2.1 and 4.1.2.2 of Method 2. In addition, the flow system shall have the capacity to generate two test-section velocities: one between 365 and 730 m/min (1200 and 2400 ft/min) and one between 730 and 1100 m/min (2400 and 3600 ft/min).

2.5.6.1 Cut two entry ports in the test section. The axes through the entry ports shall be perpendicular to each other and intersect in the centroid of the test section. The ports should be elongated slots parallel to the axis of the test section and of sufficient length to allow measurement of pitch angles while maintaining the pitot head position at the test-section centroid. To facilitate alignment of the directional probe during calibration, the test section should be constructed of plexiglass or some other transparent material. All calibration measurements should be made at the same point in the test section, preferably at the centroid of the test-section.

2.5.6.2 To ensure that the gas flow is parallel to the central axis of the test section, follow the procedure in Section 2.4 for cyclonic flow determination to measure the gas flow angles at the centroid of the test section from two test ports located 90° apart. The gas flow angle measured in each port must be $\pm 2^\circ$ of 0°. Straightening vanes should be installed, if necessary, to meet this criterion.

2.5.6.3 Pitch Angle Calibration. Perform a calibration traverse according to the manufacturer's recommended protocol in 5° increments for angles from -60° to +60° at one velocity in each of the two ranges specified above. Average the pressure ratio values obtained for each angle in the two flow ranges, and plot a calibration curve with the average values of the pressure ratio (or other suitable measurement factor as recommended by the manufacturer) versus the pitch angle. Draw a smooth line through the data points. Plot also the data values for each traverse point. Determine

for angles between 0° and 40° and within 3° for angles between 40° and 60°.

2.5.6.4 Yaw Angle Calibration. Mark the three-dimensional probe to allow the determination of the yaw position of the probe. This is usually a line extending the length of the probe and aligned with the impact opening. To determine the accuracy of measurements of the yaw angle, only the zero or null position need be calibrated as follows. Place the directional probe in the test section, and rotate the probe until the zero position is found. With a protractor or other angle measuring device, measure the angle indicated by the yaw angle indicator on the three-dimensional probe. This should be within 2° of 0°. Repeat this measurement for any other points along the length of the pitot where yaw angle measurements could be read in order to account for variations in the pitot markings used to indicate pitot head positions.

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METHOD 1A—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES WITH SMALL STACKS OR DUCTS

1. Applicability and Principle

1.1 The applicability and principle of this method are identical to Method 1, except this method's applicability is limited to stacks or ducts less than about 0.30 meter (12 in.) in diameter or 0.071 m² (113 in.²) in cross-sectional area, but equal to or greater

than about 0.10 meter (4 in.) in diameter or 0.0081 m² (12.57 in.²) in cross-sectional area.

1.2 In these small diameter stacks or ducts, the conventional Method 5 stack assembly (consisting of a Type S pitot tube attached to a sampling probe, equipped with a nozzle and thermocouple) blocks a significant portion of the cross section of the duct and causes inaccurate measurements. Therefore, for particulate matter (PM) sampling in small stacks or ducts, the gas velocity is measured using a standard pitot tube downstream of the actual emission sampling site. The straight run of duct between the PM sampling and velocity measurement sites allows the flow profile, temporarily disturbed by the presence of the sampling probe, to redevelop and stabilize.

1.3 The cross-sectional layout and location of traverse points and the verification of the absence of cyclonic flow are the same as in Method 1, Sections 2.3 and 2.4, respectively. Differences from Method 1, except as noted, are given below.

2. Procedure

2.1 Selection of Sampling and Measurement Sites.

2.1.1 PM Measurements. Select a PM sampling site located preferably at least 8 equivalent stack or duct diameters downstream and 10 equivalent diameters upstream from any flow disturbances such as bends, expansions, or contractions in the stack, or from a visible flame. Next, locate the velocity measurement site 8 equivalent diameters downstream of the PM sampling site. See Figure 1A-1. If such locations are not available, select an alternative PM sampling site that is at least 2 equivalent stack or duct diameters downstream and 2½ diameters upstream from any flow disturbance. Then, locate the velocity measurement site 2 equivalent diameters downstream from the PM sampling site. Follow Section 2.1 of Method 1 for calculating equivalent diameters for a rectangular cross section.

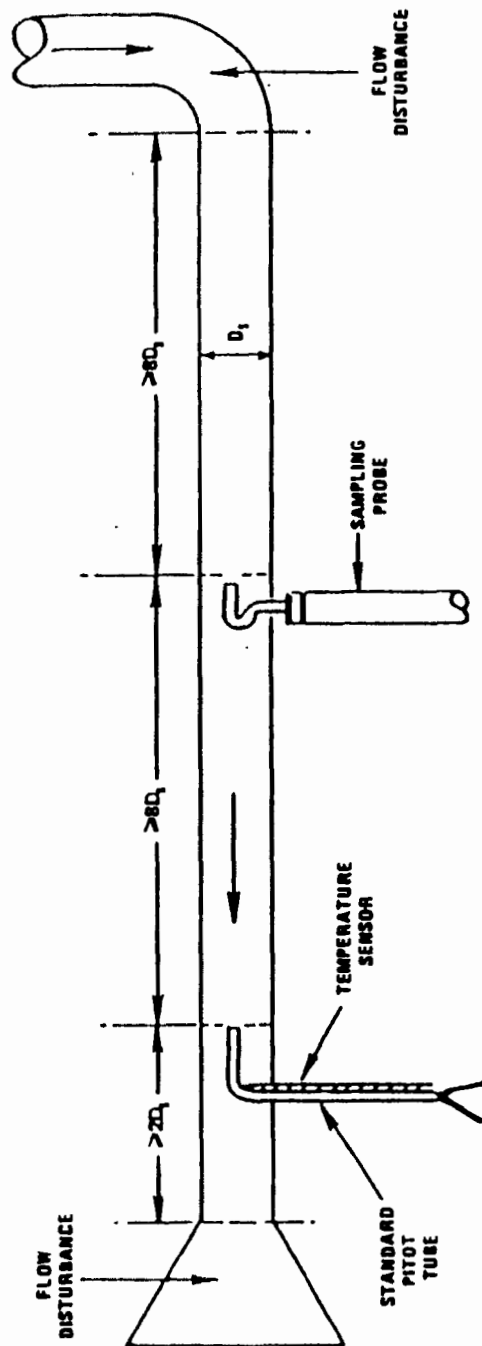


Figure 1A-1. Recommended sampling arrangement for small ducts.

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2.1.2 PM Sampling (Steady Flow) or only Velocity Measurements. For PM sampling when the volumetric flow rate in a duct is constant with respect to time, Section 2.1 of Method 1 may be followed, with the PM sampling and velocity measurement performed at one location. To demonstrate that the flow rate is constant (within 10 percent) when PM measurements are made, perform complete velocity traverses before and after the PM sampling run, and calculate the deviation of the flow rate derived after the PM sampling run from the one derived before the PM sampling run. The PM sampling run is acceptable if the deviation does not exceed 10 percent.

2.2 Determining the Number of Traverse Points

2.2.1 PM Sampling. Use Figure 1-1 of Method 1 to determine the number of traverse points to use at both the velocity measurement and PM sampling locations. Before referring to the figure, however, determine the distances between both the velocity measurement and PM sampling sites to the nearest upstream and downstream disturbances. Then divide each distance by the stack diameter or equivalent diameter to express the distances in terms of the number of duct diameters. Next, determine the number of traverse points from Figure 1-1 of Method 1 corresponding to each of these four distances. Choose the highest of the four numbers of traverse points (or a greater number) so that, for circular ducts, the number is a multiple of four, and for rectangular ducts, the number is one of those shown in Table 1-1 of Method 1. When the optimum duct diameter location criteria can be satisfied, the minimum number of traverse points required is eight for circular ducts and nine for rectangular ducts.

2.2.2 PM Sampling (Steady Flow) or Velocity Measurements. Use Figure 1-2 of Method 1 to determine the number of traverse points, following the same procedure used for PM sampling traverses as described in Section 2.2.1 of Method 1. When the optimum duct diameter location criteria can be satisfied, the minimum number of traverse

points required is eight for circular ducts and nine for rectangular ducts.

3. Bibliography

1. Same as in Method 1, Section 3, Citations 1 through 6.
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METHOD 2—DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)

1. Principle and Applicability

1.1 Principle. The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube.

1.2 Applicability. This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow.

This procedure is not applicable at measurement sites which fail to meet the criteria of Method 1, Section 2.1. Also, the method cannot be used for direct measurement in cyclonic or swirling gas streams; Section 2.4 of Method 1 shows how to determine cyclonic or swirling flow conditions. When unacceptable conditions exist, alternative procedures, subject to the approval of the Administrator, U.S. Environmental Protection Agency, must be employed to make accurate flow rate determinations; examples of such alternative procedures are: (1) to install straightening vanes; (2) to calculate the total volumetric flow rate stoichiometrically, or (3) to move to another measurement site at which the flow is acceptable.

2. Apparatus

Specifications for the apparatus are given below. Any other apparatus that has been demonstrated (subject to approval of the Administrator) to be capable of meeting the specifications will be considered acceptable.

METHOD 201 - DETERMINATION OF PM_{10} EMISSIONS (Exhaust Gas Recycle Procedure)

1. Applicability and Principle

1.1 Applicability. This method applies to the in-stack measurement of particulate matter (PM) emissions equal to or less than an aerodynamic diameter of nominally $10\ \mu m$ (PM_{10}) from stationary sources. The EPA recognizes that condensible emissions not collected by an in-stack method are also PM_{10} , and that emissions that contribute to ambient PM_{10} levels are the sum of condensible emissions and emissions measured by an in-stack PM_{10} method, such as this method or Method 201A. Therefore, for establishing source contributions to ambient levels of PM_{10} , such as for emission inventory purposes, EPA suggests that source PM_{10} measurement include both in-stack PM_{10} and condensible emissions. Condensible emissions may be measured by an impinger analysis in combination with this method.

1.2 Principle. A gas sample is isokinetically extracted from the source. An in-stack cyclone is used to separate PM greater than PM_{10} , and an in-stack glass fiber filter is used to collect the PM_{10} . To maintain isokinetic flow rate conditions at the tip of the probe and a constant flow rate through the cyclone, a clean, dried portion of the sample gas at stack temperature is recycled into the nozzle. The particulate mass is determined gravimetrically after removal of uncombined water.

2. Apparatus

NOTE: Method 5 as cited in this method refers to the method in 40 CFR Part 60, Appendix A.

2.1 Sampling Train. A schematic of the exhaust of the exhaust gas recycle (EGR) train is shown in Figure 1.

2.1.1 Nozzle with Recycle Attachment. Stainless steel (316 or equivalent) with a sharp tapered leading edge, and recycle attachment welded directly on the side of the nozzle (see schematic in Figure 2). The angle of the taper shall be on the outside. Use only straight sampling nozzles. "Gooseneck" or other nozzle extensions designed to turn the sample gas flow 90°, as in Method 5 are not acceptable. Locate a thermocouple in the recycle attachment to measure the temperature of the recycle gas as shown in Figure 3. The recycle attachment shall be made of stainless steel and shall be connected to the probe and nozzle with stainless steel fittings. Two nozzle sizes, e.g., 0.125 and 0.160 in., should be available to allow isokinetic sampling to be conducted over a range of flow rates. Calibrate each nozzle as described in Method 5, Section 5.1.

2.1.2 PM₁₀ Sizer. Cyclone, meeting the specifications in Section 5.7.

2.1.3 Filter Holder. 63-mm, stainless steel. An Andersen filter, part number SE274, has been found to be acceptable for the in-stack filter.

NOTE: Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

2.1.4 Pitot Tube. Same as in Method 5, Section 2.1.3. Attach the pitot to the pitot lines with stainless steel fittings and to the cyclone in a configuration similar to that shown in Figure 3. The pitot lines shall be made of heat resistant material and attached to the probe with stainless steel fittings.

2.1.5 EGR Probe. Stainless steel, 15.9-mm (5/8-in.) ID tubing with a probe liner, stainless steel 9.53-mm (3/8-in.) ID stainless steel recycle tubing, two 6.35-mm (1/4-in.) ID stainless steel tubing for the pitot tube extensions, three thermocouple leads, and one power lead, all contained by

stainless steel tubing with a diameter of approximately 51 mm (2.0 in.).

Design considerations should include minimum weight construction materials sufficient for probe structural strength. Wrap the sample and recycle tubes with a heating tape to heat the sample and recycle gases to stack temperature.

2.1.6 Condenser. Same as in Method 5, Section 2.1.7.

2.1.7 Umbilical Connector. Flexible tubing with thermocouple and power leads of sufficient length to connect probe to meter and flow control console.

2.1.8 Vacuum Pump: Leak-tight, oil-less, noncontaminating, with an absolute filter, "HEPA" type, at the pump exit. A Gast Model 0522-V103 G18DX pump has been found to be satisfactory.

2.1.9 Meter and Flow Control Console. System consisting of a dry gas meter and calibrated orifice for measuring sample flow rate and capable of measuring volume to ± 2 percent, calibrated laminar flow elements (LFE's) or equivalent for measuring total and sample flow rates, probe heater control, and manometers and magnehelic gauges (as shown in Figures 4 and 5), or equivalent. Temperatures needed for calculations include stack, recycle, probe, dry gas meter, filter, and total flow. Flow measurements include velocity head (Δp), orifice differential pressure (ΔH), total flow, recycle flow, and total back-pressure through the system.

2.1.10 Barometer. Same as in Method 5, Section 2.1.9.

2.1.11 Rubber Tubing. 6.35-mm (1/4-in.) ID flexible rubber tubing.

2.2 Sample Recovery.

2.2.1 Nozzle, Cyclone, and Filter Holder Brushes. Nylon bristle brushes properly sized and shaped for cleaning the nozzle, cyclone, filter holder, and probe or probe liner, with stainless steel wire shafts and handles.

2.2.2 Wash Bottles, Glass Sample Storage Containers, Petri Dishes, Graduated Cylinder and Balance, Plastic Storage Containers, and Funnels. Same as Method 5, Sections 2.2.2 through 2.2.6, and 2.2.8, respectively.

2.3 Analysis. Same as in Method 5, Section 2.3.

3. Reagents

The reagents used in sampling, sample recovery, and analysis are the same as that specified in Method 5, Sections 3.1, 3.2, and 3.3, respectively.

4. Procedure

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. Same as in Method 5, Section 4.1.1.

4.1.2 Preliminary Determinations. Same as in Method 5, Section 4.1.2, except use the directions on nozzle size selection in this section. Use of the EGR method may require a minimum sampling port diameter of 0.2 m (6 in.). Also, the required maximum number of sample traverse points at any location shall be 12.

4.1.2.1 The cyclone and filter holder must be in-stack or at stack temperature during sampling. The blockage effects of the EGR sampling assembly will be minimal if the cross-sectional area of the sampling assembly is 3 percent or less of the cross-sectional area of the duct and a pitot coefficient of 0.84 may be assigned to the pitot. If the cross-sectional area of the assembly is greater than 3 percent of the cross-sectional area of the duct, then either determine the pitot coefficient at sampling conditions or use a standard pitot with a known coefficient in a configuration with the EGR sampling assembly such that flow disturbances are minimized.

4.1.2.2 Construct a setup sheet of pressure drops for various Δp 's and temperatures. A computer is useful for these calculations. An example of the output of the EGR setup program is shown in Figure 6, and directions on its use are in Section 4.1.5.2. Computer programs, written in IBM BASIC computer language, to do these types of setup and reduction calculations for the EGR procedure, are available through the National Technical Information Services (NTIS), Accession number PB90-500000, 5285 Port Royal Road, Springfield, Virginia 22161.

4.1.2.3 The EGR setup program allows the tester to select the nozzle size based on anticipated average stack conditions and prints a setup sheet for field use. The amount of recycle through the nozzle should be between 10 and 80 percent. Inputs for the EGR setup program are stack temperature (minimum, maximum, and average), stack velocity (minimum, maximum, and average), atmospheric pressure, stack static pressure, meter box temperature, stack moisture, percent O_2 and percent CO_2 in the stack gas, pitot coefficient (C_p), orifice ΔH_0 , flow rate measurement calibration values [slope (m) and y-intercept (b) of the calibration curve], and the number of nozzles available and their diameters.

4.1.2.4 A less rigorous calculation for the setup sheet can be done manually using the equations on the example worksheets in Figures 7, 8, and 9, or by a Hewlett-Packard HP41 calculator using the program provided in Appendix D of the EGR operators manual, entitled Applications Guide for Source PM_{10} Exhaust Gas Recycle Sampling System. This calculation uses an approximation of the total flow rate and agrees within 1 percent of the exact solution for pressure drops at stack temperatures from 38 to 260°C (100 to 500°F) and stack moisture up to 50 percent. Also, the example worksheets use

a constant stack temperature in the calculations, ignoring the complicated temperature dependence from all three pressure drop equations. Errors for this at stack temperatures $\pm 28^{\circ}\text{C}$ ($\pm 50^{\circ}\text{F}$) of the temperature used in the setup calculations are within 5 percent for flow rate and within 5 percent for cyclone cut size.

4.1.2.5 The pressure upstream of the LFE's is assumed to be constant at 0.6 in. Hg in the EGR setup calculations.

4.1.2.6 The setup sheet constructed using this procedure shall be similar to Figure 6. Inputs needed for the calculation are the same as for the setup computer except that stack velocities are not needed.

4.1.3 Preparation of Collection Train. Same as in Method 5, Section 4.1.3, except use the following directions to set up the train.

4.1.3.1 Assemble the EGR sampling device, and attach it to probe as shown in Figure 3. If stack temperatures exceed 260°C (500°F), then assemble the EGR cyclone without the O-ring and reduce the vacuum requirement to 130 mm Hg (5.0 in. Hg) in the leak-check procedure in Section 4.1.4.3.2.

4.1.3.2 Connect the probe directly to the filter holder and condenser as in Method 5. Connect the condenser and probe to the meter and flow control console with the umbilical connector. Plug in the pump and attach pump lines to the meter and flow control console.

4.1.4 Leak-Check Procedure. The leak-check for the EGR Method consists of two parts: the sample-side and the recycle-side. The sample-side leak-check is required at the beginning of the run with the cyclone attached, and after the run with the cyclone removed. The cyclone is removed before the post-test leak-check to prevent any disturbance of the collected sample prior to analysis. The recycle-side leak-check tests the leak tight integrity of

the recycle components and is required prior to the first test run and after each shipment.

4.1.4.1 Pretest Leak-Check. A pretest leak-check of the entire sample-side, including the cyclone and nozzle, is required. Use the leak-check procedure in Section 4.1.4.3 to conduct a pretest leak-check.

4.1.4.2 Leak-Checks During Sample Run. Same as in Method 5, Section 4.1.4.1.

4.1.4.3 Post-Test Leak-Check. A leak-check is required at the conclusion of each sampling run. Remove the cyclone before the leak-check to prevent the vacuum created by the cooling of the probe from disturbing the collected sample and use the following procedure to conduct a post-test leak-check.

4.1.4.3.1 The sample-side leak-check is performed as follows: After removing the cyclone, seal the probe with a leak-tight stopper. Before starting pump, close the coarse total valve and both recycle valves, and open completely the sample back pressure valve and the fine total valve. After turning the pump on, partially open the coarse total valve slowly to prevent a surge in the manometer. Adjust the vacuum to at least 381 mm Hg (15.0 in. Hg) with the fine total valve. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak-check as shown below and start over. CAUTION: Do not decrease the vacuum with any of the valves. This may cause a rupture of the filter. NOTE: A lower vacuum may be used, provided that it is not exceeded during the test.

4.1.4.3.2 Leak rates in excess of $0.00057 \text{ m}^3/\text{min}$ ($0.020 \text{ ft}^3/\text{min}$) are unacceptable. If the leak rate is too high, void the sampling run.

4.1.4.3.3 To complete the leak-check, slowly remove the stopper from the nozzle until the vacuum is near zero, then immediately turn off the pump. This procedure sequence prevents a pressure surge in the manometer fluid and rupture of the filter.

4.1.4.3.4 The recycle-side leak-check is performed as follows: Close the coarse and fine total valves and sample back pressure valve. Plug the sample inlet at the meter box. Turn on the power and the pump, close the recycle valves, and open the total flow valves. Adjust the total flow fine adjust valve until a vacuum of 25 inches of mercury is achieved. If the desired vacuum is exceeded, either leak-check at this higher vacuum, or end the leak-check and start over. Minimum acceptable leak rates are the same as for the sample-side. If the leak rate is too high, void the sampling run.

4.1.5 EGR Train Operation. Same as in Method 5, Section 4.1.5, except omit references to nomographs and recommendations about changing the filter assembly during a run.

4.1.5.1 Record the data required on a data sheet such as the one shown in Figure 10. Make periodic checks of the manometer level and zero to ensure correct ΔH and Δp values. An acceptable procedure for checking the zero is to equalize the pressure at both ends of the manometer by pulling off the tubing, allowing the fluid to equilibrate and, if necessary, to re-zero. Maintain the probe temperature to within 11°C (20°F) of stack temperature.

4.1.5.2 The procedure for using the example EGR setup sheet is as follows: Obtain a stack velocity reading from the pitot manometer (Δp), and find this value on the ordinate axis of the setup sheet. Find the stack temperature on the abscissa. Where these two values intersect are the

differential pressures necessary to achieve isokineticity and 10 μm cut size (interpolation may be necessary).

4.1.5.3 The top three numbers are differential pressures (in. H_2O), and the bottom number is the percent recycle at these flow settings. Adjust the total flow rate valves, coarse and fine, to the sample value (ΔH) on the setup sheet, and the recycle flow rate valves, coarse and fine, to the recycle flow on the setup sheet.

4.1.5.4 For startup of the EGR sample train, the following procedure is recommended. Preheat the cyclone in the stack for 30 minutes. Close both the sample and recycle coarse valves. Open the fine total, fine recycle, and sample back pressure valves halfway. Ensure that the nozzle is properly aligned with the sample stream. After noting the Δp and stack temperature, select the appropriate ΔH and recycle from the EGR setup sheet. Start the pump and timing device simultaneously. Immediately open both the coarse total and the coarse recycle valves slowly to obtain the approximate desired values. Adjust both the fine total and the fine recycle valves to achieve more precisely the desired values. In the EGR flow system, adjustment of either valve will result in a change in both total and recycle flow rates, and a slight iteration between the total and recycle valves may be necessary. Because the sample back pressure valve controls the total flow rate through the system, it may be necessary to adjust this valve in order to obtain the correct flow rate. NOTE: Isokinetic sampling and proper operation of the cyclone are not achieved unless the correct ΔH and recycle flow rates are maintained.

4.1.5.5 During the test run, monitor the probe and filter temperatures periodically, and make adjustments as necessary to maintain the desired

temperatures. If the sample loading is high, the filter may begin to blind or the cyclone may clog. The filter or the cyclone may be replaced during the sample run. Before changing the filter or cyclone, conduct a leak-check (Section 4.1.4.2). The total particulate mass shall be the sum of all cyclone and the filter catch during the run. Monitor stack temperature and Δp periodically, and make the necessary adjustments in sampling and recycle flow rates to maintain isokinetic sampling and the proper flow rate through the cyclone. At the end of the run, turn off the pump, close the coarse total valve, and record the final dry gas meter reading. Remove the probe from the stack, and conduct a post-test leak-check as outlined in Section 4.1.4.3.

4.1.6 Calculation of Percent Isokinetic Rate and Aerodynamic Cut Size. Calculate percent isokinetic rate and the aerodynamic cut size (D_{50}) (see Calculations, Section 6) to determine whether the test was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates or a D_{50} of $10 \mu m$ because of source conditions, the Administrator may be consulted for possible variance.

4.2 Sample Recovery. Allow the probe to cool. When the probe can be safely handled, wipe off all external PM adhering to the outside of the nozzle, cyclone, and nozzle attachment, and place a cap over the nozzle to prevent losing or gaining PM. Do not cap the nozzle tip tightly while the sampling train is cooling, as this action would create a vacuum in the filter holder. Disconnect the probe from the umbilical connector, and take the probe to the cleanup site. Sample recovery should be conducted in a dry indoor area or, if outside, in an area protected from wind and free of dust. Cap the ends of the impingers and carry them to the cleanup site. Inspect the components of the train prior to and during disassembly to note any abnormal conditions.

Disconnect the pitot from the cyclone. Remove the cyclone from the probe.

Recover the sample as follows:

4.2.1 Container Number 1 (Filter). The recovery shall be the same as that for Container Number 1 in Method 5, Section 4.2.

4.2.2 Container Number 2 (Cyclone or Large PM Catch). The cyclone must be disassembled and the nozzle removed in order to recover the large PM catch. Quantitatively recover the PM from the interior surfaces of the nozzle and the cyclone, excluding the "turn around" cup and the interior surfaces of the exit tube. The recovery shall be the same as that for Container Number 2 in Method 5, Section 4.2.

4.2.3 Container Number 3 (PM₁₀) Quantitatively recover the PM from all of the surfaces from cyclone exit to the front half of the in-stack filter holder, including the "turn around" cup and the interior of the exit tube. The recovery shall be the same as that for Container Number 2 in Method 5, Section 4.2.

4.2.4 Container Number 4 (Silica Gel). Same as that for Container Number 3 in Method 5, Section 4.2.

4.2.5 Impinger Water. Same as in Method 5, Section 4.2, under "Impinger Water."

4.3 Analysis. Same as in Method 5, Section 4.3, except handle EGR Container Numbers 1 and 2 like Container Number 1 in Method 5, EGR Container Numbers 3, 4, and 5 like Container Number 3 in Method 5, and EGR Container Number 6 like Container Number 3 in Method 5. Use Figure 11 to record the weights of PM collected.

4.4 Quality Control Procedures. Same as in Method 5, Section 4.4.

5. Calibration

Maintain an accurate laboratory log of all calibrations.

5.1 Probe Nozzle. Same as in Method 5, Section 5.1.

5.2 Pitot Tube. Same as in Method 5, Section 5.2.

5.3 Meter and Flow Control Console.

5.3.1 Dry Gas Meter. Same as in Method 5, Section 5.3.

5.3.2 LFE Gauges. Calibrate the recycle, total, and inlet total LFE gauges with a manometer. Read and record flow rates at 10, 50, and 90 percent of full scale on the total and recycle pressure gauges. Read and record flow rates at 10, 20, and 30 percent of full scale on the inlet total LFE pressure gauge. Record the total and recycle readings to the nearest 0.3 mm (0.01 in.). Record the inlet total LFE readings to the nearest 3 mm (0.1 in.). Make three separate measurements at each setting and calculate the average. The maximum difference between the average pressure reading and the average manometer reading shall not exceed 1 mm (0.05 in.). If the differences exceed the limit specified, adjust or replace the pressure gauge. After each field use, check the calibration of the pressure gauges.

5.3.3 Total LFE. Same as the metering system in Method 5, Section 5.3.

5.3.4 Recycle LFE. Same as the metering system in Method 5, Section 5.3, except completely close both the coarse and fine recycle valves.

5.4 Probe Heater. Connect the probe to the meter and flow control console with the umbilical connector. Insert a thermocouple into the probe sample line approximately half the length of the probe sample line. Calibrate the probe heater at 66°C (150°F), 121°C (250°F), and 177°C (350°F). Turn on the power, and set the probe heater to the specified temperature. Allow the heater to equilibrate, and record the thermocouple temperature and the meter

and flow control console temperature to the nearest 0.5°C (1°F). The two temperatures should agree within 5.5°C (10°F). If this agreement is not met, adjust or replace the probe heater controller.

5.5 Temperature Gauges. Connect all thermocouples, and let the meter and flow control console equilibrate to ambient temperature. All thermocouples shall agree to within 1.1°C (2.0°F) with a standard mercury-in-glass thermometer. Replace defective thermocouples.

5.6 Barometer. Calibrate against a standard mercury-in-glass barometer.

5.7 Probe Cyclone and Nozzle Combinations. The probe cyclone and nozzle combinations need not be calibrated if the cyclone meets the design specifications in Figure 12 and the nozzle meets the design specifications in Appendix B of the Application Guide for the Source PM₁₀ Exhaust Gas Recycle Sampling System, EPA/600/3-88-058. This document may be obtained from Roy Huntley at (919)541-1060. If the nozzles do not meet the design specifications, then test the cyclone and nozzle combination for conformity with the performance specifications (PS's) in Table 1. The purpose of the PS tests is to determine if the cyclone's sharpness of cut meets minimum performance criteria. If the cyclone does not meet design specifications, then, in addition to the cyclone and nozzle combination conforming to the PS's, calibrate the cyclone and determine the relationship between flow rate, gas viscosity, and gas density. Use the procedures in Section 5.7.5 to conduct PS tests and the procedures in Section 5.8 to calibrate the cyclone. Conduct the PS tests in a wind tunnel described in Section 5.7.1 and using a particle generation system described in Section 5.7.2. Use five particle sizes and three wind velocities as listed in Table 2. Perform a minimum of

three replicate measurements of collection efficiency for each of the 15 conditions listed, for a minimum of 45 measurements.

5.7.1 Wind Tunnel. Perform calibration and PS tests in a wind tunnel (or equivalent test apparatus) capable of establishing and maintaining the required gas stream velocities within 10 percent.

5.7.2 Particle Generation System. The particle generation system shall be capable of producing solid monodispersed dye particles with the mass median aerodynamic diameters specified in Table 2. The particle size distribution verification should be performed on an integrated sample obtained during the sampling period of each test. An acceptable alternative is to verify the size distribution of samples obtained before and after each test, with both samples required to meet the diameter and monodispersity requirements for an acceptable test run.

5.7.2.1 Establish the size of the solid dye particles delivered to the test section of the wind tunnel using the operating parameters of the particle generation system, and verify the size during the tests by microscopic examination of samples of the particles collected on a membrane filter. The particle size, as established by the operating parameters of the generation system, shall be within the tolerance specified in Table 2. The precision of the particle size verification technique shall be at least $\pm 0.5 \mu\text{m}$, and the particle size determined by the verification technique shall not differ by more than 10 percent from that established by the operating parameters of the particle generation system.

5.7.2.2 Certify the monodispersity of the particles for each test either by microscopic inspection of collected particles on filters or by other suitable monitoring techniques such as an optical particle counter followed by

a multichannel pulse height analyzer. If the proportion of multiplets and satellites in an aerosol exceeds 10 percent by mass, the particle generation system is unacceptable for purposes of this test. Multiplets are particles that are agglomerated, and satellites are particles that are smaller than the specified size range.

5.7.3 Schematic Drawings. Schematic drawings of the wind tunnel and blower system and other information showing complete procedural details of the test atmosphere generation, verification, and delivery techniques shall be furnished with calibration data to the reviewing agency.

5.7.4 Flow Rate Measurement. Determine the cyclone flow rates with a dry gas meter and a stopwatch, or a calibrated orifice system capable of measuring flow rates to within 2 percent.

5.7.5 Performance Specification Procedure. Establish the test particle generator operation and verify the particle size microscopically. If monodispersity is to be verified by measurements at the beginning and the end of the run rather than by an integrated sample, these measurements may be made at this time.

5.7.5.1 The cyclone cut size (D_{50}) is defined as the aerodynamic diameter of a particle having a 50 percent probability of penetration. Determine the required cyclone flow rate at which D_{50} is 10 μm . A suggested procedure is to vary the cyclone flow rate while keeping a constant particle size of 10 μm . Measure the PM collected in the cyclone (m_c), exit tube (m_t), and filter (m_f). Compute the cyclone efficiency (E_c) as follows:

$$E_c = \frac{m_c}{(m_c + m_t + m_f)} \times 100$$

5.7.5.2 Perform three replicates and calculate the average cyclone efficiency as follow:

$$E_{avg} = \frac{(E_1 + E_2 + E_3)}{3}$$

where E_1 , E_2 , and E_3 are replicate measurements of E_o .

5.7.5.3 Calculate the standard deviation (σ) for the replicate measurements of E_c as follows:

$$\sigma = \left[\frac{(E_1^2 + E_2^2 + E_3^2) - \frac{(E_1 + E_2 + E_3)^2}{3}}{2} \right]^{1/2}$$

if σ exceeds 0.10, repeat the replicate runs.

5.7.5.4 Using the cyclone flow rate that produces D_{50} for 10 μm , measure the overall efficiency of the cyclone and nozzle, E_o , at the particle sizes and nominal gas velocities in Table 2 using the following procedure.

5.7.5.5 Set the air velocity in the wind tunnel to one of the nominal gas velocities from Table 2. Establish isokinetic sampling conditions and the correct flow rate through the sampler (cyclone and nozzle) using recycle capacity so that the D_{50} is 10 μm . Sample long enough to obtain ± 5 percent precision on the total collected mass as determined by the precision and the sensitivity of the measuring technique. Determine separately the nozzle catch (m_n), cyclone catch (m_c), cyclone exit tube catch (m_t), and collection filter catch (m_f).

5.7.5.6 Calculate the overall efficiency (E_o) as follows:

$$E_o = \frac{(m_n + m_c)}{(m_n + m_c + m_t + m_f)} \times 100$$

5.7.5.7 Do three replicates for each combination of gas velocities and particle sizes in Table 2. Calculate E_0 for each particle size following the procedures described in this section for determining efficiency. Calculate the standard deviation (σ) for the replicate measurements. If σ exceeds 0.10, repeat the replicate runs.

5.7.6 Criteria for Acceptance. For each of the three gas stream velocities, plot the average E_0 as a function of particle size on Figure 13. Draw a smooth curve for each velocity through all particle sizes. The curve shall be within the banded region for all sizes, and the average E_c for a D_{50} for 10 μm shall be 50 ± 0.5 percent.

5.8 Cyclone Calibration Procedure. The purpose of this section is to develop the relationship between flow rate, gas viscosity, gas density, and D_{50} . This procedure only needs to be done on those cyclones that do not meet the design specifications in Figure 12.

5.8.1 Calculate cyclone flow rate. Determine the flow rates and D_{r0} 's for three different particle sizes between 5 μm and 15 μm , one of which shall be 10 μm . All sizes must be within 0.5 μm . For each size, use a different temperature within 60°C (108°F) of the temperature at which the cyclone is to be used and conduct triplicate runs. A suggested procedure is to keep the particle size constant and vary the flow rate. Some of the values obtained in the PS tests in Section 5.7.5 may be used.

5.8.1.1 On log-log graph paper, plot the Reynolds number (Re) on the abscissa, and the square root of the Stokes 50 number $[(STK_{50})^{1/2}]$ on the ordinate for each temperature. Use the following equations:

$$Re = \frac{4 \rho Q_{cyc}}{d_{-yc} \pi \mu_{cyc}}$$

$$(Stk_{50})^{1/2} = \left[\frac{4 Q_{cyc} (D_{50})^2}{9 \pi \mu_{cyc} (d_{cyc})^3} \right]^{1/2}$$

where:

Q_{cyc} = Cyclone flow rate cm^3/sec .

ρ = Gas density, g/cm^3 .

d_{cyc} = Diameter of cyclone inlet, cm .

μ_{cyc} = Viscosity of gas through the cyclone, poise.

D_{50} = Cyclone cut size, cm .

5.8.1.2 Use a linear regression analysis to determine the slope (m), and the y-intercept (b). Use the following formula to determine Q, the cyclone flow rate required for a cut size of $10 \mu\text{m}$.

$$Q = \frac{\pi \mu_{cyc}}{4} \left[(3000) (K_1)^b \right]^{-(0.5 - m)} \left[\frac{T_s}{M_c P_c} \right]^{m/(m - 0.5)} d^{(m-1.5)/(m-0.5)}$$

where:

Q = Cyclone flow rate for a cut size of $10 \mu\text{m}$, cm^3/sec .

T_s = Stack gas temperature, $^{\circ}\text{K}$.

d = Diameter of nozzle, cm .

$K_1 = 4.077 \times 10^{-3}$

5.8.2 Directions for Using Q. Refer to Section 5 of the EGR operators manual for directions in using this expression for Q in the setup calculations.

6. Calculations

6.1 The EGR data reduction calculations are performed by the EGR reduction computer program, which is written in IBM BASIC computer language and is available through NTIS. Accession number PB90-500000, 5295 Port Royal

Road, Springfield, Virginia 22161. Examples of program inputs and outputs are shown in Figure 14.

6.1.1 Calculations can also be done manually, as specified in Method 5, Sections 6.3 through 6.7, and 6.9 through 6.12, with the addition of the following:

6.1.2 Nomenclature.

B_c = Moisture fraction of mixed cyclone gas, by volume,
dimensionless.

C_1 = Viscosity constant, 51.12 micropoise for $^{\circ}\text{K}$ (51.05 micropoise for $^{\circ}\text{R}$).

C_2 = Viscosity constant, 0.372 micropoise/ $^{\circ}\text{K}$ (0.207 micropoise/ $^{\circ}\text{R}$).

C_3 = Viscosity constant, 1.05×10^{-4} micropoise/ $^{\circ}\text{K}^2$ (3.24×10^{-5} micropoise/ $^{\circ}\text{R}^2$).

C_4 = Viscosity constant, 53.147 micropoise/fraction O_2 .

C_5 = Viscosity constant, 74.143 micropoise/fraction H_2O .

D_{50} = Diameter of particles having a 50 percent probability of penetration, μm .

f_{O_2} = Stack gas fraction O_2 , by volume, dry basis.

K_1 = 0.3858 $^{\circ}\text{K}/\text{mm Hg}$ (17.64 $^{\circ}\text{R}/\text{in. Hg}$).

M_c = Wet molecular weight of mixed gas through the PM_{10} cyclone, g/g-mole (lb/lb-mole).

M_d = Dry molecular weight of stack gas, g/g-mole (lb/lb-mole).

P_{bar} = Barometer pressure at sampling site, mm Hg (in. Hg).

P_{inl} = Gauge pressure at inlet to total LFE, mm H_2O (in. H_2O).

P_s = Absolute stack pressure, mm Hg (in. Hg).

- Q_s = Total cyclone flow rate at wet cyclone conditions, m^3/min (ft^3/min).
- $Q_{s(std)}$ = Total cyclone flow rate at standard conditions, $dscm/min$ ($dscf/min$).
- T_m = Average temperature of dry gas meter, $^{\circ}K$ ($^{\circ}R$).
- T_s = Average stack gas temperature, $^{\circ}K$ ($^{\circ}R$).
- $V_{w(std)}$ = Volume of water vapor in gas sample (standard conditions), scm (scf).
- X_T = Total LFE linear calibration constant, $m^3/[(min)(mm\ H_2O)]$ ($ft^3/[(min)(in.\ H_2O)]$).
- Y_T = Total LFE linear calibration constant, $dscm/min$ ($dscf/min$).
- ΔP_T = Pressure differential across total LFE, $mm\ H_2O$ ($in.\ H_2O$).
- θ = Total sampling time, min .
- μ_{cyc} = Viscosity of mixed cyclone gas, micropoise.
- μ_{LFE} = Viscosity of gas at laminar flow elements, micropoise.
- μ_{std} = Viscosity of standard air, 180.1 micropoise.

6.2 PM_{10} Particulate Weight. Determine the weight of PM_{10} by summing the weights obtained from Container Numbers 1 and 3, less the acetone blank.

6.3 Total Particulate Weight. Determine the particulate catch for PM greater than PM_{10} from the weight obtained from Container Number 2 less the acetone blank, and add it to the PM_{10} particulate weight.

6.4 PM_{10} Fraction. Determine the PM_{10} fraction of the total particulate weight by dividing the PM_{10} particulate weight by the total particulate weight.

6.5 Total Cyclone Flow Rate. The average flow rate at standard conditions is determined from the average pressure drop across the total LFE and is calculated as follows:

$$Q_{s(std)} = K_1 \left[X_T \Delta P \frac{\mu_{std}}{\mu_{LFE}} + Y_T \right] \frac{P_{bar} + P_{inl}/13.6}{T_m}$$

The flow rate, at actual cyclone conditions, is calculated as follows:

$$Q_s = \frac{T_s}{K_1 P_s} \left[Q_{s(std)} + \frac{V_{m(std)}}{\theta} \right]$$

6.6 Aerodynamic Cut Size. Use the following procedure to determine the aerodynamic cut size (D_{50}).

6.6.1 Determine the water fraction of the mixed gas through the cyclone by using the equation below.

$$B_c = \frac{V_{w(std)}}{Q_{s(std)} \theta + V_{w(std)}}$$

6.6.2 Calculate the cyclone gas viscosity as follows:

$$\mu_{cyc} = C_1 + C_2 T_s + C_3 T_s^2 + C_4 f_{O_2} - C_5 B_c$$

6.6.3 Calculate the molecular weight on a wet basis of the cyclone gas as follows:

$$M_c = M_d(1 - B_c) + 18.0(B_c)$$

6.6.4 If the cyclone meets the design specification in Figure 12, calculate the actual D_{50} of the cyclone for the run as follows:

$$D_{50} = \beta_1 \left[\frac{T_s}{M_c P_s} \right]^{0.2091} \left[\frac{\mu_{cyc}}{Q_s} \right]^{0.7091}$$

where $\beta_1 = 0.1562$.

6.6.5 If the cyclone does not meet the design specifications in Figure 12, then use the following equation to calculate D_{50} .

$$D_{50} = (3)(10)^b (7.376 \times 10^{-4})^m \left[\frac{M_c P_s}{T_s} \right] \left[\frac{4 Q_s}{\pi \mu_{cyc}} \right] d^{(1.5-m)}$$

where:

m = Slope of the calibration curve obtained in Section 5.8.2.

b = y-intercept of the calibration curve obtained in Section 5.8.2.

6.7 Acceptable Results. Acceptability of anisokinetic variation is the same as Method 5, Section 6.12.

6.7.1 If $9.0 \mu m \leq D_{50} \leq 11 \mu m$ and $90 \leq I \leq 110$, the results are acceptable. If D_{50} is greater than $11 \mu m$, the Administrator may accept the results. If D_{50} is less than $9.0 \mu m$, reject the results and repeat the test.

7. Bibliography

1. Same as Bibliography in Method 5.
2. McCain, J.D., J.W. Ragland, and A.D. Williamson. Recommended Methodology for the Determination of Particles Size Distributions in Ducted Sources, Final Report. Prepared for the California Air Resources Board by Southern Research Institute. May 1986.
3. Farthing, W.E., S.S. Dawes, A.D. Williamson, J.D. McCain, R.S. Martin, and J.W. Ragland. Development of Sampling Methods for Source PM-10 Emissions. Southern Research Institute for the Environmental Protection Agency. April 1989.
4. Application Guide for the Source PM₁₀ Exhaust Gas Recycle Sampling System, EPA/600/3-88-058.

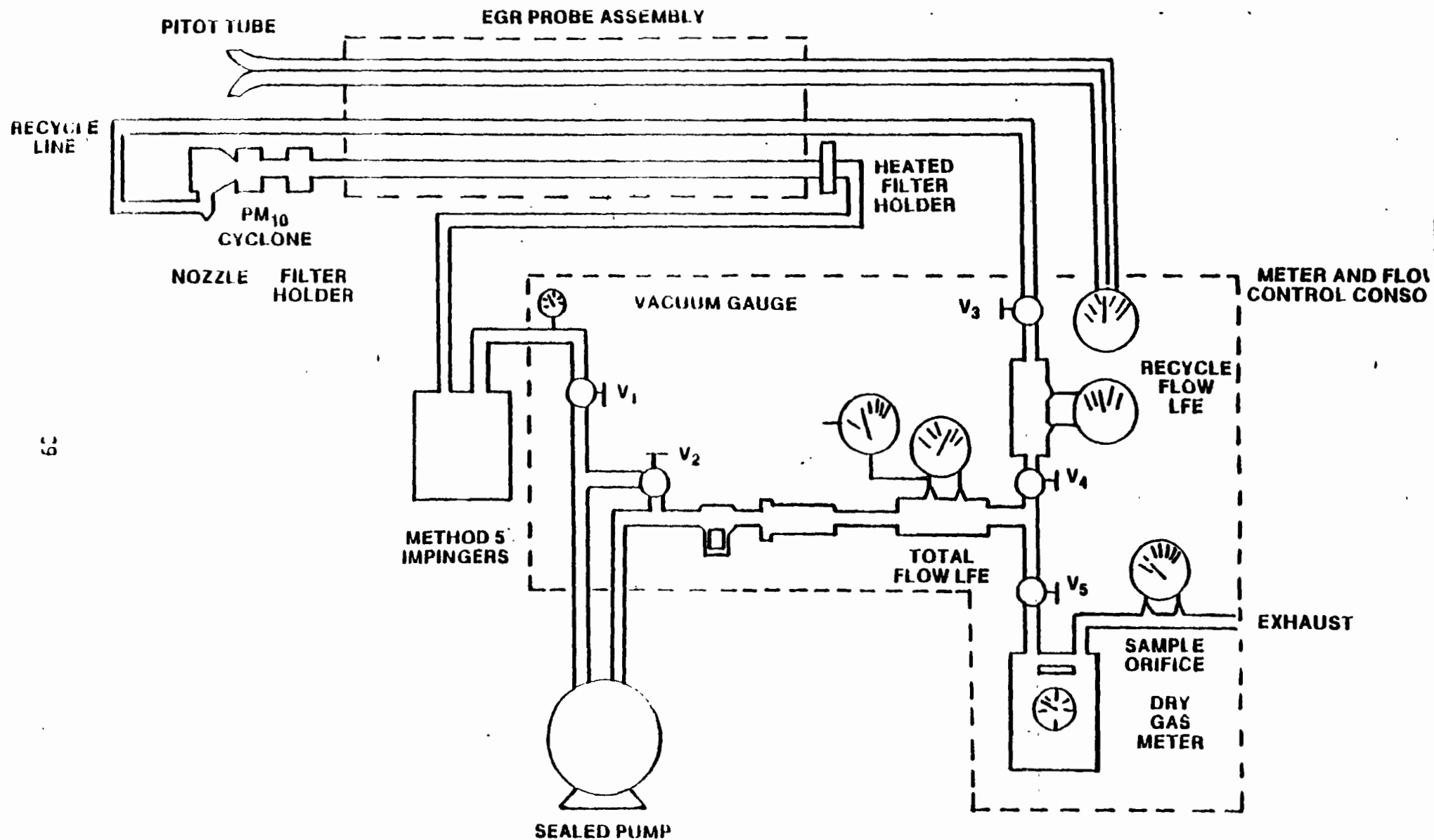


Figure 1. Schematic of the exhaust gas recycle train.

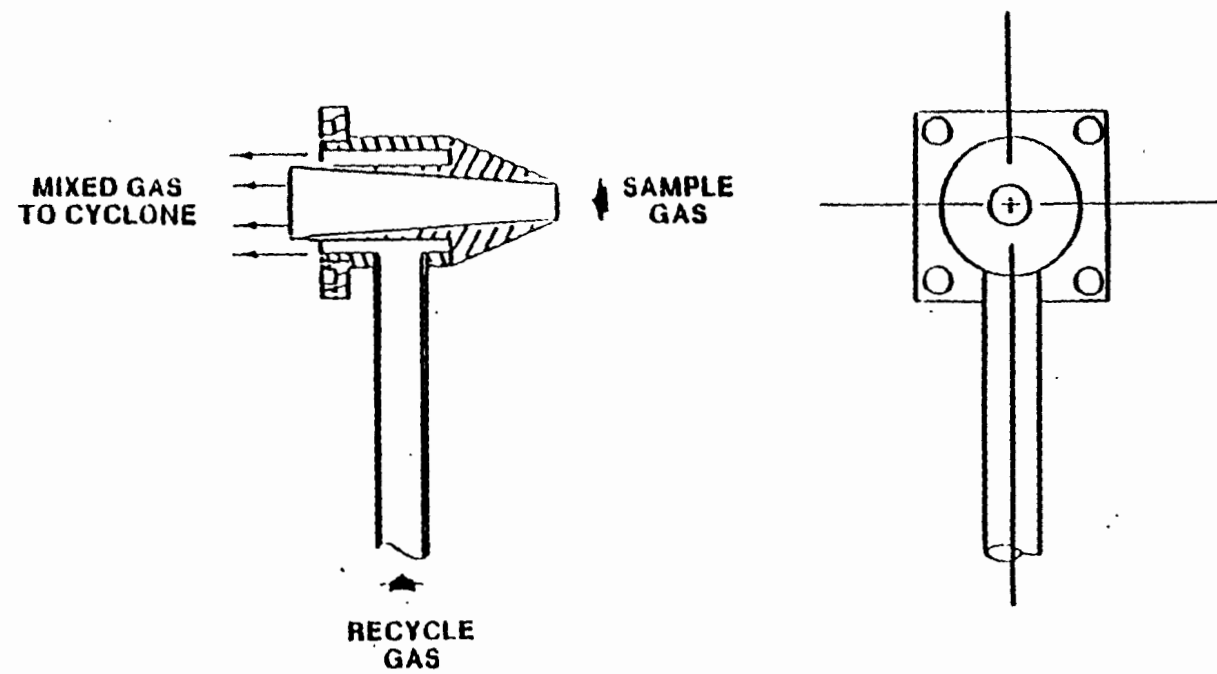


Figure 2. Schematic of EGR nozzle assembly.

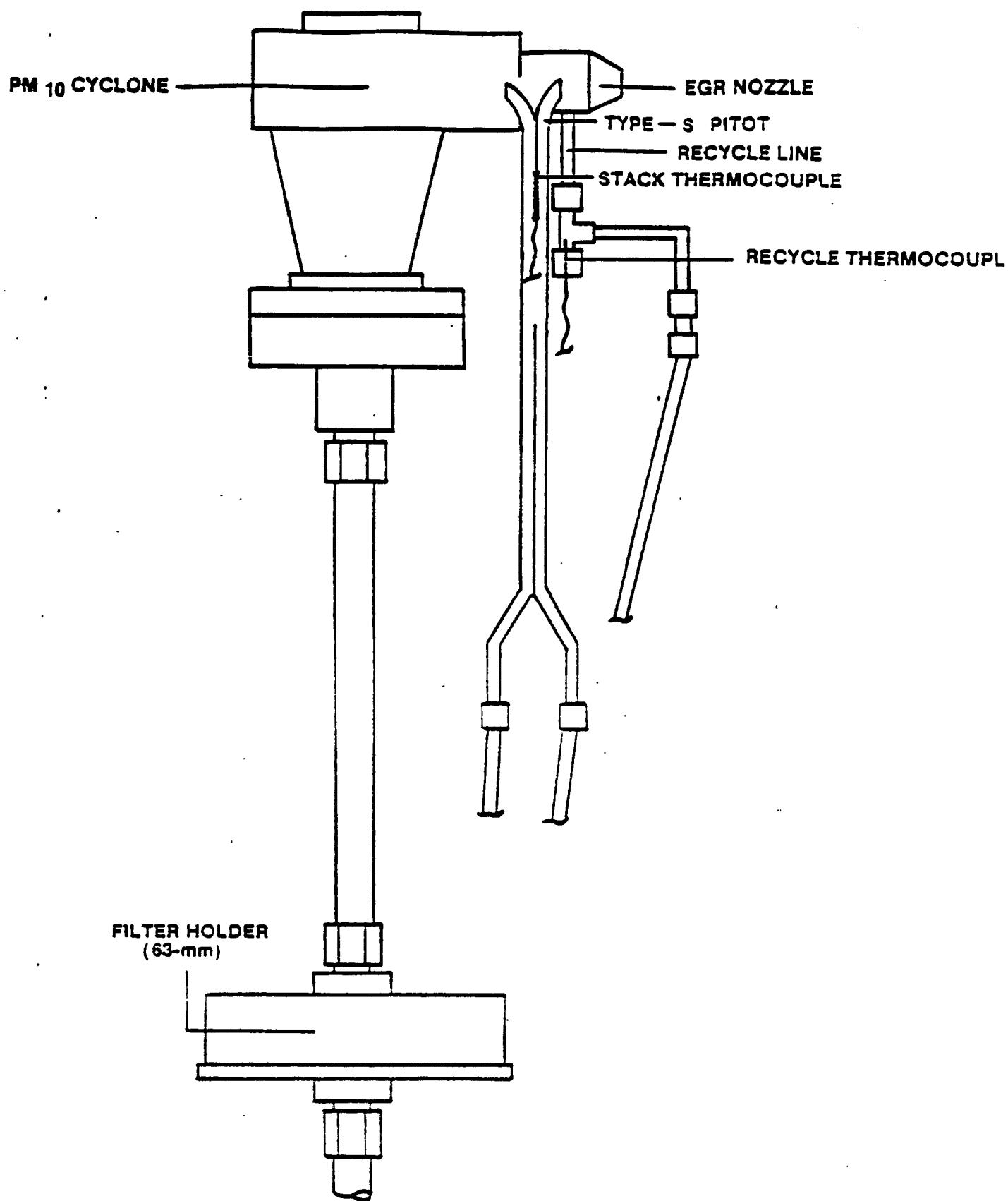


Figure 3. EGR PM₁₀ cyclone sampling device.

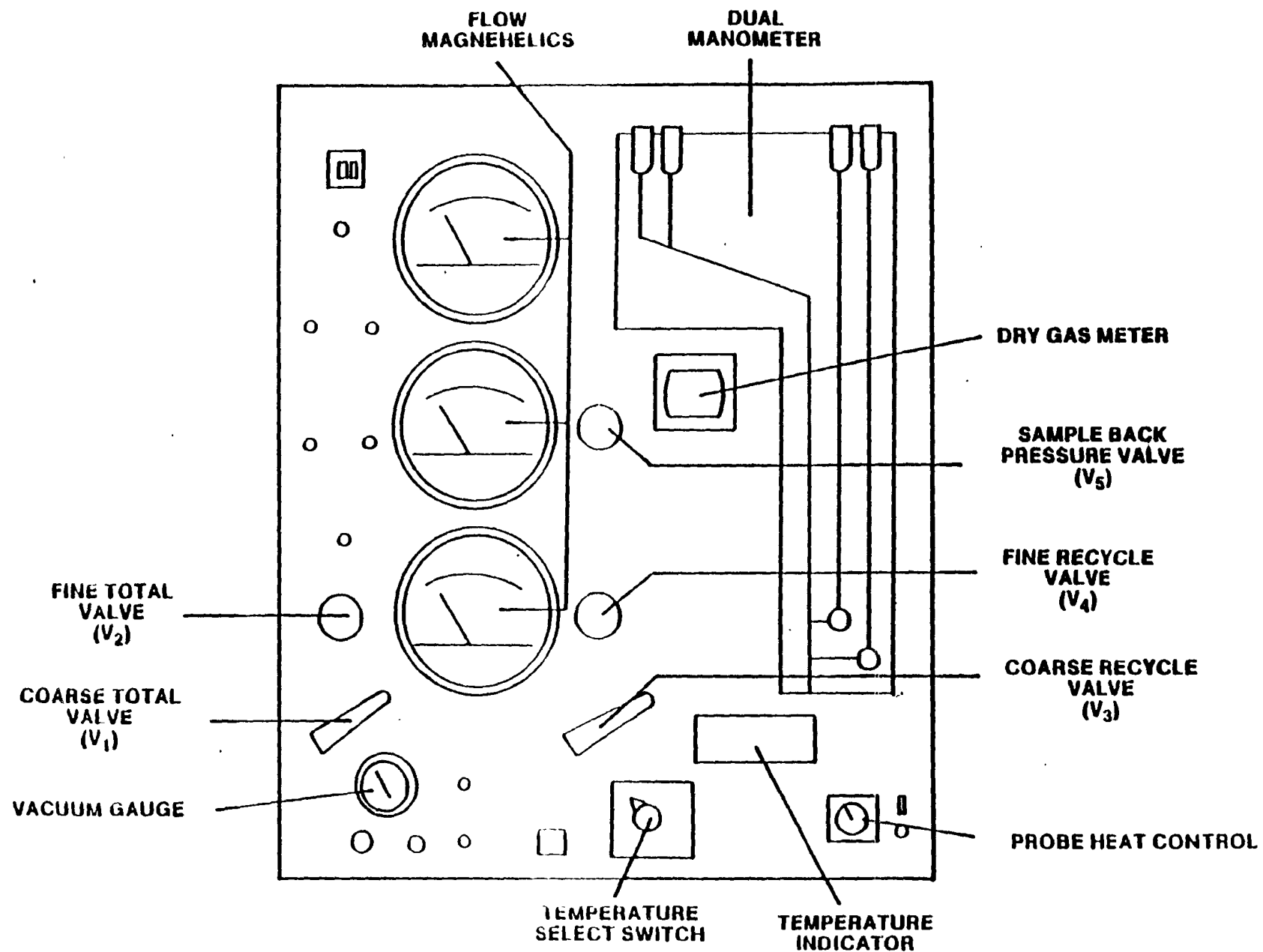


Figure 4. Example EGR control module (front view) showing principle components.

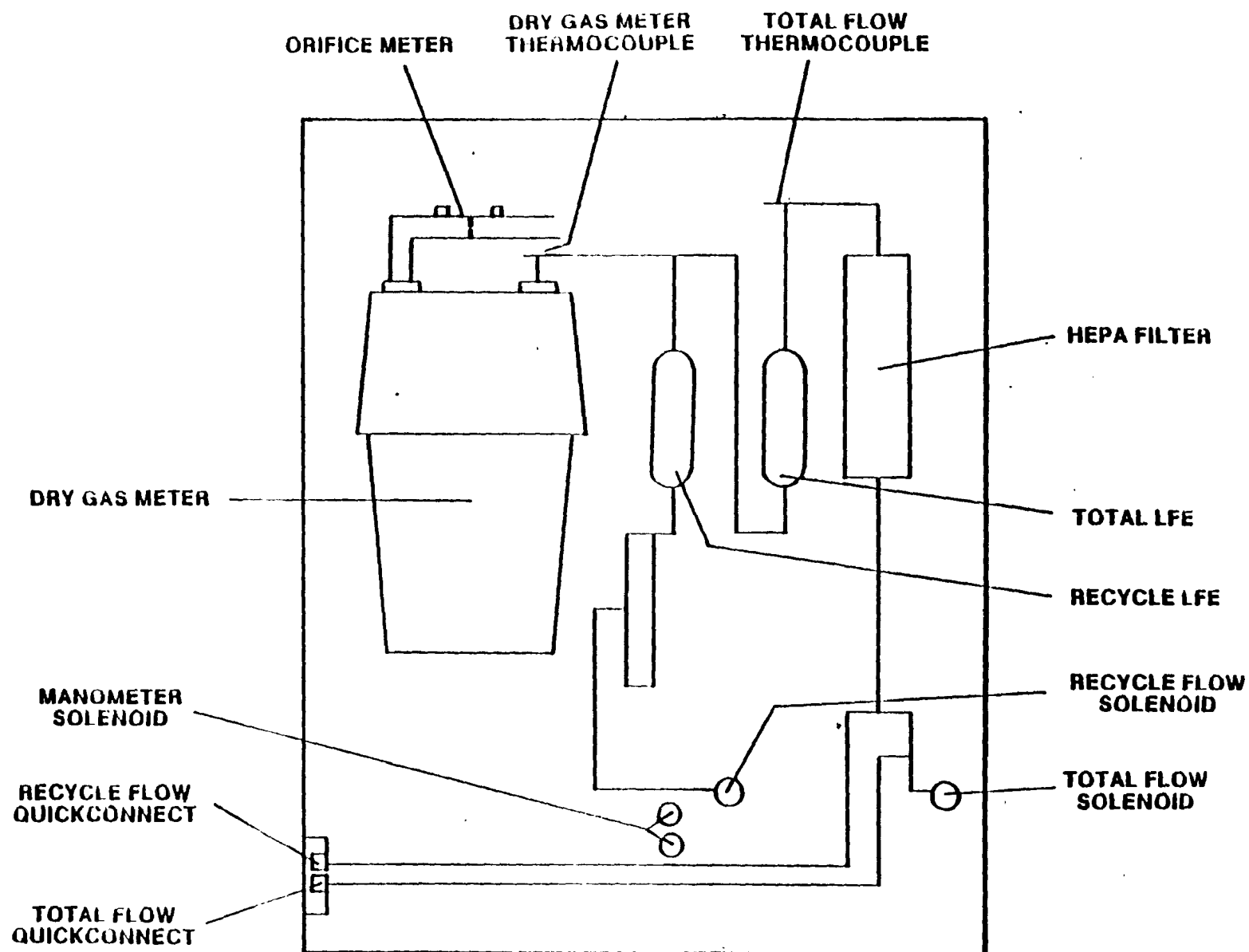


Figure 5. Example EGR control module (rear view) showing principle components.

EXAMPLE EMISSION GAS RECYCLE SETUP SHEET
VERSION 3.1 MAY 1986

TEST I.D. : SAMPLE SETUP
RUN DATE : 11/24/86
LOCATION : SOURCE SIM
OPERATOR(S) : RH JB
NOZZLE DIAMETER (IN) : .25

STACK CONDITIONS:

AVERAGE TEMPERATURE (F) : 200.0	GAS COMPOSITION	
AVERAGE VELOCITY (FT/SEC) : 15.0	H2O = 10.0 %	MD = 28.84
AMBIENT PRESSURE (IN HG) : 29.92	O2 = 20.9 %	MW = 27.75
STACK PRESSURE (IN H2O) : .10	CO2 = .0 %	(LB/LB MOLE)

**** TARGET PRESSURE DROPS ****

		TEMPERATURE (F)							
DP(PTO)		150	161	172	183	194	206	217	228
0.026	SAMPLE	.49	.49	.48	.47	.46	.45	.45	
	TOTAL	1.90	1.90	1.91	1.92	1.92	1.92	1.93	
	RECYCLE	2.89	2.92	2.94	2.97	3.00	3.02	3.05	
	% RCL	61 %	61 %	62 %	62 %	62 %	63 %	63 %	
.031		.58	.56	.55	.55	.55	.54	.53	.52
		1.88	1.89	1.89	1.90	1.91	1.91	1.91	1.92
		2.71	2.74	2.77	2.80	2.82	2.85	2.88	2.90
		57 %	57 %	58 %	58 %	59 %	59 %	60 %	60 %
.035		.67	.65	.64	.63	.62	.61	.60	.59
		1.88	1.88	1.89	1.89	1.90	1.90	1.91	1.91
		2.57	2.60	2.63	2.66	2.69	2.72	2.74	2.74
		54 %	55 %	55 %	56 %	56 %	57 %	57 %	57 %
.039		.75	.74	.72	.71	.70	.69	.67	.66
		1.87	1.88	1.88	1.89	1.89	1.90	1.90	1.91
		2.44	2.47	2.50	2.53	2.56	2.59	2.62	2.65
		51 %	52 %	52 %	53 %	53 %	54 %	54 %	55 %

Figure 6. Example EGR setup sheet.

Barometric pressure, P_{bar} , in. Hg = _____
 Stack static pressure, P_g , in. H₂O = _____
 Average stack temperature, t_s , °F = _____
 Meter temperature, t_m , °F = _____

Gas analysis:

%CO₂ = _____
 %O₂ = _____
 %N₂ + %CO = _____
 Fraction moisture content, B_{ws} = _____

Calibration data:

Nozzle diameter, D_n , in. = _____
 Pitot coefficient, C_p = _____
 ΔH_0 , in. H₂O = _____

Molecular weight of stack gas, dry basis:

$$M_d = 0.44 (\%CO_2) + 0.32 (\%O_2) + 0.28 (\%N_2 + \%CO) = \text{_____ lb/lb mole}$$

Molecular weight of stack gas, wet basis:

$$M_w = M_d (1 - B_{ws}) + 18B_{ws} = \text{_____ lb/lb mole}$$

Absolute stack pressure:

$$P_s = P_{bar} + (P_g/13.6) = \text{_____ in. Hg}$$

$$K = 346.72 D_n^{-4} \Delta H_0 C_p^2 (1 - B_{ws})^2 \frac{M_d (t_m + 460) P_s}{M_w (t_s + 460) P_{bar}} = \text{_____}$$

Desired meter orifice pressure (ΔH) for velocity head of stack gas (Δp):

$$\Delta H = K \Delta p = \text{_____ in. H}_2\text{O}$$

Figure 7. Example worksheet 1, meter orifice pressure head calculation.

Barometric pressure, P_{bar} , in. Hg = _____
 Absolute stack pressure, P_s , in. Hg = _____
 Average stack temperature, T_s , °R = _____
 Meter temperature, T_m , °R = _____
 Molecular weight of stack gas, wet basis, M_d lb/lb mole = _____
 Pressure upstream of LFE, in. Hg = 0.6

Gas analysis:

Fraction moisture content, B_{ws} = _____
 %O₂ = _____

Calibration data:

Nozzle diameter, D_n , in. = _____
 Pitot coefficient, C_p = _____
 Total LFE calibration constant, X_t = _____
 Total LFE calibration constant, T_t = _____

Absolute pressure upstream of LFE:

$$P_{LFE} = P_{bar} + 0.6 = \text{_____ in. Hg}$$

Viscosity of gas in total LFE:

$$\mu_{LFE} = 152.418 + 0.2552 T_m + 3.2355 \times 10^{-5} T_m^2 + 0.53147 (\%O_2) = \text{_____}$$

Viscosity of dry stack gas:

$$\mu_d = 152.418 + 0.2552 T_s + 3.2355 \times 10^{-5} T_s^2 + 0.53147 (\%O_2) = \text{_____}$$

Constants:

$$K_1 = 1.5752 \times 10^{-5} \frac{\mu_{LFE} T_m P_s^{0.7051} \mu_d}{P_{LFE} M_d^{0.2949} T_s^{0.7051}} = \text{_____}$$

$$K_2 = 0.1539 \frac{\mu_{LFE} T_m D_n^2 C_p}{P_{LFE}} \left[\frac{P_s}{T_s} \right]^{1/2}$$

$$K_3 = \frac{B_{ws} \mu_d [1 - 0.2949 (1 - 18/M_d)] + 74.143 B_{ws} (1 - B_{ws})}{\mu_d - 74.143 B_{ws}} = \text{_____}$$

Figure 8. Example worksheet 2 (page 1 of 2), total LFE pressure head.

$$A_1 = \frac{K_1}{X_t} - \frac{\mu_{LFE} Y_t}{180.1 X_t} = \underline{\hspace{2cm}}$$

$$B_1 = \frac{K_2 K_3}{(M_w)^{1/2} X_t} = \underline{\hspace{2cm}}$$

Total LFE pressure head:

$$\Delta p_t = A_1 - B_1 (\Delta p)^{1/2} = \underline{\hspace{2cm}} \text{ in. H}_2\text{O}$$

Figure 8. Example worksheet 2 (page 2 of 2), total LFE pressure head.

Barometric pressure, P_{bar} , in. Hg = _____
 Absolute stack pressure, P_s , in. Hg = _____
 Average stack temperature, T_s , °R = _____
 Meter temperature, T_m , °R = _____
 Molecular weight of stack gas, dry basis, M_d , lb/lb mole = _____
 Viscosity of LFE gas, μ_{LFE} , poise = _____
 Viscosity of dry stack gas, μ_d , poise = _____
 Absolute pressure upstream of LFE, P_{LFE} , in. Hg = _____

Calibration data:

Nozzle diameter, D_n , in. = _____
 Pitot coefficient, C_p = _____
 Recycle LFE calibration constant, X_r = _____
 Recycle LFE calibration constant, Y_r = _____

$$K_1 = 1.5752 \times 10^{-5} \frac{\mu_{LFE} T_m P_s^{0.7051} \mu_d}{P_{LFE} M_d^{0.2949} T_s^{0.7051}} = \underline{\hspace{2cm}}$$

$$K_2 = 0.1539 \frac{M_{LFE} T_m D_n^2 C_p}{P_{LFE}} \left[\frac{P_s}{T_s} \right]^{1/2}$$

$$K_3 = \frac{\mu_d}{M_w^{0.2051} M_d^{0.2949} (\mu_d - 74.143 B_{ws})} = \underline{\hspace{2cm}}$$

$$A_2 = \frac{K_1}{X_r} - \frac{\mu_{LFE} Y_r}{180.1 X_r} = \underline{\hspace{2cm}}$$

$$B_2 = \frac{K_4 K_2}{X_r} = \underline{\hspace{2cm}}$$

Pressure head for recycle LFE:

$$\Delta P_r = A_2 - B_2 (\Delta p)^{1/2} = \underline{\hspace{2cm}} \text{ in. H}_2\text{O}$$

Figure 9. Example worksheet 3, recycle LFE pressure head.

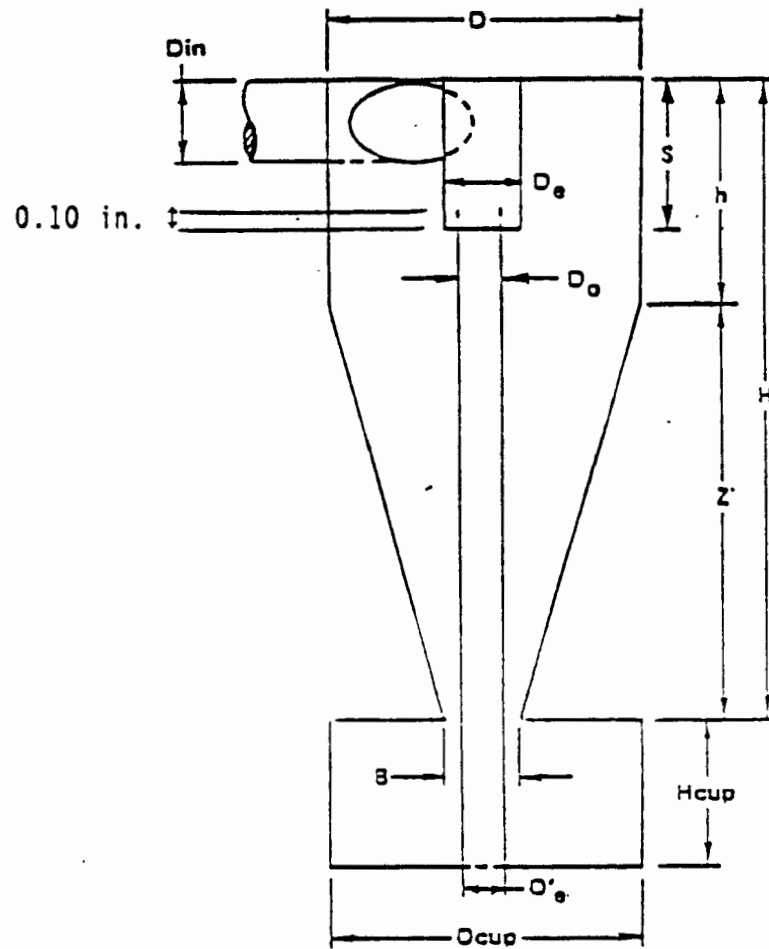
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Plant _____
 Date _____
 Run no. _____
 Filter no. _____
 Amount liquid lost during transport _____
 Acetone blank volume, ml _____
 Acetone wash volume, ml (2) _____ (3) _____
 Acetone blank conc., mg/mg (Equation 5-4, Method 5) _____
 Acetone wash blank, mg (Equation 5-5, Method 5) _____

Container number	Weight of particulate matter mg		
	Final weight	Tare weight	Weight gain
1			
3			
Total.....			
Less acetone blank.....			
Weight of PM ₁₀			
2			
Less acetone blank.....			
Total particulate weight.....			

Figure 11. EGR method analysis sheet.

Cyclone Interior Dimensions



		Dimensions (± 0.02 cm, ± 0.01 in.)										
		Din	D	De	B	H	h	Z	S	Hcup	Ocup	O'e
cm		1.27	4.47	1.50	1.88	6.95	2.24	4.71	1.57	2.25	4.45	1.02
inches		0.50	1.76	0.59	0.74	2.74	0.88	1.85	0.62	0.89	1.75	0.40
												O _o
												1.24
												0.49

Figure 12. Cyclone design specifications.

TABLE 1. PERFORMANCE SPECIFICATIONS FOR SOURCE PM₁₀ CYCLONES
AND NOZZLE COMBINATIONS

Parameter	Units	Specification
1. Collection efficiency	Percent	Such that collection efficiency falls within envelope specified by Section 5.7.6 and Figure 13.
2. Cyclone cut size (D ₅₀)	μm	10 ± 1 μm aerodynamic diameter.

TABLE 2. PARTICLE SIZES AND NOMINAL GAS VELOCITIES FOR EFFICIENCY

Particle size (μm) ^a	Target gas velocities (m/sec)		
	7 ± 1.0	15 ± 1.5	25 ± 2.5
5 ± 0.5			
7 ± 0.5			
10 ± 0.5			
14 ± 1.0			
20 ± 1.0			

(a) Mass median aerodynamic diameter.

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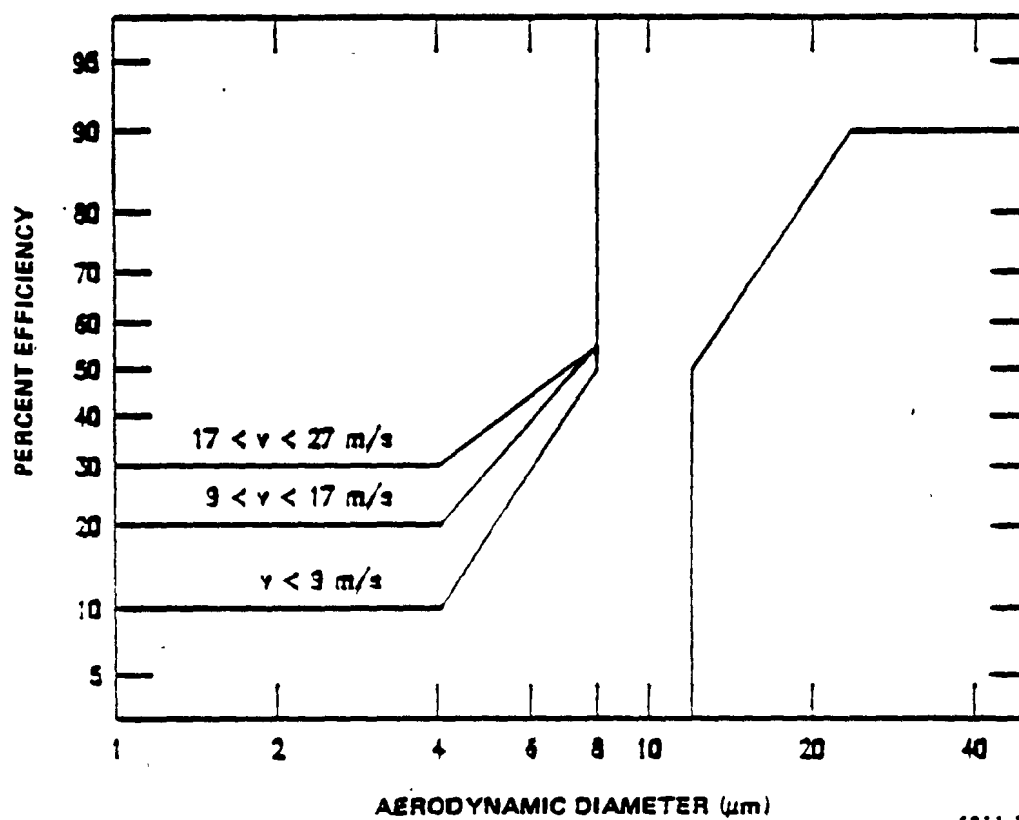


Figure 13. Efficiency envelope for the PM₁₀ cyclone.

EMISSION GAS RECYCLE
DATA REDUCTION
VERSION 3.4 MAY 1986

TEST ID. CODE: CHAPEL HILL 2
TEST LOCATION: BAGHOUSE OUTLET
TEST SITE: CHAPEL HILL
TEST DATE: 10/20/86
OPERATORS(S): JB RH MH

*****ENTERED RUN DATA*****

TEMPERATURES T(STK): 251.0 F T(RCL): 259.0 F T(LFE): 81.0 F T(DGM): 76.0 F	SYSTEM PRESSURES DH(ORI) : 1.18 INWG DP(TOT) : 1.91 INWG P(INL) : 12.15 INWG DP(RCL) : 2.21 INWG DP(PTO) : 0.06 INWG	MISCELLANEA P(BAR) : 29.99 INWG DP(STK): 0.10 INWG V(DGM) : 13.744 FT3 TIME : 60.00 MIN % CO2 : 8.00 % O2 : 20.00 NOZ (IN): 0.2500
--	---	---

WATER CONTENT ESTIMATE : 0.0 % OR CONDENSER: 7.0 ML COLUMN : 0.0 GM	RAW MASSES CYCLONE 1: 21.7 MG FILTER : 11.7 MG IMPINGER RESIDUE : 0.0 MG	BLANK VALUES CYC RINSE : 0.0 MG FILTER HOLDER RINSE : 0.0 MG FILTER BLANK : 0.0 MG IMPINGER RINSE : 0.0 MG
---	--	--

CALIBRATION VALUES
CP(PITOT) : 0.840
DH0(ORI) : 10.980
M(TOT LFE) : 0.2298
B(TOT LFE) : -.0058
M(RCL LFE) : 0.0948
B(RCL LFE) : -.0007
DGM GAMMA : 0.9940

***** REDUCED DATA *****

STACK VELOCITY (FT/SEC)	15.95
STACK GAS MOISTURE (%)	2.4
SAMPLE FLOW RATE (ACFM)	0.3104
TOTAL FLOW RATE (ACFM)	0.5819
RECYCLE FLOW RATE (ACFM)	0.2760
PERCENT RECYCLE	46.7
ISOKINETIC RATIO (%)	95.1

	(UM)	(% <)	(MG/DNCM)	(GR/ACF)	(GR/DCF)	(LB/DSCF)
	(PARTICULATE)					(X 1E6)
CYCLONE 1	10.15	35.8	56.6	0.01794	0.02470	3.53701
BACKUP FILTER	---	---	30.5	0.00968	0.01332	1.907
PARTICULATE TOTAL	---	---	87.2	0.02762	0.03802	5.444

Figure 14. Example inputs and outputs of the EGR reduction program.

METHOD 201A - DETERMINATION OF PM₁₀ EMISSIONS
(Constant Sampling Rate Procedure)

1. Applicability and Principle

1.1 Applicability. This method applies to the in-stack measurement of particulate matter (PM) emissions equal to or less than an aerodynamic diameter of nominally 10 μm (PM₁₀) from stationary sources. The EPA recognizes that condensible emissions not collected by an in-stack method are also PM₁₀, and that emissions that contribute to ambient PM₁₀ levels are the sum of condensible emissions and emissions measured by an in-stack PM₁₀ method, such as this method or Method 201. Therefore, for establishing source contributions to ambient levels of PM₁₀, such as for emission inventory purposes, EPA suggests that source PM₁₀ measurement include both in-stack PM₁₀ and condensible emissions. Condensible emissions may be measured by an impinger analysis in combination with this method.

1.2 Principle. A gas sample is extracted at a constant flow rate through an in-stack sizing device, which separates PM greater than PM₁₀. Variations from isokinetic sampling conditions are maintained within well-defined limits. The particulate mass is determined gravimetrically after removal of uncombined water.

2. Apparatus

NOTE: Methods cited in this method are part of 40 CFR Part 60, Appendix A.

2.1 Sampling Train. A schematic of the Method 201A sampling train is shown in Figure 1. With the exception of the PM₁₀ sizing device and in-stack filter, this train is the same as an EPA Method 17 train.

2.1.1 Nozzle. Stainless steel (316 or equivalent) with a sharp tapered leading edge. Eleven nozzles that meet the design specifications in Figure 2

are recommended. A large number of nozzles with small nozzle increments increase the likelihood that a single nozzle can be used for the entire traverse. If the nozzles do not meet the design specifications in Figure 2, then the nozzles must meet the criteria in Section 5.2.

2.1.2 PM_{10} Sizer. Stainless steel (316 or equivalent), capable of determining the PM_{10} fraction. The sizing device shall be either a cyclone that meets the specifications in Section 5.2 or a cascade impactor that has been calibrated using the procedure in Section 5.4.

2.1.3 Filter Holder. 63-mm, stainless steel. An Andersen filter, part number SE274, has been found to be acceptable for the in-stack filter.

NOTE: Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

2.1.4 Pitot Tube. Same as in Method 5, Section 2.1.3. The pitot lines shall be made of heat resistant tubing and attached to the probe with stainless steel fittings.

2.1.5 Probe Liner. Optional, same as in Method 5, Section 2.1.2.

2.1.6 Differential Pressure Gauge, Condenser, Metering System, Barometer, and Gas Density Determination Equipment. Same as in Method 5, Sections 2.1.4, and 2.1.7 through 2.1.10, respectively.

2.2 Sample Recovery.

2.2.1 Nozzle, Sizing Device, Probe, and Filter Holder Brushes. Nylon bristle brushes with stainless steel wire shafts and handles, properly sized and shaped for cleaning the nozzle, sizing device, probe or probe liner, and filter holders.

2.2.2 Wash Bottles, Glass Sample Storage Containers, Petri Dishes, Graduated Cylinder and Balance, Plastic Storage Containers, Funnel and Rubber

Policeman, and Funnel. Same as in Method 5, Sections 2.2.2 through 2.2.8, respectively.

2.3 Analysis. Same as in Method 5, Section 2.3.

3. Reagents

The reagents for sampling, sample recovery, and analysis are the same as that specified in Method 5, Sections 3.1, 3.2, and 3.3, respectively.

4. Procedure

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. Same as in Method 5, Section 4.1.1.

4.1.2 Preliminary Determinations. Same as in Method 5, Section 4.1.2, except use the directions on nozzle size selection and sampling time in this method. Use of any nozzle greater than 0.16 in. in diameter require a sampling port diameter of 6 inches. Also, the required maximum number of traverse points at any location shall be 12.

4.1.2.1 The sizing device must be in-stack or maintained at stack temperature during sampling. The blockage effect of the CSR sampling assembly will be minimal if the cross-sectional area of the sampling assembly is 3 percent or less of the cross-sectional area of the duct. If the cross-sectional area of the assembly is greater than 3 percent of the cross-sectional area of the duct, then either determine the pitot coefficient at sampling conditions or use a standard pitot with a known coefficient in a configuration with the CSR sampling assembly such that flow disturbances are minimized.

4.1.2.2 The setup calculations can be performed by using the following procedures.

4.1.2.2.1 In order to maintain a cut size of $10\ \mu\text{m}$ in the sizing device, the flow rate through the sizing device must be maintained at a constant, discrete value during the run. If the sizing device is a cyclone that meets the design specifications in Figure 3, use the equations in Figure 4 to calculate three orifice heads (ΔH): one at the average stack temperature, and the other two at temperatures $\pm 28^\circ\text{C}$ ($\pm 50^\circ\text{F}$) of the average stack temperature. Use the ΔH calculated at the average stack temperature as the pressure head for the sample flow rate as long as the stack temperature during the run is within 28°C (50°F) of the average stack temperature. If the stack temperature varies by more than 28°C (50°F), then use the appropriate ΔH .

4.1.2.2.2 If the sizing device is a cyclone that does not meet the design specifications in Figure 3, use the equations in Figure 4, except use the procedures in Section 5.3 to determine Q_s , the correct cyclone flow rate for a $10\ \mu\text{m}$ cut size.

4.1.2.2.3 To select a nozzle, use the equations in Figure 5 to calculate Δp_{\min} and Δp_{\max} for each nozzle at all three temperatures. If the sizing device is a cyclone that does not meet the design specifications in Figure 3, the example worksheets can be used.

4.1.2.2.4 Correct the Method 2 pitot readings to Method 201A pitot readings by multiplying the Method 2 pitot readings by the square of a ratio of the Method 201A pitot coefficient to the Method 2 pitot coefficient. Select the nozzle for which Δp_{\min} and Δp_{\max} bracket all of the corrected Method 2 pitot readings. If more than one nozzle meets this requirement,

select the nozzle giving the greatest symmetry. Note that if the expected pitot reading for one or more points is near a limit for a chosen nozzle, it may be outside the limits at the time of the run.

4.1.2.2.5 Vary the dwell time, or sampling time, at each traverse point proportionately with the point velocity. Use the equations in Figure 6 to calculate the dwell time at the first point and at each subsequent point. It is recommended that the number of minutes sampled at each point be rounded to the nearest 15 seconds.

4.1.3 Preparation of Collection Train. Same as in Method 5, Section 4.1.3, except omit directions about a glass cyclone.

4.1.4 Leak-Check Procedure. The sizing device is removed before the post-test leak-check to prevent any disturbance of the collected sample prior to analysis.

4.1.4.1 Pretest Leak-Check. A pretest leak-check of the entire sampling train, including the sizing device, is required. Use the leak-check procedure in Method 5, Section 4.1.4.1 to conduct a pretest leak-check.

4.1.4.2 Leak-Checks During Sample Run. Same as in Method 5, Section 4.1.4.1.

4.1.4.3 Post-Test Leak-Check. A leak-check is required at the conclusion of each sampling run. Remove the cyclone before the leak-check to prevent the vacuum created by the cooling of the probe from disturbing the collected sample and use the procedure in Method 5, Section 4.1.4.3 to conduct a post-test leak-check.

4.1.5 Method 201A Train Operation. Same as in Method 5, Section 4.1.5, except use the procedures in this section for isokinetic sampling and flow rate adjustment. Maintain the flow rate calculated in Section 4.1.2.2.1

throughout the run provided the stack temperature is within 28°C (50°F) of the temperature used to calculate ΔH . If stack temperatures vary by more than 28°C (50°F), use the appropriate ΔH value calculated in Section 4.1.2.2.1. Calculate the dwell time at each traverse point as in Figure 6.

4.1.6 Calculation of Percent Isokinetic Rate and Aerodynamic Cut Size (D_{50}). Calculate percent isokinetic rate and D_{50} (see Calculations, Section 6) to determine whether the test was valid or another test run should be made. If there was difficulty in maintaining isokinetic sampling rates within the prescribed range, or if the D_{50} is not in its proper range because of source conditions, the Administrator may be consulted for possible variance.

4.2 Sample Recovery. If a cascade impactor is used, use the manufacturer's recommended procedures for sample recovery. If a cyclone is used, use the same sample recovery as that in Method 5, Section 4.2, except an increased number of sample recovery containers is required.

4.2.1 Container Number 1 (In-Stack Filter). The recovery shall be the same as that for Container Number 1 in Method 5, Section 4.2.

4.2.3 Container Number 2 (Cyclone or Large PM Catch). This step is optional. The anisokinetic error for the cyclone PM is theoretically larger than the error for the PM_{10} catch. Therefore, adding all the fractions to get a total PM catch is not as accurate as Method 5 or Method 201. Disassemble the cyclone and remove the nozzle to recover the large PM catch. Quantitatively recover the PM from the interior surfaces of the nozzle and cyclone, excluding the "turn around" cup and the interior surfaces of the exit tube. The recovery shall be the same as that for Container Number 2 in Method 5, Section 4.2.

4.2.4 Container Number 3 (PM_{10}). Quantitatively recover the PM from all of the surfaces from the cyclone exit to the front half of the in-stack filter holder, including the "turn around" cup inside the cyclone and the interior surfaces of the exit tube. The recovery shall be the same as that for Container Number 2 in Method 5, Section 4.2.

4.2.6 Container Number 4 (Silica Gel). The recovery shall be the same as that for Container Number 3 in Method 5, Section 4.2.

4.2.7 Impinger Water. Same as in Method 5, Section 4.2, under "Impinger Water."

4.3 Analysis. Same as in Method 5, Section 4.3, except handle Method 201A Container Number 1 like Container Number 1, Method 201A Container Numbers 2 and 3 like Container Number 2, and Method 201A Container Number 4 like Container Number 3. Use Figure 7 to record the weights of PM collected. Use Figure 5-3 in Method 5, Section 4.3, to record the volume of water collected.

4.4 Quality Control Procedures. Same as in Method 5, Section 4.4.

5. Calibration

Maintain an accurate laboratory log of all calibrations.

5.1 Probe Nozzle, Pitot Tube, Metering System, Probe Heater Calibration, Temperature Gauges, Leak-check of Metering System, and Barometer. Same as in Method 5, Section 5.1 through 5.7, respectively.

5.2 Probe Cyclone and Nozzle Combinations. The probe cyclone and nozzle combinations need not be calibrated if both meet design specifications in Figures 2 and 3. If the nozzles do not meet design specifications, then test the cyclone and nozzle combinations for conformity with performance specifications (PS's) in Table 1. If the cyclone does not meet design

specifications, then the cyclone and nozzle combination shall conform to the PS's and calibrate the cyclone to determine the relationship between flow rate, gas viscosity, and gas density. Use the procedures in Section 5.2 to conduct PS tests and the procedures in Section 5.3 to calibrate the cyclone. The purpose of the PS tests are to confirm that the cyclone and nozzle combination has the desired sharpness of cut. Conduct the PS tests in a wind tunnel described in Section 5.2.1 and particle generation system described in Section 5.2.2. Use five particle sizes and three wind velocities as listed in Table 2. A minimum of three replicate measurements of collection efficiency shall be performed for each of the 15 conditions listed, for a minimum of 45 measurements.

5.2.1 Wind Tunnel. Perform the calibration and PS tests in a wind tunnel (or equivalent test apparatus) capable of establishing and maintaining the required gas stream velocities within 10 percent.

5.2.2 Particle Generation System. The particle generation system shall be capable of producing solid monodispersed dye particles with the mass median aerodynamic diameters specified in Table 2. Perform the particle size distribution verification on an integrated sample obtained during the sampling period of each test. An acceptable alternative is to verify the size distribution of samples obtained before and after each test, with both samples required to meet the diameter and monodispersity requirements for an acceptable test run.

5.2.2.1 Establish the size of the solid dye particles delivered to the test section of the wind tunnel by using the operating parameters of the particle generation system, and verify them during the tests by microscopic examination of samples of the particles collected on a membrane filter. The

particle size, as established by the operating parameters of the generation system, shall be within the tolerance specified in Table 2. The precision of the particle size verification technique shall be at least $\pm 0.5 \mu\text{m}$, and particle size determined by the verification technique shall not differ by more than 10 percent from that established by the operating parameters of the particle generation system.

5.2.2.2. Certify the monodispersity of the particles for each test either by microscopic inspection of collected particles on filters or by other suitable monitoring techniques such as an optical particle counter followed by a multichannel pulse height analyzer. If the proportion of multiplets and satellites in an aerosol exceeds 10 percent by mass, the particle generation system is unacceptable for the purpose of this test. Multiplets are particles that are agglomerated, and satellites are particles that are smaller than the specified size range.

5.2.3 Schematic Drawings. Schematic drawings of the wind tunnel and blower system and other information showing complete procedural details of the test atmosphere generation, verification, and delivery techniques shall be furnished with calibration data to the reviewing agency.

5.2.4 Flow Measurements. Measure the cyclone air flow rates with a dry gas meter and a stopwatch, or a calibrated orifice system capable of measuring flow rates to within 2 percent.

5.2.5 Performance Specification Procedure. Establish test particle generator operation and verify particle size microscopically. If monodispersity is to be verified by measurements at the beginning and the end of the run rather than by an integrated sample, these measurements may be made at this time.

5.2.5.1 The cyclone cut size, or D_{50} , of a cyclone is defined here as the particle size having a 50 percent probability of penetration. Determine the cyclone flow rate at which D_{50} is 10 μm . A suggested procedure is to vary the cyclone flow rate while keeping a constant particle size of 10 μm . Measure the PM collected in the cyclone (m_c), the exit tube (m_t), and the filter (m_f). Calculate cyclone efficiency (E_c) for each flow rate as follows:

$$E_c = \frac{m_c}{(m_c + m_t + m_f)} \times 100$$

5.2.5.2 Do three replicates and calculate the average cyclone efficiency [$E_{c(\text{avg})}$] as follows:

$$E_{c(\text{avg})} = (E_1 + E_2 + E_3)/3$$

where E_1 , E_2 , and E_3 are replicate measurements of E_c .

5.2.5.3 Calculate the standard deviation (σ) for the replicate measurements of E_c as follows:

$$\sigma = \left[\frac{(E_1^2 + E_2^2 + E_3^2) - \frac{(E_1 + E_2 + E_3)^2}{3}}{2} \right]^{1/2}$$

If σ exceeds 0.10, repeat the replicated runs.

5.2.5.4 Measure the overall efficiency of the cyclone and nozzle, E_o , at the particle sizes and nominal gas velocities in Table 2 using the following procedure.

5.2.5.5 Set the air velocity and particle size from one of the conditions in Table 2. Establish isokinetic sampling conditions and the correct flow rate in the cyclone (obtained by procedures in this section) such that the D_{50} is 10 μm . Sample long enough to obtain ± 5 percent precision on total collected mass as determined by the precision and the sensitivity of measuring technique. Determine separately the nozzle catch (m_n), cyclone catch (m_c), cyclone exit tube (m_t), and collection filter catch (m_f) for each particle size and nominal gas velocity in Table 2. Calculate overall efficiency (E_o) as follows:

$$E_o = \frac{(m_n + m_c)}{(m_n + m_c + m_t + m_f)} \times 100$$

5.2.5.6 Do three replicates for each combination of gas velocity and particle size in Table 2. Use the equation below to calculate the average overall efficiency [$E_{o(\text{avg})}$] for each combination following the procedures described in this section for determining efficiency.

$$E_{o(\text{avg})} = (E_1 + E_2 + E_3)/3$$

where E_1 , E_2 , and E_3 are replicate measurements of E_o .

5.2.5.7 Use the formula in Section 5.2.5.3 to calculate σ for the replicate measurements. If σ exceeds 0.10 or if the particle sizes and nominal gas velocities are not within the limits specified in Table 2, repeat the replicate runs.

5.2.6 Criteria for Acceptance. For each of the three gas stream velocities, plot the $E_{o(\text{avg})}$ as a function of particle size on Figure 8. Draw

smooth curves through all particle sizes. $E_{o(avg)}$ shall be within the banded region for all sizes, and the $E_{c(avg)}$ shall be 50 ± 0.5 percent at $10 \mu\text{m}$.

5.3 Cyclone Calibration Procedure. The purpose of this procedure is to develop the relationship between flow rate, gas viscosity, gas density, and D_{50} .

5.3.1 Calculate Cyclone Flow Rate. Determine flow rates and D_{50} 's for three different particle sizes between $5 \mu\text{m}$ and $15 \mu\text{m}$, one of which shall be $10 \mu\text{m}$. All sizes must be determined within $0.5 \mu\text{m}$. For each size, use a different temperature within 60°C (108°F) of the temperature at which the cyclone is to be used and conduct triplicate runs. A suggested procedure is to keep the particle size constant and vary the flow rate.

5.3.1.1 On log-log graph paper, plot the Reynolds number (Re) on the abscissa, and the square root of the Stokes 50 number $[(Stk_{50})^{\frac{1}{2}}]$ on the ordinate for each temperature. Use the following equations to compute both values:

$$Re = \frac{4 \rho Q_{cyc}}{d_{cyc} \pi \mu_{cyc}}$$

$$(Stk_{50})^{\frac{1}{2}} = \left[\frac{4 Q_{cyc} (D_{50})^2}{9 \pi \mu_{cyc} (d_{cyc})^3} \right]^{\frac{1}{2}}$$

where:

Q_{cyc} = Cyclone flow rate, cm^3/sec .

ρ = Gas density, g/cm^3 .

d_{cyc} = Diameter of cyclone inlet, cm.

μ_{cyc} = Viscosity of gas through the cyclone, micropoise.

D_{50} = Aerodynamic diameter of a particle having a 50 percent probability of penetration, cm.

5.3.1.2 Use a linear regression analysis to determine the slope (m) and the Y-intercept (b). Use the following formula to determine Q, the cyclone flow rate required for a cut size of 10 μm .

$$Q_s = \frac{\pi \mu_{cyc}}{4} \left[(3000)(K_1) - b \right]^{- (0.5-m)} \left[\frac{T_s}{M_c P_s} \right]^{m/(m-0.5)} d^{(m-1.5)/(m-0.5)}$$

where:

m = Slope of the calibration line.

b = y-intercept of the calibration line.

Q_s = Cyclone flow rate for a cut size of 10 μm , cm^3/sec .

d = Diameter of nozzle, cm.

T_s = Stack gas temperature, $^{\circ}\text{R}$.

P_s = Absolute stack pressure, in. Hg..

M_c = Molecular weight of the stack gas, lb/lb-mole.

$K_1 = 4.077 \times 10^{-3}$.

5.3.1.3 Refer to the Method 201A operators manual, entitled Application Guide for Source PM_{10} Measurement with Constant Sampling Rate, for directions in the use of this equation for Q in the setup calculations.

5.4 Cascade Impactor. The purpose of calibrating a cascade impactor is to determine the empirical constant (Stk_{50}), which is specific to the impactor and which permits the accurate determination of the cut sizes of the impactor stages at field conditions. It is not necessary to calibrate each individual impactor. Once an impactor has been calibrated, the calibration data can be applied to other impactors of identical design.

5.4.1 Wind Tunnel. Same as in Section 5.2.1.

5.4.2 Particle Generation System. Same as in Section 5.2.2.

5.4.3 Hardware Configuration for Calibrations. An impaction stage constrains an aerosol to form circular or rectangular jets, which are directed toward a suitable substrate where the larger aerosol particles are collected. For calibration purposes, three stages of the cascade impactor shall be discussed and designated calibration stages 1, 2, and 3. The first calibration stage consists of the collection substrate of an impaction stage and all upstream surfaces up to and including the nozzle. This may include other preceding impactor stages. The second and third calibration stages consist of each respective collection substrate and all upstream surfaces up to but excluding the collection substrate of the preceding calibration stage. This may include intervening impactor stages which are not designated as calibration stages. The cut size, or D_{50} , of the adjacent calibration stages shall differ by a factor of not less than 1.5 and not more than 2.0. For example, if the first calibration stage has a D_{50} of 12 μm , then the D_{50} of the downstream stage shall be between 6 and 8 μm .

5.4.3.1 It is expected, but not necessary, that the complete hardware assembly will be used in each of the sampling runs of the calibration and performance determinations. Only the first calibration stage must be tested under isokinetic sampling conditions. The second and third calibration stages must be calibrated with the collection substrate of the preceding calibration stage in place, so that gas flow patterns existing in field operation will be simulated.

5.4.3.2 Each of the PM_{10} stages should be calibrated with the type of collection substrate, viscid material (such as grease) or glass fiber, used in PM_{10} measurements. Note that most materials used as substrates at elevated

temperatures are not viscid at normal laboratory conditions. The substrate material used for calibrations should minimize particle bounce, yet be viscous enough to withstand erosion or deformation by the impactor jets and not interfere with the procedure for measuring the collected PM.

5.4.4 Calibration Procedure. Establish test particle generator operation and verify particle size microscopically. If monodispersity is to be verified by measurements at the beginning and the end of the run rather than by an integrated sample, these measurements shall be made at this time. Measure in triplicate the PM collected by the calibration stage (m) and the PM on all surfaces downstream of the respective calibration stage (m') for all of the flow rates and particle size combinations shown in Table 2. Techniques of mass measurement may include the use of a dye and spectrophotometer. Particles on the upstream side of a jet plate shall be included with the substrate downstream, except agglomerates of particles, which shall be included with the preceding or upstream substrate. Use the following formula to calculate the collection efficiency (E) for each stage.

5.4.4.1 Use the formula in Section 5.2.5.3 to calculate the standard deviation (σ) for the replicate measurements. If σ exceeds 0.10, repeat the replicate runs.

5.4.4.2 Use the following formula to calculate the average collection efficiency (E_{avg}) for each set of replicate measurements.

$$E_{avg} = (E_1 + E_2 + E_3)/3$$

where E_1 , E_2 , and E_3 are replicate measurements of E .

5.4.4.3 Use the following formula to calculate Stk for each E_{avg} .

$$Stk = \frac{D^2 Q}{9 \mu A d_j}$$

where:

D = Aerodynamic diameter of the test particle, cm $(g/cm^3)^{1/2}$.

Q = Gas flow rate through the calibration stage at inlet conditions, cm^3/sec .

μ = Gas viscosity, micropoise.

A = Total cross-sectional area of the jets of the calibration stage, cm^2 .

d_j = Diameter of one jet of the calibration stage, cm.

5.4.4.4 Determine Stk_{50} for each calibration stage by plotting E_{avg} versus Stk on log-log paper. Stk_{50} is the Stk number at 50 percent efficiency. Note that particle bounce can cause efficiency to decrease at high values of Stk. Thus, 50 percent efficiency can occur at multiple values of Stk. The calibration data should clearly indicate the value of Stk_{50} for minimum particle bounce. Impactor efficiency versus Stk with minimal particle bounce is characterized by a monotonically increasing function with constant or increasing slope with increasing Stk.

5.4.4.5 The Stk_{50} of the first calibration stage can potentially decrease with decreasing nozzle size. Therefore, calibrations should be performed with enough nozzle sizes to provide a measured value within 25 percent of any nozzle size used in PM_{10} measurements.

5.4.5 Criteria For Acceptance. Plot E_{avg} for the first calibration stage versus the square root of the ratio of Stk to Stk_{50} on Figure 9. Draw a

smooth curve through all of the points. The curve shall be within the banded region.

6. Calculations

6.1 Nomenclature.

B_{ws} = Moisture fraction of stack, by volume, dimensionless.

C_1 = Viscosity constant, 51.12 micropoise for $^{\circ}K$ (51.05 micropoise for $^{\circ}R$).

C_2 = Viscosity constant, 0.372 micropoise/ $^{\circ}K$ (0.207 micropoise/ $^{\circ}R$).

C_3 = Viscosity constant, 1.05×10^{-4} micropoise/ $^{\circ}K^2$
(3.24×10^{-5} micropoise/ $^{\circ}R^2$).

C_4 = Viscosity constant, 53.147 micropoise/fraction O_2 .

C_5 = Viscosity constant, 74.143 micropoise/fraction H_2O .

D_{50} = Diameter of particles having a 50 percent probability of penetration, μm .

f_0 = Stack gas fraction O_2 , by volume, dry basis.

K_1 = 0.3858 $^{\circ}K/mm$ Hg (17.64 $^{\circ}R/in.$ Hg).

M_c = Wet molecular weight of mixed gas through the PM_{10} cyclone, g/g-mole (lb/lb-mole).

M_d = Dry molecular weight of stack gas, g/g-mole (lb/lb-mole).

P_{bar} = Barometric pressure at sampling site, mm Hg (in. Hg).

P_s = Absolute stack pressure, mm Hg (in. Hg).

Q_s = Total cyclone flow rate at wet cyclone conditions, m^3/min (ft^3/min).

$Q_{s(std)}$ = Total cyclone flow rate at standard conditions, dscm/min (dscf/min).

T_m = Average absolute temperature of dry meter, $^{\circ}K$ ($^{\circ}R$).

T_s = Average absolute stack gas temperature, °K (°R).

$V_{w(std)}$ = Volume of water vapor in gas sample (standard conditions),
scm (scf).

θ = Total sampling time, min.

μ_{cyc} = Viscosity of mixed cyclone gas, micropoise.

μ_{std} = Viscosity of standard air, 180.1 micropoise.

6.2 Analysis of Cascade Impactor Data. Use the manufacturer's recommended procedures to analyze data from cascade impactors.

6.3 Analysis of Cyclone Data. Use the following procedures to analyze data from a single stage cyclone.

6.3.1 PM_{10} Weight. Determine the PM catch in the PM_{10} range from the sum of the weights obtained from Container Numbers 1 and 3 less the acetone blank.

6.3.2 Total PM Weight (optional). Determine the PM catch for greater than PM_{10} from the weight obtained from Container Number 2 less the acetone blank, and add it to the PM_{10} weight.

6.3.3 PM_{10} Fraction. Determine the PM_{10} fraction of the total particulate weight by dividing the PM_{10} particulate weight by the total particulate weight.

6.3.4 Aerodynamic Cut Size. Calculate the stack gas viscosity as follows:

$$\mu_{cyc} = C_1 + C_2 T_s + C_3 T_s^2 + C_4 f_{O_2} - C_5 B_{ws}$$

6.3.4.1 The PM_{10} flow rate, at actual cyclone conditions, is calculated as follows:

$$Q_s = \frac{T_s}{K_1 P_s} \left[Q_{s(std)} + \frac{V_{w(std)}}{\theta} \right]$$

6.3.4.2 Calculate the molecular weight on a wet basis of the stack gas as follows:

$$M_c = M_d(1 - B_{ws}) + 18.0(B_{ws})$$

6.3.4.3 Calculate the actual D_{50} of the cyclone for the given conditions as follows:

$$D_{50} = \beta_1 \left[\frac{T_s}{M_c P_s} \right]^{0.2091} \left[\frac{\mu_{cyc}}{Q_s} \right]^{0.7091}$$

where $\beta_1 = 0.027754$ for metric units (0.15625 for English units).

6.3.5 Acceptable Results. The results are acceptable if two conditions are met. The first is that $9.0 \mu m \leq D_{50} \leq 11.0 \mu m$. The second is that no sampling points are outside Δp_{min} and Δp_{max} , or that $80 \text{ percent} \leq I \leq 120 \text{ percent}$ and no more than one sampling point is outside Δp_{min} and Δp_{max} . If D_{50} is less than $9.0 \mu m$, reject the results and repeat the test.

7. Bibliography

1. Same as Bibliography in Method 5.
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3. Farthing, W.E., S.S. Dawes, A.D. Williamson, J.D. McCain, R.S. Martin, and J.W. Ragland. Development of Sampling Methods for Source PM₁₀ Emissions. Southern Research Institute for the Environmental Protection Agency. April 1989. NTIS PB 89 190375, EPA/600/3-88-056.
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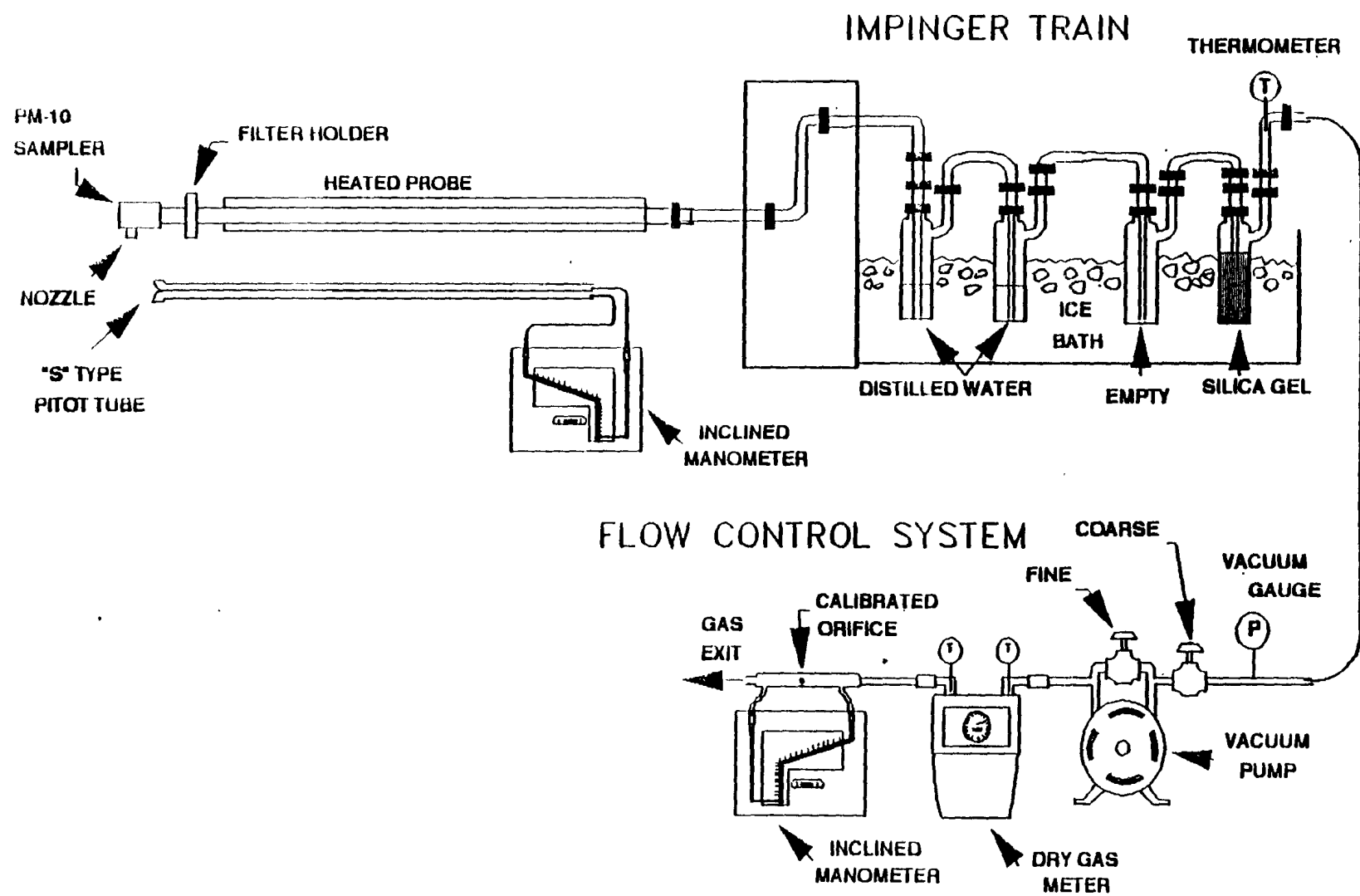
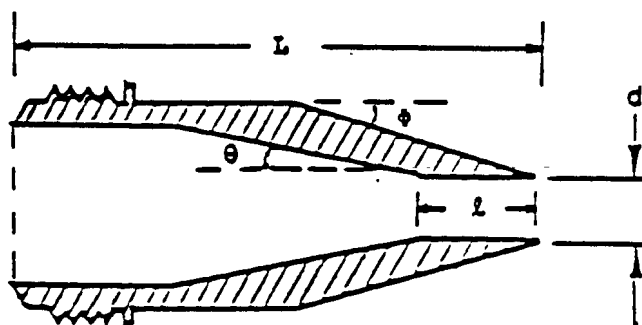


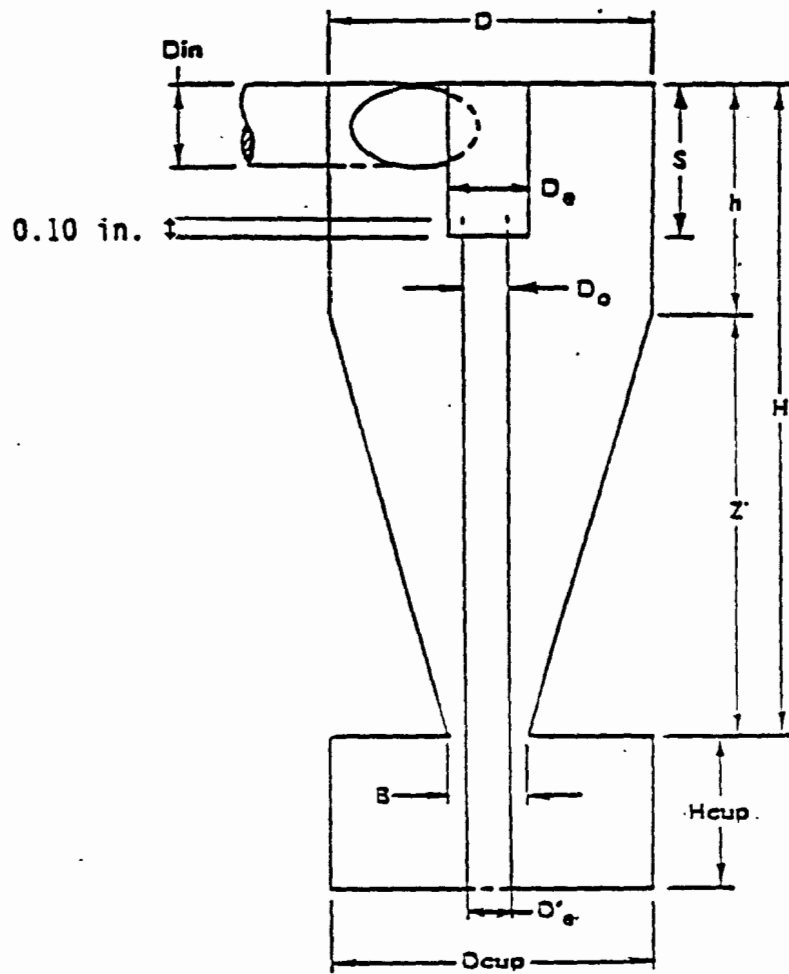
Figure 1. CSR Sampling Train



Nozzle Diameter (inches)	Cone Angle, θ (degrees)	Outside taper, ϕ (degrees)	Straight inlet length, l (inches)	Total Length L (inches)
0.136	4	15	<0.05	2.653 ± 0.05
0.150	4	15	<0.05	2.553 ± 0.05
0.164	5	15	<0.05	1.970 ± 0.05
0.180	6	15	<0.05	1.572 ± 0.05
0.197	6	15	<0.05	1.491 ± 0.05
0.215	6	15	<0.05	1.45 ± 0.05
0.233	6	15	<0.05	1.45 ± 0.05
0.264	5	15	<0.05	1.45 ± 0.05
0.300	4	15	<0.05	1.48 ± 0.05
0.342	4	15	<0.05	1.45 ± 0.05
0.390	3	15	<0.05	1.45 ± 0.05

Figure 2. Nozzle design specifications.

Cyclone Interior Dimensions



Dimensions (± 0.02 cm, ± 0.01 in.)												
	D_{in}	D	D_e	B	H	h	Z	S	H_{cup}	D_{cup}	D'_e	D
cm	1.27	4.47	1.50	1.88	6.95	2.24	4.71	1.57	2.25	4.45	1.02	1.27
inches	0.50	1.76	0.59	0.74	2.74	0.88	1.85	0.62	0.89	1.75	0.40	0.50

Figure 3. Cyclone design specifications.

Barometric pressure, P_{bar} , in. Hg = _____
 Stack static pressure, P_g , in. H₂O = _____
 Average stack temperature, t_s , °F = _____
 Meter temperature, t_m , °F = _____
 Orifice ΔH_g , in. H₂O = _____

Gas analysis:

%CO₂ = _____
 %O₂ = _____
 %N₂ + %CO = _____
 Fraction moisture content, B_{ws} = _____

Molecular weight of stack gas, dry basis:

$$M_d = 0.44 (\%CO_2) + 0.32 (\%O_2) + 0.28 (\%N_2 + \%CO) = \text{_____ lb/lb mole}$$

Molecular weight of stack gas, wet basis:

$$M_w = M_d (1 - B_{ws}) + 18 (B_{ws}) = \text{_____ lb/lb mole}$$

Absolute stack pressure:

$$P_s = P_{\text{bar}} + \frac{P_g}{13.6} = \text{_____ in. Hg}$$

Viscosity of stack gas:

$$\mu_s = 152.418 + 0.2552 t_s + 3.2355 \times 10^{-5} t_s^2 + 0.53147 (\%O_2) - 74.143 B_{ws} = \text{_____ micropoise}$$

Cyclone flow rate:

$$Q_s = 0.002837 \mu_s \left[\frac{(t_s + 460)}{M_w P_s} \right]^{0.2949} = \text{_____ ft}^3/\text{min}$$

Figure 4. Example worksheet 1 (Page 1 of 2), cyclone flow rate and ΔH .

Orifice pressure head (ΔH) needed for cyclone flow rate:

$$\Delta H = \left[\frac{Q_s (1-B_{ws}) P_s}{t_s + 460} \right]^2 \frac{(t_m + 460) M_d 1.083 \Delta H_g}{P_{bar}} = \underline{\hspace{2cm}} \text{ in. H}_2\text{O}$$

Calculate ΔH for three temperatures:

$t_s, ^\circ\text{F}$			
$\Delta H, \text{ in. H}_2\text{O}$			

Figure 4. Example worksheet 1 (Page 2 of 2), cyclone flow rate and ΔH .

Stack viscosity, μ_s , micropoise = _____
 Absolute stack pressure, P_s , in. Hg = _____
 Average stack temperature, t_s , °F = _____
 Meter temperature, t_m , °F = _____
 Method 201A pitot coefficient, C_p = _____
 Cyclone flow rate, ft^3/min , Q_c = _____
 Method 2 pitot coefficient, C_p = _____
 Molecular weight of stack gas, wet basis, M_w = _____
 Nozzle diameter, D_n , in. = _____

Nozzle velocity

$$v_n = \frac{3.056 Q_s}{D_n^2} = \text{_____ ft/sec}$$

Maximum and minimum velocities:

$$v_{min} = v_n \left[0.2457 + \left[0.3072 - \frac{0.2603 Q_s^{1/2} \mu_s}{v_n^{1.5}} \right]^{1/2} \right] = \text{_____ ft/sec}$$

$$v_{max} = v_n \left[0.4457 + \left[0.5690 + \frac{0.2603 Q_s^{1/2} \mu_s}{v_n^{1.5}} \right]^{1/2} \right] = \text{_____ ft/sec}$$

Figure 5. Example worksheet 2 (page 1 of 2), nozzle selection.

Maximum and minimum velocity head values:

$$\Delta p_{\min} = 1.3686 \times 10^{-4} \frac{P_s M_w (v_{\min})^2}{(t_s + 460) C_p^2} = \underline{\hspace{2cm}} \text{ in. H}_2\text{O}$$

$$\Delta p_{\max} = 1.3686 \times 10^{-4} \frac{P_s M_w (v_{\max})^2}{(t_s + 460) C_p^2} = \underline{\hspace{2cm}} \text{ in. H}_2\text{O}$$

Nozzle number

D_n , in.				
v_n , ft/sec				
v_{\min} , ft/sec				
v_{\max} , ft/sec				
Δp_{\min} , in. H ₂ O				
Δp_{\max} , in. H ₂ O				

Velocity traverse data:

$$\Delta p(\text{Method 201A}) = \Delta p(\text{Method 2}) \left[\frac{C_p}{C_p'} \right]^2$$

Figure 5. Example worksheet 2 (page 2 of 2), nozzle selection.

Total run time, minutes = _____

Number of traverse points = _____

$$t_1 = \left[\frac{\Delta p'_1}{\Delta p'_{avg}} \right]^{\frac{1}{2}} \frac{(\text{Total run time})}{(\text{Number of points})}$$

where:

t_1 = dwell time at first traverse point, minutes.

$\Delta p'_1$ = the velocity head at the first traverse point (from a previous traverse), in. H_2O .

$\Delta p'_{avg}$ = the square of the average square root of the Δp 's (from a previous velocity traverse), in. H_2O .

At subsequent traverse points, measure the velocity Δp and calculate the dwell time by using the following equation:

$$t_n = \frac{t_1}{(\Delta p_1)^{1/2}} (\Delta p_n)^{1/2}, n = 2, 3, \dots \text{total number of sampling points}$$

where:

t_n = dwell time at traverse point n , minutes.

Δp_n = measured velocity head at point n , in. H_2O .

Δp_1 = measured velocity head at point 1, in. H_2O .

Figure 6. Example worksheet 3 (page 1 of 2), dwell time.

Point Number	Port _____		_____		_____		_____	
	Δp	t	Δp	t	Δp	t	Δp	t
1	_____	_____	_____	_____	_____	_____	_____	_____
2	_____	_____	_____	_____	_____	_____	_____	_____
3	_____	_____	_____	_____	_____	_____	_____	_____
4	_____	_____	_____	_____	_____	_____	_____	_____
5	_____	_____	_____	_____	_____	_____	_____	_____
6	_____	_____	_____	_____	_____	_____	_____	_____

Figure 6. Example worksheet 3 (page 2 of 2), dwell time.

Plant _____
 Date _____
 Run no. _____
 Filter no. _____
 Amount of liquid lost during transport _____
 Acetone blank volume, ml _____
 Acetone wash volume, ml (4) _____ (5) _____
 Acetone blank conc., mg/mg (Equation 5-4, Method 5) _____
 Acetone wash blank, mg (Equation 5-5, Method 5) _____

Container number	Weight of PM ₁₀ mg		
	Final weight	Tare weight	Weight gain
1			
3			
Total.....			
Less acetone blank.....			
Weight of PM ₁₀			

Figure 7. Method 201A analysis sheet..

**TABLE 1. PERFORMANCE SPECIFICATIONS FOR SOURCE PM₁₀ CYCLONES
AND NOZZLE COMBINATIONS**

Parameter	Units	Specification
1. Collection efficiency	Percent	Such that collection efficiency falls within envelope specified by Section 5.2.6 and Figure 8.
2. Cyclone cut size (D ₅₀)	μm	10 ± 1 μm aerodynamic diameter.

TABLE 2. PARTICLE SIZES AND NOMINAL GAS VELOCITIES FOR EFFICIENCY

Particle size (μm) ^a	Target gas velocities (m/sec)		
	7 ± 1.0	15 ± 1.5	25 ± 2.5
5 ± 0.5			
7 ± 0.5			
10 ± 0.5			
14 ± 1.0			
20 ± 1.0			

(a) Mass median aerodynamic diameter.

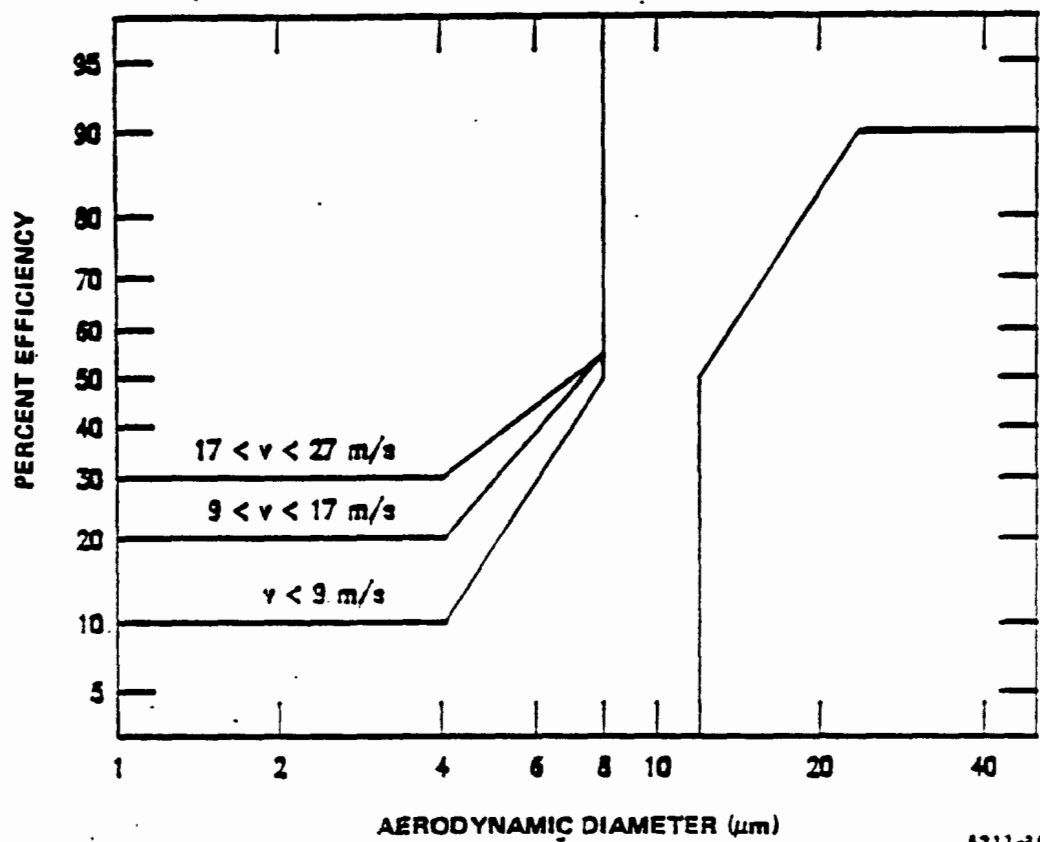


Figure 8. Efficiency envelope for the PM₁₀ cyclone.

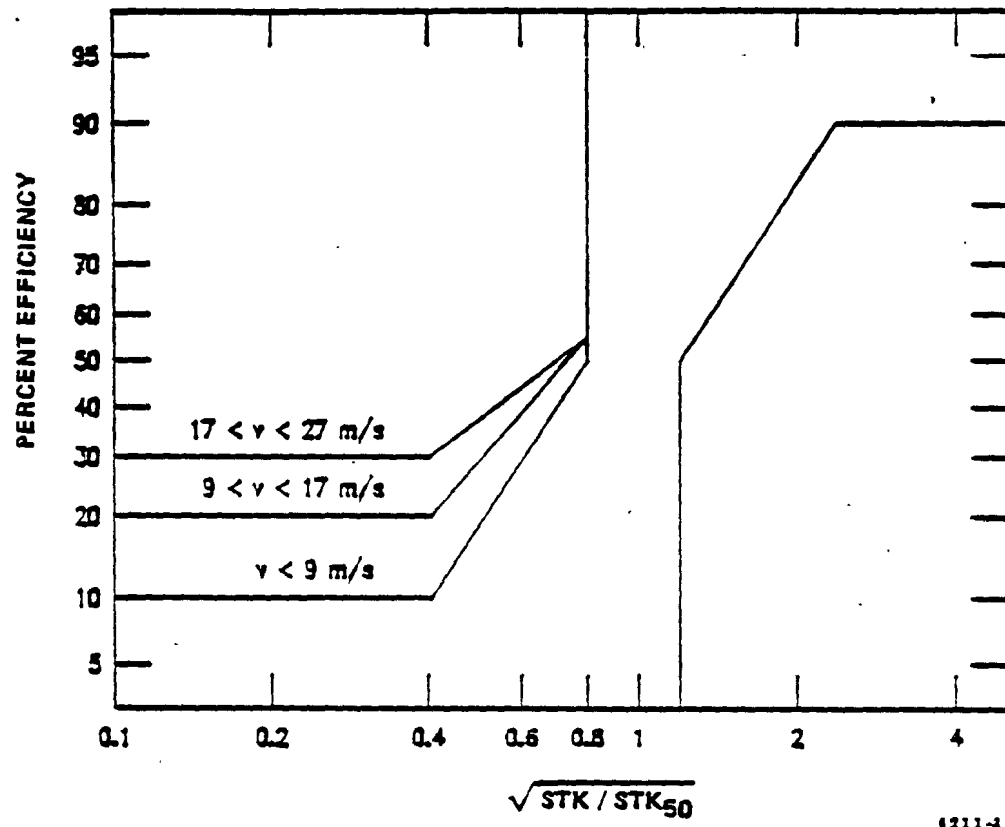


Figure 9. Efficiency envelope for first calibration stage.

Appendix B

**PM10 EMISSION FACTORS
FOR A
STONE CRUSHING PLANT
DEISTER VIBRATING SCREEN
AND CRUSHER**

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Entropy Project 11236

DECEMBER 1992

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1.0 SUMMARY

1.1 TEST PROCEDURES AND RESULTS

The National Stone Association (NSA) sponsored this PM10 emission test program in order to determine PM10 emission factors applicable to various process units at stone crushing plants. The test site was the Vulcan Materials, Inc. facility in Skippers, Virginia. The specific sources tested were a 7 foot heavy duty shorthead Simmons cone crusher (7' crusher) and an 8 by 20 foot Deister vibrating screen. Entropy Environmentalists, Inc. (Entropy) developed the emission testing program and conducted the PM10 emission tests.

A Quasi-stack system was used to conduct emission tests on the inlet and outlet of the 7' crusher. Small enclosures were installed at both locations. Clean make-up air from HEPA filters was blown into each enclosure at a rate approximately equal to the exhaust gas stream flow rate being drawn to the emission sampling location. Using this testing approach, all of the PM10 emissions from the crusher inlet and outlet were efficiently captured and adjacent sources of PM10 emissions did not affect the results.

The Deister vibrating screen emission tests were conducted using a track-mounted hood system. The hood has dimensions of 2 feet by 2 feet and was mounted 12 inches above the upper screen deck of the Deister Screen. The small scale and the mounting position of the hood ensured that the normal PM10 emissions were not significantly influenced by the presence of the hood. The capture velocity in the hood was set by adjusting the variable speed DC motor of the tubeaxial fan installed on the hood outlet duct. The hood capture velocity was selected based on observations of the fugitive dust capture characteristics of the hood. This testing approach is an adaptation of the conventional "roof monitoring" technique for fugitive emission testing.

The PM10 emissions were tested using EPA Method 201A. The tests were divided into two sets: stone moisture levels greater than 1.5%, and stone moisture levels less than 1.5%. The results of the PM10 emission tests are presented in Table 1. The emission rates determined during both series of tests on the 7' crusher and the Deister screen were low. These wet stone emission factor results are entirely consistent with the zero visible emissions operating conditions observed during all of these tests. Stone samples obtained during each of the tests were also analyzed and found to have very low levels of material below approximately less than 10 microns.

TABLE 1. CRUSHER PM10 EMISSIONS

PM10 Source	Stone Moisture (% Weight)	PM10 Emissions (Pounds/Ton)
Crusher	(< 1.5%)	0.00397
	(> 1.5%)	0.00026
Deister Screen	(< 1.5%)	0.02701
	(> 1.5%)	0.00103

1.2 KEY PERSONNEL

The National Stone Association Project Manager was Mr. Bill Ford. He was assisted by Mr. Ronnie Walker of Vulcan Materials, Inc. The Entropy project manager was Mr. Todd Brozell. Technical assistance was provided by Mr. Bill Kirk and Dr. John Richards of Entropy. The tests were observed by Mr. Solomon Ricks of the U.S. EPA, OAQPS Emission Measurement Branch, Mr. Dennis Shipman of the U.S. EPA, OAQPS Emission Inventory Branch, Mr. Horace Wilson of Martin Marietta, and Mr. Steve Witt of Martin Marietta. A summary of the key personnel and their phone number are provided in Table 2.

TABLE 2. KEY PERSONNEL

	Telephone Numbers
National Stone Association Mr. Bill Ford	(202) 342-1100
Vulcan Materials, Inc. Mr. Ronnie Walker	(804) 634-4158
Martin Marietta Mr. Horace Wilson Mr. Steve Witt	(919) 781-4550 (919) 781-4550
U.S. EPA, Emission Inventory Branch Mr. Dennis Shipman	(919) 541-5477
U.S. EPA, Emission Measurement Branch Mr. Solomon Ricks	(919) 541-5242
Entropy Environmentalists, Inc. Mr. Todd Brozell Mr. Bill Kirk Dr. John Richards	(919) 781-3550 (919) 781-3550 (919) 781-3550

2.0 PLANT AND SAMPLING LOCATION DESCRIPTION

2.1 PROCESS DESCRIPTION AND OPERATION

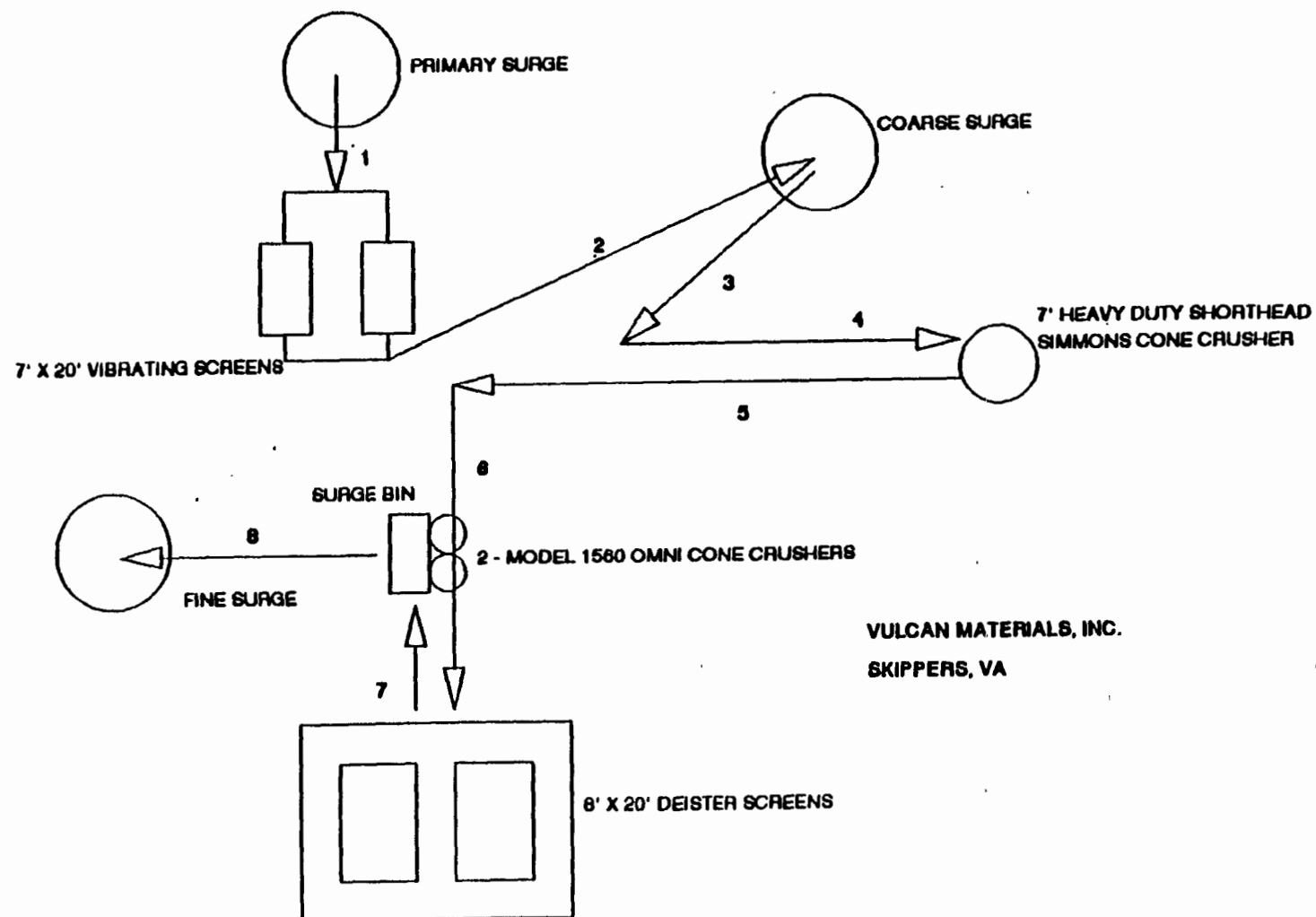
The Skippers, Virginia plant produces crushed granite used for road paving and construction. Figure 1 provides a simplified flowchart of the portion of the plant relevant to this emission testing program. The primary surge pile shown in the upper right of Figure 1 is rock which has been conveyed from the large surge pile of rock in the quarry. The stone is then conveyed via Stream 1 to the 7' X 20' vibrating screens and the coarse product is conveyed via Stream 2 to the coarse surge pile. The coarse product is transported via Streams 3 and 4 to the 7' heavy duty shorthread Simmons Cone Crusher (hereafter referred to as the 7' crusher). Entropy monitored the stone feed rate leaving the 7' crusher by weighing a two foot section of Stream 5 and multiplying this weight by the speed of the belt.

The 7' crusher reduces the size distribution of the material received from the coarse surge pile. Stone leaving the 7' crusher ranges in size from 3 inches to relatively small particles. The material from the 7' crusher discharges onto a conveyor (Stream 5) leading to the outlets of two Model 1560 omni cone crushers. Following the omni cone crushers discharge, the main feed conveyor (Stream 6) contains all of the plant production with the exception of oversized product. The main feed conveyor (Stream 6) delivers the stone to the top of the structure housing the Deister vibrating screens. The plant operates a scale on this conveyor to calculate total daily tonnage from all three crushers to the 8' X 20' screens. Entropy also used this scale as a basis for calculations of the Deister screen.

The stone flow to the Deister screens and the omni cone crushers is termed "closed circuit" since oversized material containing some fines adhering to the surface can recirculate through the Deister and omni cone crushers until the stone is crushed small enough to fall through the Deister screen. The 7' crusher that Entropy tested however had no recirculated stone flowing through it.

The Deister decks are 8 feet wide by 20 feet long and are inclined on a 20 degree slope. There are three vertically stacked decks. The upper deck has a mesh opening of 1.125 square inches, for the first 12 feet of travel and an opening of 1 square inch for the last 8 feet of travel. The middle deck has mesh opening of 0.58 square inches and the lower deck has slot openings of 0.118 inches by 1 inch. Stone collecting on the middle and lower decks are combined as one product stream. Fine particles passing through all three decks collect as a separate process stream. The oversized material remaining on the top screen goes to the inlet of the Omni Cone crushers. The total quantity of oversized material entering the Omni Cone crushers is estimated to be 500 to 600 tons per hour. The stone feed rates to the two Deister screens were approximately equal during the tests.

Figure 1. Simplified Process Flowchart



2.2 FUGITIVE DUST CONTROL

Wet suppression is used for fugitive dust control of the 7' Simmons crusher, two Model 1560 omni cone crushers, and the Deister vibrating screens. There are water spray nozzles located on the vibrating feeder to the 7' crusher, on the conveyor underneath the crusher, and on the discharge chute near the top of the Deister screens. Not all of these spray nozzles are necessary to maintain wet conditions. The nozzles on the inlet chute to the Deister screen were off during the tests. Over-wetting of the rock can cause blinding of the lower screen or blockage of the fines discharge chute underneath the Deister. During these emission tests, the plant experienced no significant screen blinding conditions.

2.3 SAMPLING AND EMISSION TESTING PROCEDURES

2.3.1 Fugitive Emission Test Approach

Since there are no air pollution control devices on the Deister screens or the 7' crusher, fugitive emission testing procedures were needed to capture and measure the PM10 emissions. Entropy considered the criteria listed in Table 3 in designing the test program. Entropy evaluated alternative testing procedures during several site visits by Entropy personnel. The emission testing techniques which are generally applied to fugitive dust emission sources include,

- Upwind-downwind profiling,
- Roof monitor sampling, and
- Enclosures and Quasi-stack sampling.

Deister Screen Testing Alternatives

The roof monitoring approach of fugitive emission testing appeared to be the most applicable technique for the Deister screen at the Skippers plant. This involved the sampling at a horizontal array of sampling points above the surface of the emission source. However, an adaption of the general procedure was necessary due to the lack of a partial enclosure to serve as the roof monitor and due to the swirling gas flows created by wind leakage around the screen enclosure. Accordingly, Entropy designed and installed a track-mounted hood system for fugitive emission capture. By using this track-mounted hood version of roof monitor sampling, it was possible to accurately capture and measure the PM10 emissions without influencing the PM10 emission rates from the screen surface.

Upwind-downwind profiling techniques involve measurement of the increase in PM10 concentrations as a gas stream passes over or around the source being evaluated. This is usually performed using ambient PM10 monitors in upwind and downwind locations. Entropy concluded that this approach was not applicable to the Deister screen at the Skippers, Virginia plant because of the building constructed around the Deister screen. Also, there were a number of possible sources immediately upwind and downwind of the 7' crusher. These sources included crushers, conveyors and conveyor transfer points, and Interstate 95 traffic. It would be impossible to isolate the 7' crusher from these nearby sources using an upwind-downwind testing procedure.

**Table 2. FUGITIVE EMISSION CAPTURE
SYSTEM DESIGN CRITERIA**

- The capture system should not create higher-than-actual PM10 emission rates due to high gas velocity conditions near the point of PM10 particle entrainment.
- The capture system should not create a sink for PM10 emissions.
- The capture system should isolate the process unit being tested from other adjacent sources of PM10 emissions.
- The capture system should not create safety hazards for the emission test crew or for plant personnel. It should not create risks to the plant process equipment.
- The capture systems should not obstruct routine access to the process equipment by plant personnel.
- The capture system and overall test procedures must be economical, practical, and readily adaptable to other plants so that these tests can be repeated by organizations wishing to confirm or challenge the emission factor data developed in this project.

The quasi-stack method involves the construction of a temporary enclosure around the Deister screen and the installation of a duct and fan system for gas handling. Entropy rejected this approach primarily because of the extremely high gas flow rates necessary. To simulate the identical emission conditions for typical wind speeds at the plant would require gas flow rates between 13,200 and 52,800 actual cubic feet per minute (ACFM). Ductwork with a diameter between 4 and 6 feet would be necessary to carry this large gas flow at velocities where PM10 losses would be minimized. Since the Deister vibrating screen is on a relatively small platform 80 feet above the ground, this ductwork would have to be quite long and carefully supported. This approach would be prohibitively expensive. Other disadvantages include:

- It would be extremely difficult to simulate actual wind speeds and wind approach angles using make-up air.
- An enclosure restricts plant operations personnel's access to the vibrating screen
- Construction safety risks are possible due to the lack of access and due to the rotating equipment in restricted areas.

7' Crusher Inlet and Outlet Testing Alternatives

The quasi-stack method appeared to be the most accurate and practical approach for capturing the fugitive emissions from the inlet and outlet areas of the 7' crusher. This approach allowed isolation of the 7' crusher from the other fugitive dust sources in the immediate vicinity.

The quasi-stack method required the construction of temporary enclosures around the inlet and outlet of the 7' crusher and the installation of a duct and fan system for gas handling. Since the PM10 emissions are generated primarily by stone-to-stone attrition in the crusher and during falling, the use of an enclosure does not influence the rate of PM10 emissions.

The roof monitoring approach of fugitive emission capture involves the sampling at a horizontal array of sampling points above the surface of the emission source. This approach was rejected because there was no logical means to sample in the area immediately above the crusher inlet or outlet. The emission profiling technique was also rejected for the crusher emission points since there were a number of other possible PM10 sources in the immediate vicinity of the crusher.

2.3.2 PM10 Emission Testing Procedure

Deister Screen Testing Equipment

The track-mounted hood system used for sampling the Deister Screen consisted of a 2 foot by 2 foot aluminum hood suspended 12 inches above the upper deck of the Deister vibrating screen. The position of the hood above the stone is shown in Figures 2 and 3. This hood position was close enough to the upper screen deck to ensure good emission capture but not so close that the entering air stream caused greater-than-actual PM10 emissions. A variable speed DC-driven tubeaxial fan controlled the capture velocity of the air entering the hood. This velocity was set at 150 feet per minute based on the hood capture characteristics observed using smoke and lightweight strips of fabric. This velocity is higher than the 50 feet per minute minimum capture velocity specified in reference 9 for vibrating screens.

The top area of the Deister screen was divided into a 3 by 9 array of sampling locations, each of which was 2 feet by 2 feet in size. The only area not sampled was the 4-foot strip across the upper inlet side of the Deister screen where the stone feed dumps onto the top of the screen. Positioning the hood in this location would have artificially increased PM10 emissions and caused rapid abrasion of the hood. PM10 from the inlet chute area of the screen are captured as the hood traverses the uppermost portions of the screen.

Entropy sized the ductwork from the hood to the sampling location for an average gas flow velocity less than 1000 feet per minute. This transport velocity is well below the 3500 to 4500 feet per minute velocity used to size commercial ductwork in stone crushing plants and other facilities handling large diameter dusts^{2,8}. The purpose of the high velocities in commercial ducts is to ensure that large diameter dust particles do not settle and accumulate in the ductwork over long time periods. PM10 sized dust particles have negligible gravity settling rates in the gas stream residence times in the ducts.

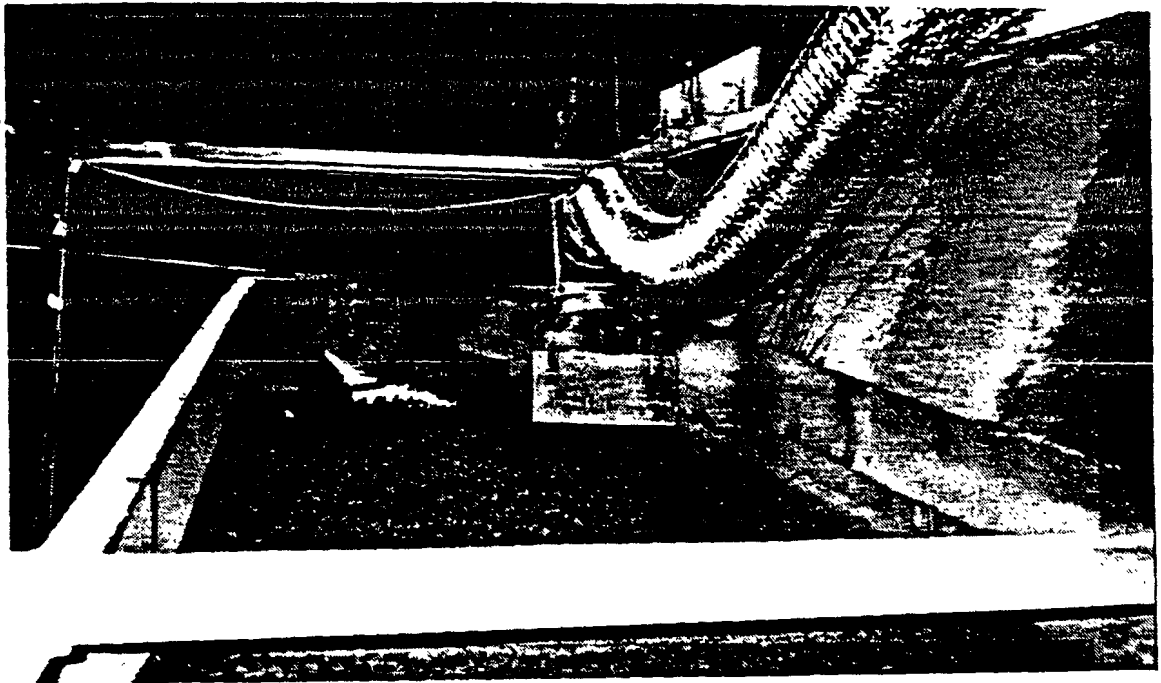


Figure 2. Side View of Traversing Hood in Deister Screen

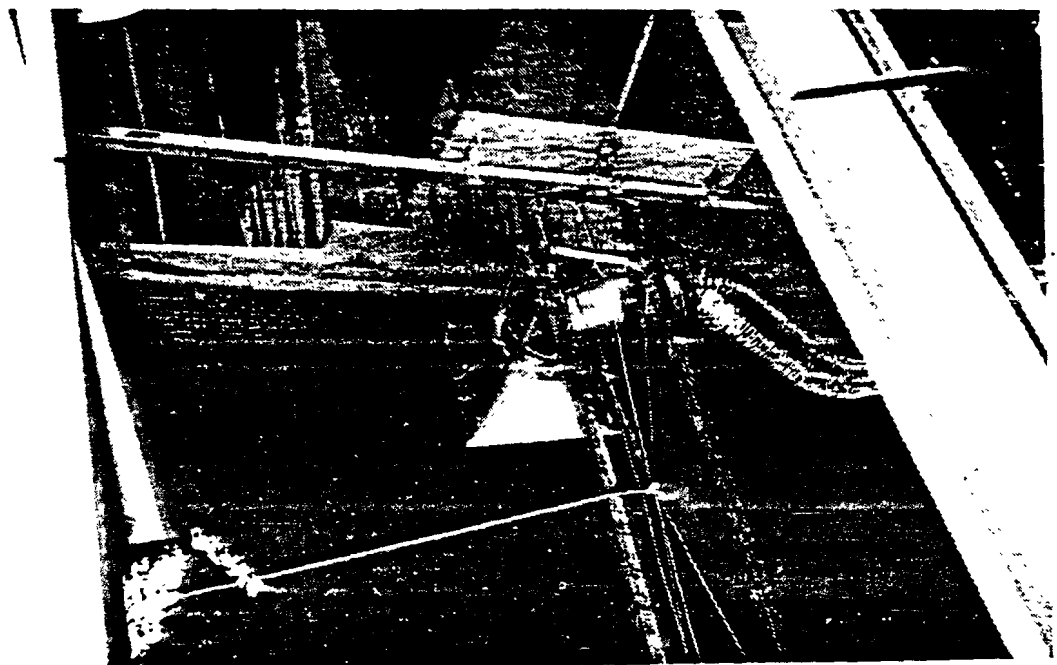


Figure 3. Top View of Traversing Hood in Deister Screen

Dust accumulation in the ductwork was not a problem during this study since the hood operating times were relatively short and the flexible duct was cleaned regularly. The 1000 feet per minute duct velocity limit is advantageous since this limits the impactation of particles less than 10 microns on the side walls of the hood elbow and the side walls of the flexible duct. Also, the low gas transport velocity limits any formation of PM10 emissions due to the movement of the gas stream over the surfaces of large diameter particles entrained in the gas stream or settling on the bottom of the duct.

7' Crusher Testing Equipment

The inlet to the 7' crusher was defined as the discharge of the vibrating feeder into the crusher vessel. This area, having a height of approximately 5 feet, was enclosed with neoprene to allow capture of the PM10 emissions caused by the stone-to-stone attrition during movement of the stone. The discharge point of the 7' crusher is a conveyor leading to the outlets of the secondary crushers to the Diester screens (Streams 5,6). The discharge point was enclosed approximately 3 feet upstream and downstream of the 7' crusher discharge point. There are several water spray nozzles on the downstream side of this conveyor. Figure 4 shows a side view of the 7' crusher.



Figure 4. Side View of 7' Crusher

Enclosures were built around the inlet and outlet of the crusher. The inlet enclosure measured approximately 40" high with a 78" diameter, the outlet measured 6'H X 12'D X 5'W. The enclosure outlet ducts were combined into a single 1 foot diameter outlet duct. The single one foot diameter duct was used as a combined sample point for both the inlet and outlet of the crusher. The one foot diameter duct was then increased to a two foot diameter duct, to allow use of a two foot diameter SCR driven tubeaxial fan. Filtered air was supplied to each of the enclosures by means of HEPA (high efficiency particulate absolute) filters and centrifugal fans. Use of HEPA make-up air ensured that PM10 emissions measured in the outlet duct were generated by the unit being tested rather than from adjacent sources. The air flows from each enclosure were set by adjusting the variable speed DC motor of the tubeaxial fan installed on the combined outlet duct. The mounting positions of the inlet and outlet ducts on the enclosures ensured that the normal PM10 emissions were not significantly influenced by air flow patterns.

Close-up views of the crusher inlet before and after installation of the enclosure are provided in Figures 5 and 6. In Figure 6, the flexible duct in the center right delivers the HEPA filtered make-up air to the enclosure and the duct in the background takes PM10-laden air to the emission testing location. The crusher outlet enclosure is shown in Figures 7 and 8. In Figure 8, the long horizontal duct in the center of the photographs contains the PM10 emissions from the outlet enclosure and the vertical duct on the right contains the PM10 emissions descending from the inlet enclosures. The gas streams are joined at the duct TEE shown in the lower right of Figure 8.

The combined gas flow from the inlet and outlet enclosures was controlled by a Dayton Model 3C411 24 inch, 2 HP direct current (DC) driven tubeaxial fan. This variable speed fan was set at the gas flow rate necessary to maintain a slightly negative static pressure within the enclosure. Negative pressures were required to ensure that there was no loss of PM10 emissions from the enclosure. Highly negative static pressures were undesirable since there could be high velocity ambient air streams entering the enclosure which could increase the PM10 emissions.

PM10 Sampling Equipment

EPA Reference Method 201A was used to monitor the PM10 emissions from the 7' crusher. This complete sampling system consists of: (1) a sampling nozzle, (2) a PM10 sampler, (3) a probe and umbilical cord, (4) an impinger train, and (5) flow control system. Due to the relatively small ducts and the constant sample gas flow rates set using the DC-driven tubeaxial fans, the "S"-type pitot tube was not mounted on the PM10 sampler probe. Gas velocities were determined prior to the emission tests.

Particulate matter larger than 10 microns in diameter is collected in the cyclone located immediately downstream of the sampling nozzle. Particulate smaller than 10 microns is collected on the outlet tube of the cyclone and on the downstream glass-fiber filter.

The cyclone and filter system used in this study met the design and sizing requirements of Section 5.2 of Method 201A. The gas flow rate through the cyclone was set based on the orifice pressure head equation provided in Figure 4 of Method 201A. The gas flow rate was kept constant throughout the emission test program.



Figure 5. Crusher Inlet Before Installation of Enclosure

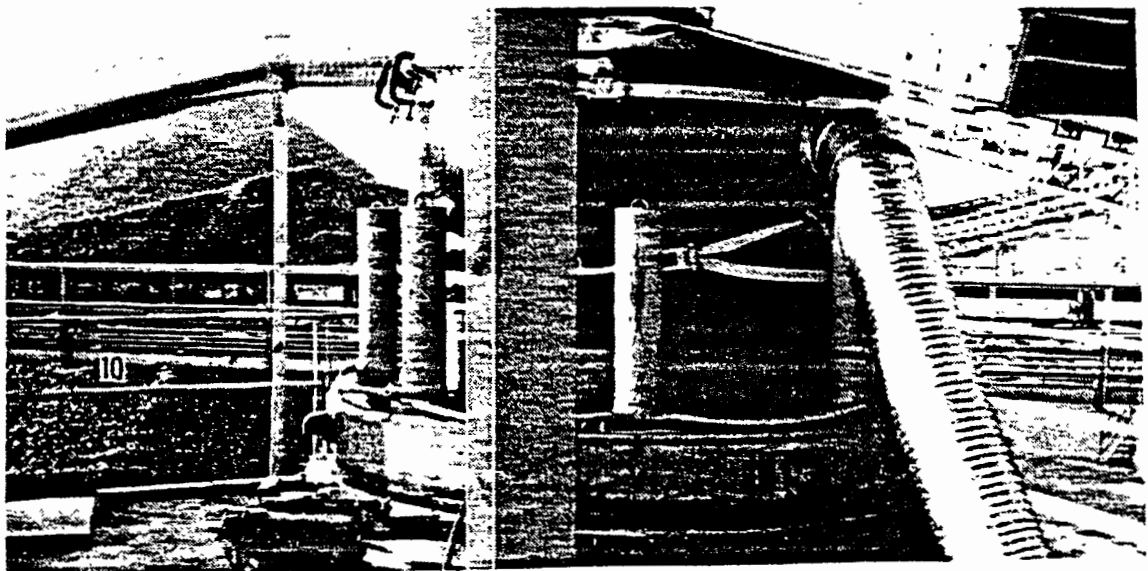


Figure 6. Crusher Inlet with Enclosure

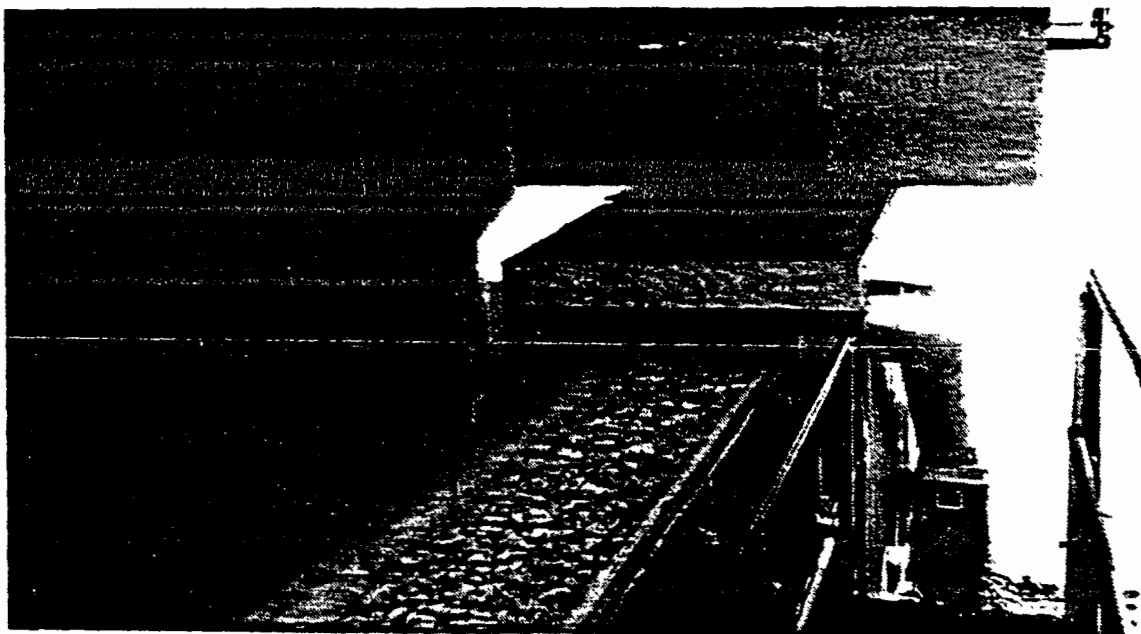


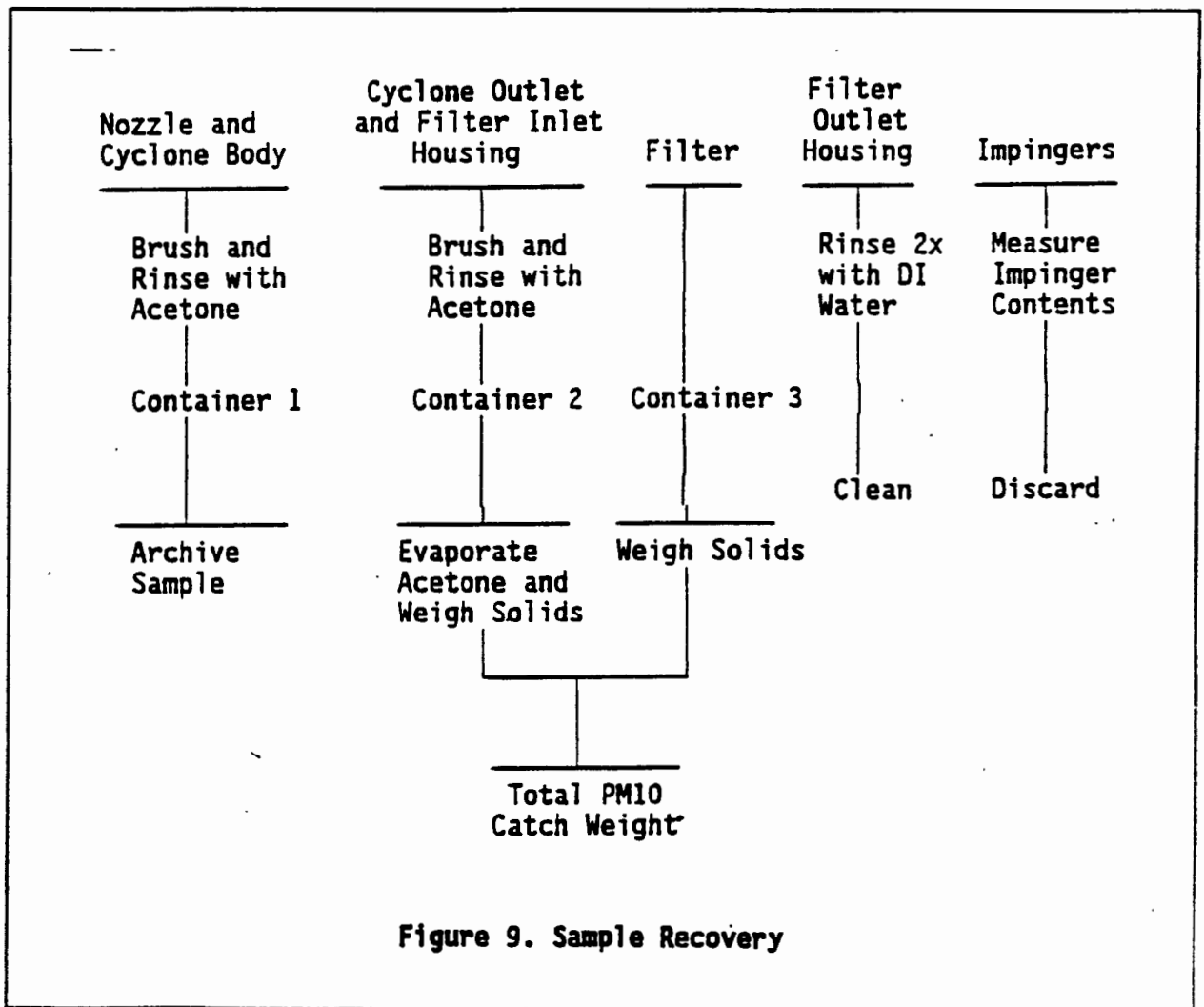
Figure 7. Crusher Outlet Enclosure



Figure 8. Crusher Outlet Enclosure

PM10 sampling was performed in a 1-foot (inlet / outlet location) diameter smooth wall duct mounted directly off the enclosures of the crusher. The 4-inch diameter sampling port was located 8 duct diameters downstream of the flexible duct connection and 2 duct diameters upstream of the fan. Sampling in the vertical direction across the ducts was not possible since dust collected in the cyclone could be resuspended and pass through to the filter. The sampling nozzles were selected to provide 80 to 120% isokinetic conditions. The cyclone and nozzle assembly were mounted within the duct during sampling.

The particulate samples were recovered using the procedures specified in Method 201A. The sample recovery scheme is illustrated in Figure 9. The material from the filter, cyclone outlet tube, and filter inlet housing were combined to determine the total PM10 catch weight.



2.4 MONITORING OF PROCESS OPERATING CONDITIONS

There are a number of process variables and weather conditions which could conceivably influence PM10 emission rates from the Deister screen:

- Stone moisture level
- Stone size distribution
- Stone silt content
- Deister stone feed rates
- Stone friability
- Stone hardness and density

All of these variables with the exception of stone type were monitored using a combination of plant instruments, special monitoring equipment, and stone sample analyses. Stone type was not monitored since granite is the only type of stone processed at this plant.

2.4.1 Stone Moisture Level

A stone sample was removed during each of the emission tests. In all cases, this sample consisted of a 2 linear foot sample of stone from the main conveyor leaving the 7' crusher (Stream 5 of Figure 1). The conveyor was stopped by plant personnel for approximately 5 minutes to permit the Entropy test crew to remove the stone sample. The sample was placed in a sealed plastic bucket.

A sample was selected for analysis by placing the stone in a pile and dividing it into four quadrants. The quadrant randomly selected for analysis was further subdivided in quadrants until the sample quantity was less than approximately 2 pounds. This sample was then weighed and heated in an oven at a gas temperature of approximately 350 degrees Fahrenheit. The weight loss during heating was calculated and reported as the stone moisture level.

2.4.2 Ambient PM10 Levels

One ambient PM10 monitor was operated inside the Deister screen enclosure. It was operated only during the time periods that PM10 emission sampling was in progress. The ambient air flow rates through the samplers were calibrated using an Airdata micromanometer. The filters were weighed and PM10 levels during the test were calculated. This data however was not used in the emissions calculations because it became apparent that the ambient PM10 monitor was being strongly influenced by emissions from the Deister screen and was not providing data representative of PM10 levels in the ambient air entering the Deister screen building.

2.4.3 Stone Size Distribution and Silt Content

Samples of the stone obtained during the test (see Section 2.4.1) were used to determine the size distribution and silt content. The initial sample quadrants used for moisture analysis was used for analysis by ASTM sizing screens. The sample of approximately 2 pounds was heated to 350 Fahrenheit for

30 minutes to drive off the moisture, then allowed to cool, then loaded into the top pan. The screen size mesh openings included:

- 37.5 Millimeters
- 19.0 Millimeters
- 4.75 Millimeters
- 2.00 Millimeters
- 150 Microns
- 75 Microns
- 38 Microns
- Bottom pan

The loaded ASTM screens were placed in a RO-TAP shaker and processed for 10 minutes. The weights of stone remaining on each of the screens were then determined by subtracting the screen tare weights from the loaded weights.

2.4.4 Stone Processing and Production Rates

The stone processing rate of the 7' crusher has been defined by Entropy as the total volume of stone leaving the 7' crusher (Stream 5). The volume of stone in tons for a particular test was calculated by removing and weighing a 2 foot section of the stone from the conveyor leaving the 7' crusher. This amount in pounds/feet was then multiplied by the speed of the conveyor in feet/minute to produce a rate in pounds/minute. Then to obtain the total amount of stone per test this number was multiplied by the length of the test (minutes). This calculation is shown below:

$$\begin{aligned} &(\text{Pounds Stone per 2 FT}) \times (\text{380 FT per Minute}) \\ &= \text{Pounds Stone per Minute} \end{aligned}$$

$$\begin{aligned} &(\text{Pounds Stone per Minute}) \times (\text{Test Minutes}) \times (\text{Ton/2000 Pounds}) \\ &= \text{Tons of Stone/Test} \end{aligned}$$

3.0 TEST RESULTS

3.1 OBJECTIVES AND TEST MATRIX

The objective of this test program was to determine the PM10 emission factors for a Simmons 7' crusher and a Deister vibrating screen at a stone crushing plant. The test program concerned both wet and dry stone conditions. The specific objectives included the following:

- Capture the PM10 emissions from the inlet and outlet of a 7' crusher without significantly affecting the emission rate.
- Capture the PM10 emissions from the Deister vibrating screen without significantly affecting the emission rate.
- Determine the PM10 emission concentrations by means of EPA Reference Method 201A.
- Calculate the total PM10 emission rates using the known outlet duct gas flow rates and the Method 201A emission concentrations.
- Measure the stone moisture content, stone feed rate, stone size distribution, and stone silt content.

The stone processing rate of the Deister screen has been defined by Entropy as the total quantity of stone produced by the plant minus the fines removed prior to the secondary crusher. The actual quantities of stone passing through the Deister are considerably higher than this value since all of the oversized material remaining on the top deck of the Deister is sent to the 2 Omni Cone crushers and then returned to the Deister screen. The quantities of stone in stream 6 shown Figure 1 are approximately 50% higher than the quantity in stream 3 due to this recycle loop. This recycle estimate is based on measurements of the stone feed rates via the Plant weigh belt scale, on the conveyor discharging stone to the two Deister screens.

The secondary feed weigh belt scale has been chosen as the basis for the production rate definition since these data are most readily available at other stone crushing plants. The disadvantage of this definition is that it creates emission factor values in pounds per ton of stone, which are higher than would be calculated if the production rate were based on the total feed rate.

The stone processing rate calculation at the Skippers plant tested during this study is further complicated by the presence of two Deister screens operated in parallel. Because of the configuration of the equipment there is no quantitative means to determine the separate stone flow rates to each. Entropy has based on emission factor calculations of a 50%-50% split based on observations during the emission tests.

Appendix C

May 1976

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

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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	<p>Drawings:</p> <ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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.

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 porous 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 nature 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

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

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

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

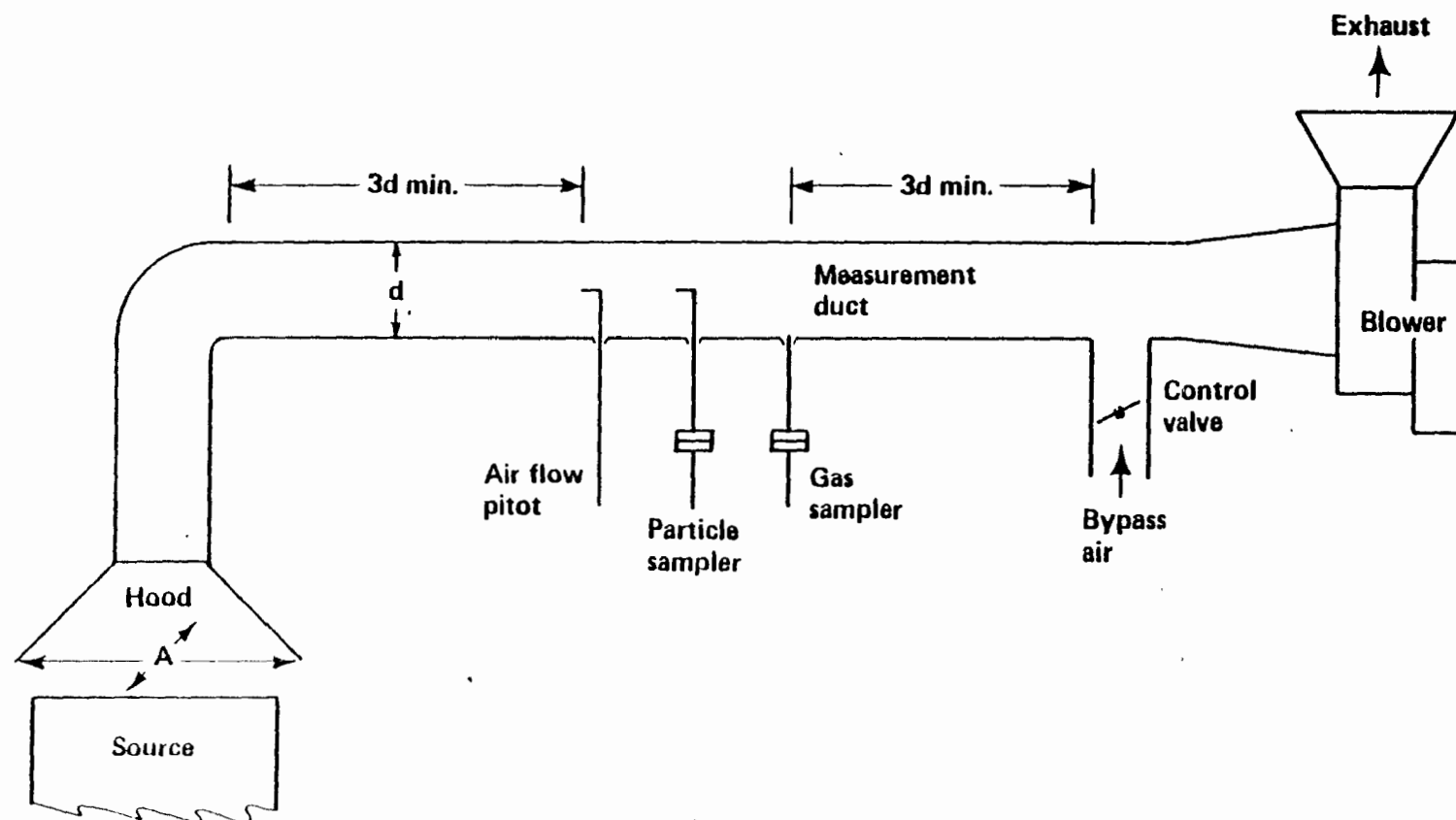


Fig. 3-1. Typical survey program sampling system.

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:

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

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,

$$F_{\max} = Q \frac{d_s^2}{d^2} \quad \text{[Equation 3-4]}$$

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 plane 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 enclosure 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 complex 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	$\pm 500\%$	$\pm 200\%$	$\pm 100\%$	$\pm 50\%$

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	<u>100</u>	<u>100</u>	<u>300</u>	<u>300</u>
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.

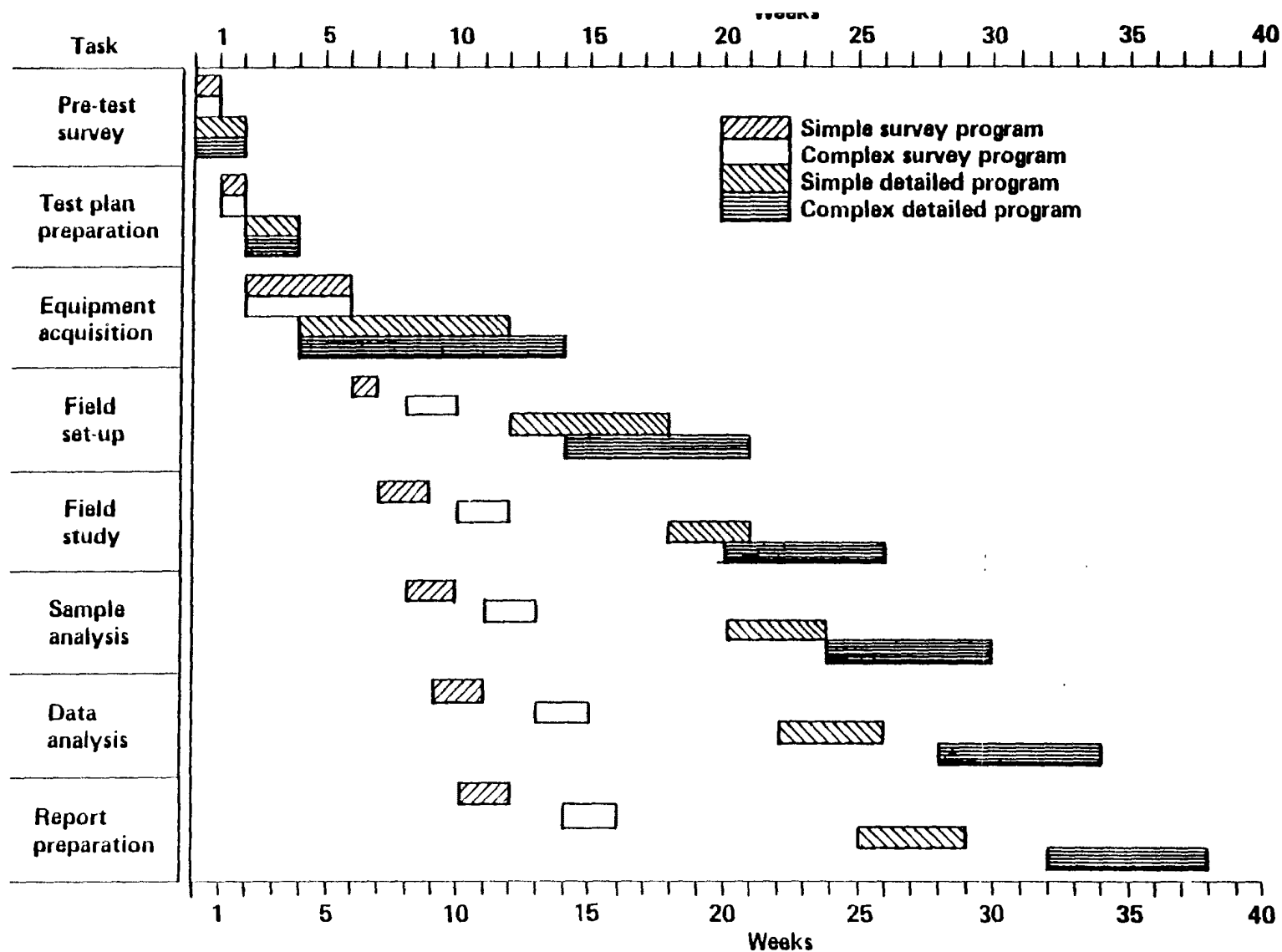


Fig. 4-1. Elapsed-time estimates for quasi-stack fugitive emissions sampling programs.

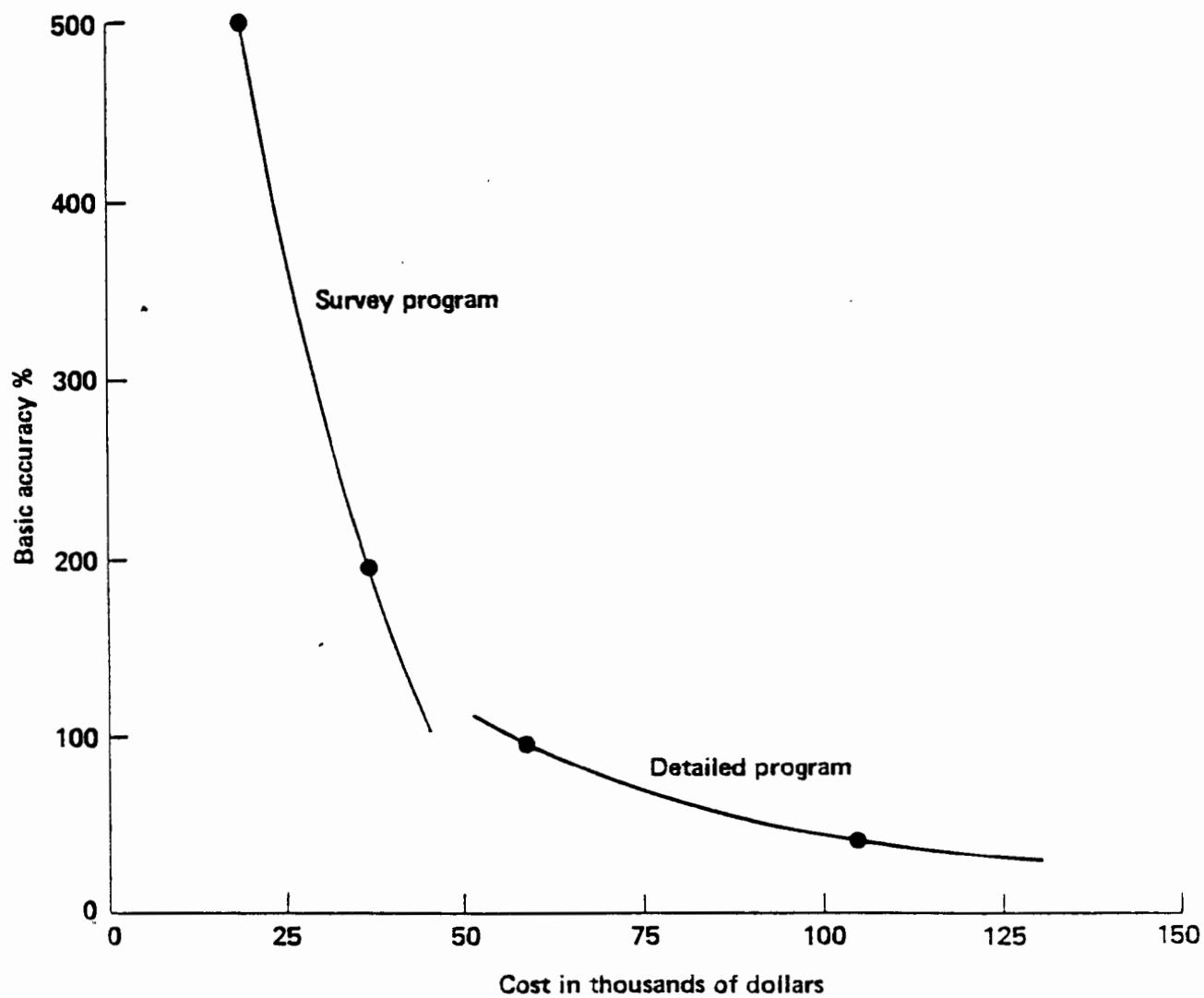


Fig. 4-2. Cost effectiveness of quasi-stack fugitive emissions sampling programs.

APPENDIX A

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

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,

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

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

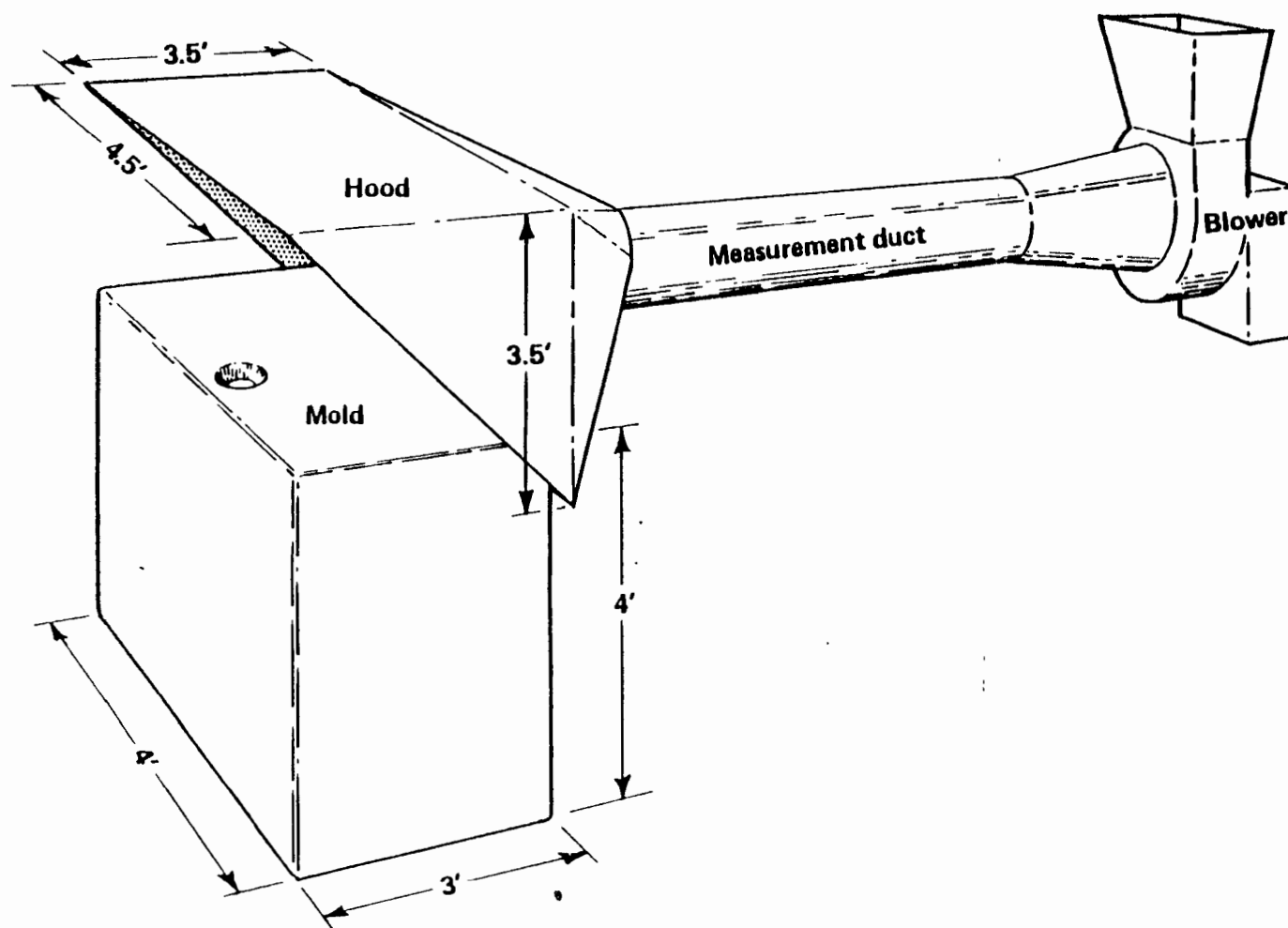


Fig. A-1. Survey program sampling hood design.

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.

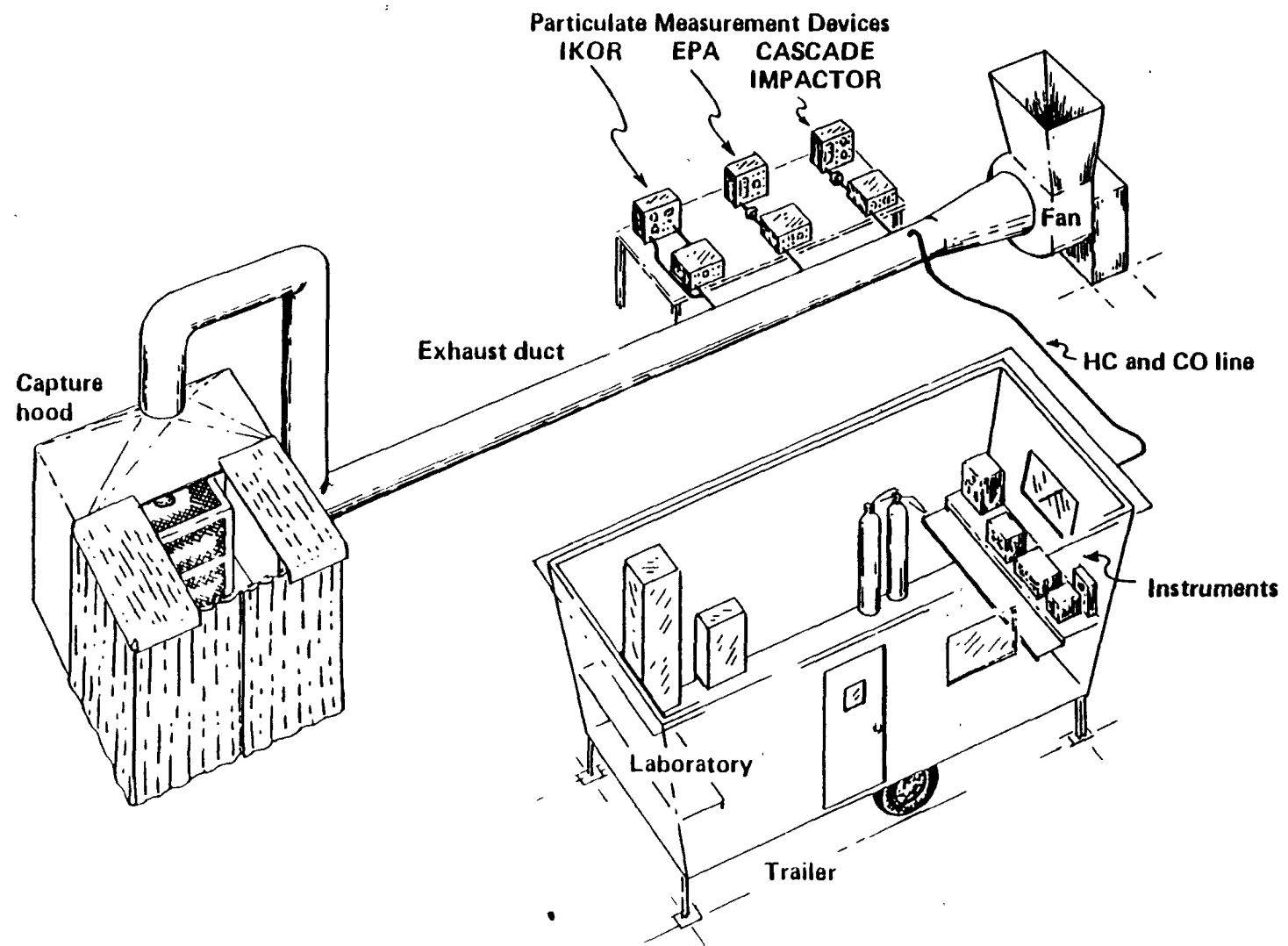


Fig. A-2. Detailed program sampling system.

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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
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Appendix D

[44 FR 6220, Feb. 8, 1979]

APPENDIX I—(RESERVED)

APPENDIX J TO PART 50—REFERENCE METHOD FOR THE DETERMINATION OF PARTICULATE MATTER AS PM_{10} IN THE ATMOSPHERE

1.0 Applicability.

1.1 This method provides for the measurement of the mass concentration of particulate matter with an aerodynamic diameter less than or equal to a nominal 10 micrometers (PM_{10}) in ambient air over a 24-hour period for purposes of determining attainment and maintenance of the primary and secondary national ambient air quality standards for particulate matter specified in § 50.6 of this chapter. The measurement process is nondestructive, and the PM_{10} sample can be subjected to subsequent physical or chemical analyses. Quality assurance procedures and guidance are provided in part 58, appendices A and B, of this chapter and in References 1 and 2.

2.0 Principle.

2.1 An air sampler draws ambient air at a constant flow rate into a specially shaped inlet where the suspended particulate matter is inertially separated into one or more size fractions within the PM_{10} size range. Each size fraction in the PM_{10} size range is then collected on a separate filter over the specified sampling period. The particle size discrimination characteristics (sampling effectiveness and 50 percent cut-point) of the sampler inlet are prescribed as performance specifications in part 53 of this chapter.

2.2 Each filter is weighed (after moisture equilibration) before and after use to determine the net weight (mass) gain due to collected PM_{10} . The total volume of air sampled, corrected to EPA reference conditions (25° C, 101.3 kPa), is determined from the measured flow rate and the sampling time. The mass concentration of PM_{10} in the ambient air is computed as the total mass of collected particles in the PM_{10} size range divided by the volume of air sampled, and is expressed in micrograms per standard cubic meter ($\mu\text{g}/\text{std m}^3$). For PM_{10} samples collected at temperatures and pressures significantly different from EPA reference conditions, these corrected concentrations sometimes differ substantially from actual concentrations (in micrograms per actual cubic meter), particularly at high elevations. Although not required, the actual PM_{10} concentration can be calculated from the corrected concentration, using the average ambient temperature and barometric pressure during the sampling period.

2.3 A method based on this principle will be considered a reference method only if (a) the associated sampler meets the requirements specified in this appendix and the requirements in part 53 of this chapter, and (b) the method has been designated as a reference method in accordance with part 53 of this chapter.

3.0 Range.

3.1 The lower limit of the mass concentration range is determined by the repeatability of filter tare weights, assuming the nominal air sample volume for the sampler. For samplers having an automatic filter-changing mechanism, there may be no upper limit. For samplers that do not have an automatic filter-changing mechanism, the upper limit is determined by the filter mass loading beyond which the sampler no longer maintains the operating flow rate within specified limits due to increased pressure drop across the loaded filter. This upper limit cannot be specified precisely because it is a complex function of the ambient particle size distribution and type, humidity, filter type, and perhaps other factors. Nevertheless, all samplers should be capable of measuring 24-hour PM_{10} mass concentrations of at least 300 $\mu\text{g}/\text{std m}^3$ while maintaining the operating flow rate within the specified limits.

4.0 Precision.

4.1 The precision of PM_{10} samplers must be 5 $\mu\text{g}/\text{m}^3$ for PM_{10} concentrations below 80 $\mu\text{g}/\text{m}^3$ and 7 percent for PM_{10} concentrations above 80 $\mu\text{g}/\text{m}^3$, as required by Part 53 of this chapter, which prescribes a test procedure that determines the variation in the PM_{10} concentration measurements of identical samplers under typical sampling conditions. Continual assessment of precision via collocated samplers is required by Part 58 of this chapter for PM_{10} samplers used in certain monitoring networks.

5.0 Accuracy.

5.1 Because the size of the particles making up ambient particulate matter varies over a wide range and the concentration of particles varies with particle size, it is difficult to define the absolute accuracy of PM_{10} samplers. Part 53 of this chapter provides a specification for the sampling effectiveness of PM_{10} samplers. This specification requires that the expected mass concentration calculated for a candidate PM_{10} sampler, when sampling a specified particle size distribution, be within ± 10 percent of that calculated for an ideal sampler whose sampling effectiveness is explicitly specified. Also, the particle size for 50 percent sampling effectiveness is required to be 10 ± 0.5 micrometers. Other specifications related to accuracy apply to flow measurement and calibration, filter media, analytical (weighing) procedures, and artifact. The flow rate accuracy of PM_{10} samplers used in certain

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monitoring networks is required by Part 58 of this chapter to be assessed periodically via flow rate audits.

6.0 Potential Sources of Error.

6.1 Volatile Particles. Volatile particles collected on filters are often lost during shipment and/or storage of the filters prior to the post-sampling weighing. Although shipment or storage of loaded filters is sometimes unavoidable, filters should be reweighed as soon as practical to minimize these losses.

6.2 Artifacts. Positive errors in PM_{10} concentration measurements may result from retention of gaseous species on filters. Such errors include the retention of sulfur dioxide and nitric acid. Retention of sulfur dioxide on filters, followed by oxidation to sulfate, is referred to as artifact sulfate formation, a phenomenon which increases with increasing filter alkalinity. Little or no artifact sulfate formation should occur using filters that meet the alkalinity specification in section 7.2.4. Artifact nitrate formation, resulting primarily from retention of nitric acid, occurs to varying degrees on many filter types, including glass fiber, cellulose ester, and many quartz fiber filters. Loss of true atmospheric particulate nitrate during or following sampling may also occur due to dissociation or chemical reaction. This phenomenon has been observed on Teflon® filters and inferred for quartz fiber filters. The magnitude of nitrate artifact errors in PM_{10} mass concentration measurements will vary with location and ambient temperature; however, for most sampling locations, these errors are expected to be small.

6.3 Humidity. The effects of ambient humidity on the sample are unavoidable. The filter equilibration procedure in section 9.0 is designed to minimize the effects of moisture on the filter medium.

6.4 Filter Handling. Careful handling of filters between presampling and postsampling weighings is necessary to avoid errors due to damaged filters or loss of collected particles from the filters. Use of a filter cartridge or cassette may reduce the magnitude of these errors. Filters must also meet the integrity specification in section 7.2.3.

6.5 Flow Rate Variation. Variations in the sampler's operating flow rate may alter the particle size discrimination characteristics of the sampler inlet. The magnitude of this error will depend on the sensitivity of the inlet to variations in flow rate and on the particle distribution in the atmosphere during the sampling period. The use of a flow control device (section 7.1.3) is required to minimize this error.

6.6 Air Volume Determination. Errors in the air volume determination may result from errors in the flow rate and/or sampling time measurements. The flow control device serves to minimize errors in the flow

rate determination, and an elapsed time meter (section 7.1.5) is required to minimize the error in the sampling time measurement.

7.0 Apparatus.

7.1 PM_{10} Sampler.

7.1.1 The sampler shall be designed to:

a. Draw the air sample into the sampler inlet and through the particle collection filter at a uniform face velocity.

b. Hold and seal the filter in a horizontal position so that sample air is drawn downward through the filter.

c. Allow the filter to be installed and removed conveniently.

d. Protect the filter and sampler from precipitation and prevent insects and other debris from being sampled.

e. Minimize air leaks that would cause error in the measurement of the air volume passing through the filter.

f. Discharge exhaust air at a sufficient distance from the sampler inlet to minimize the sampling of exhaust air.

g. Minimize the collection of dust from the supporting surface.

7.1.2 The sampler shall have a sample air inlet system that, when operated within a specified flow rate range, provides particle size discrimination characteristics meeting all of the applicable performance specifications prescribed in part 53 of this chapter. The sampler inlet shall show no significant wind direction dependence. The latter requirement can generally be satisfied by an inlet shape that is circularly symmetrical about a vertical axis.

7.1.3 The sampler shall have a flow control device capable of maintaining the sampler's operating flow rate within the flow rate limits specified for the sampler inlet over normal variations in line voltage and filter pressure drop.

7.1.4 The sampler shall provide a means to measure the total flow rate during the sampling period. A continuous flow recorder is recommended but not required. The flow measurement device shall be accurate to ± 2 percent.

7.1.5 A timing/control device capable of starting and stopping the sampler shall be used to obtain a sample collection period of 24 ± 1 hr ($1,440 \pm 60$ min). An elapsed time meter, accurate to within ± 15 minutes, shall be used to measure sampling time. This meter is optional for samplers with continuous flow recorders if the sampling time measurement obtained by means of the recorder meets the ± 15 minute accuracy specification.

7.1.6 The sampler shall have an associated operation or instruction manual as required by part 53 of this chapter which includes detailed instructions on the calibration, operation, and maintenance of the sampler.

7.3 Filters.

7.3.1 Filter Medium. No commercially available filter medium is ideal in all respects for all samplers. The user's goals in sampling determine the relative importance of various filter characteristics (e.g., cost, ease of handling, physical and chemical characteristics, etc.) and, consequently, determine the choice among acceptable filters. Furthermore, certain types of filters may not be suitable for use with some samplers, particularly under heavy loading conditions (high mass concentrations), because of high or rapid increase in the filter flow resistance that would exceed the capability of the sampler's flow control device. However, samplers equipped with automatic filter-changing mechanisms may allow use of these types of filters. The specifications given below are minimum requirements to ensure acceptability of the filter medium for measurement of PM_{10} mass concentrations. Other filter evaluation criteria should be considered to meet individual sampling and analysis objectives.

7.3.2 Collection Efficiency. ≥ 99 percent, as measured by the DOP test (ASTM-2986) with $0.3 \mu m$ particles at the sampler's operating face velocity.

7.3.3 Integrity. $\pm 5 \mu g/m^3$ (assuming sampler's nominal 24-hour air sample volume). Integrity is measured as the PM_{10} concentration equivalent corresponding to the average difference between the initial and the final weights of a random sample of test filters that are weighed and handled under actual or simulated sampling conditions, but have no air sample passed through them (i.e., filter blanks). As a minimum, the test procedure must include initial equilibration and weighing, installation on an inoperative sampler, removal from the sampler, and final equilibration and weighing.

7.3.4 Alkalinity. < 25 microequivalents/gram of filter, as measured by the procedure given in Reference 13 following at least two months storage in a clean environment (free from contamination by acidic gases) at room temperature and humidity.

7.3 Flow Rate Transfer Standard. The flow rate transfer standard must be suitable for the sampler's operating flow rate and must be calibrated against a primary flow or volume standard that is traceable to the National Bureau of Standards (NBS). The flow rate transfer standard must be capable of measuring the sampler's operating flow rate with an accuracy of ± 2 percent.

7.4 Filter Conditioning Environment.

7.4.1 Temperature range: 15° to $30^\circ C$.

7.4.2 Temperature control: $\pm 3^\circ C$.

7.4.3 Humidity range: 20% to 45% RH.

7.4.4 Humidity control: $\pm 5\%$ RH.

7.5 Analytical Balance. The analytical balance must be suitable for weighing the type and size of filters required by the sampler. The range and sensitivity required will

depend on the filter tare weights and mass loadings. Typically, an analytical balance with a sensitivity of 0.1 mg is required for high volume samplers (flow rates $> 0.5 m^3/min$). Lower volume samplers (flow rates $< 0.5 m^3/min$) will require a more sensitive balance.

8.0 Calibration.

8.1 General Requirements.

8.1.1 Calibration of the sampler's flow measurement device is required to establish traceability of subsequent flow measurements to a primary standard. A flow rate transfer standard calibrated against a primary flow or volume standard shall be used to calibrate or verify the accuracy of the sampler's flow measurement device.

8.1.2 Particle size discrimination by inertial separation requires that specific air velocities be maintained in the sampler's air inlet system. Therefore, the flow rate through the sampler's inlet must be maintained throughout the sampling period within the design flow rate range specified by the manufacturer. Design flow rates are specified as actual volumetric flow rates, measured at existing conditions of temperature and pressure (Q_a). In contrast, mass concentrations of PM_{10} are computed using flow rates corrected to EPA reference conditions of temperature and pressure (Q_{ref}).

8.2 Flow Rate Calibration Procedure.

8.2.1 PM_{10} samplers employ various types of flow control and flow measurement devices. The specific procedure used for flow rate calibration or verification will vary depending on the type of flow controller and flow indicator employed. Calibration in terms of actual volumetric flow rates (Q_a) is generally recommended, but other measures of flow rate (e.g., Q_{ref}) may be used provided the requirements of section 8.1 are met. The general procedure given here is based on actual volumetric flow units (Q_a) and serves to illustrate the steps involved in the calibration of a PM_{10} sampler. Consult the sampler manufacturer's instruction manual and Reference 2 for specific guidance on calibration. Reference 14 provides additional information on the use of the commonly used measures of flow rate and their interrelationships.

8.2.2 Calibrate the flow rate transfer standard against a primary flow or volume standard traceable to NBS. Establish a calibration relationship (e.g., an equation or family of curves) such that traceability to the primary standard is accurate to within 2 percent over the expected range of ambient conditions (i.e., temperatures and pressures) under which the transfer standard will be used. Recalibrate the transfer standard periodically.

8.2.3 Following the sampler manufacturer's instruction manual, remove the sampler inlet and connect the flow rate transfer

standard to the sampler such that the transfer standard accurately measures the sampler's flow rate. Make sure there are no leaks between the transfer standard and the sampler.

8.2.4 Choose a minimum of three flow rates (actual m^3/min), spaced over the acceptable flow rate range specified for the inlet (see 7.1.2) that can be obtained by suitable adjustment of the sampler flow rate. In accordance with the sampler manufacturer's instruction manual, obtain or verify the calibration relationship between the flow rate (actual m^3/min) as indicated by the transfer standard and the sampler's flow indicator response. Record the ambient temperature and barometric pressure. Temperature and pressure corrections to subsequent flow indicator readings may be required for certain types of flow measurement devices. When such corrections are necessary, correction on an individual or daily basis is preferable. However, seasonal average temperature and average barometric pressure for the sampling site may be incorporated into the sampler calibration to avoid daily corrections. Consult the sampler manufacturer's instruction manual and Reference 2 for additional guidance.

8.2.5 Following calibration, verify that the sampler is operating at its design flow rate (actual m^3/min) with a clean filter in place.

8.2.6 Replace the sampler inlet.

9.0 Procedure.

9.1 The sampler shall be operated in accordance with the specific guidance provided in the sampler manufacturer's instruction manual and in Reference 2. The general procedure given here assumes that the sampler's flow rate calibration is based on flow rates at ambient conditions (Q_a) and serves to illustrate the steps involved in the operation of a PM_{10} sampler.

9.2 Inspect each filter for pinholes, particles, and other imperfections. Establish a filter information record and assign an identification number to each filter.

9.3 Equilibrate each filter in the conditioning environment (see 7.4) for at least 24 hours.

9.4 Following equilibration, weigh each filter and record the presampling weight with the filter identification number.

9.5 Install a preweighed filter in the sampler following the instructions provided in the sampler manufacturer's instruction manual.

9.6 Turn on the sampler and allow it to establish run-temperature conditions. Record the flow indicator reading and, if needed, the ambient temperature and barometric pressure. Determine the sampler flow rate (actual m^3/min) in accordance with the instructions provided in the sampler manufacturer's instruction manual.

NOTE.—No onsite temperature or pressure

measurements are necessary if the sampler's flow indicator does not require temperature or pressure corrections or if seasonal average temperature and average barometric pressure for the sampling site are incorporated into the sampler calibration (see step 8.2.4). If individual or daily temperature and pressure corrections are required, ambient temperature and barometric pressure can be obtained by on-site measurements or from a nearby weather station. Barometric pressure readings obtained from airports must be station pressure, not corrected to sea level, and may need to be corrected for differences in elevation between the sampling site and the airport.

9.7 If the flow rate is outside the acceptable range specified by the manufacturer, check for leaks, and if necessary, adjust the flow rate to the specified setpoint. Stop the sampler.

9.8 Set the timer to start and stop the sampler at appropriate times. Set the elapsed time meter to zero or record the initial meter reading.

9.9 Record the sample information (site location or identification number, sample date, filter identification number, and sampler model and serial number).

9.10 Sample for 24 ± 1 hours.

9.11 Determine and record the average flow rate (Q_a) in actual m^3/min for the sampling period in accordance with the instructions provided in the sampler manufacturer's instruction manual. Record the elapsed time meter final reading and, if needed, the average ambient temperature and barometric pressure for the sampling period (see note following step 9.8).

9.12 Carefully remove the filter from the sampler, following the sampler manufacturer's instruction manual. Touch only the outer edges of the filter.

9.13 Place the filter in a protective holder or container (e.g., petri dish, glassine envelope, or manila folder).

9.14 Record any factors such as meteorological conditions, construction activity, fires or dust storms, etc., that might be pertinent to the measurement on the filter information record.

9.15 Transport the exposed sample filter to the filter conditioning environment as soon as possible for equilibration and subsequent weighing.

9.16 Equilibrate the exposed filter in the conditioning environment for at least 24 hours under the same temperature and humidity conditions used for presampling filter equilibration (see 9.3).

9.17 Immediately after equilibration, reweigh the filter and record the postsampling weight with the filter identification number.

10.0 Sample...

10.1. The PM_{10} sampler shall be maintained in strict accordance with the maintenance procedures specified in the sampler manufacturer's instruction manual.

11.0 Calculations.

11.1. Calculate the average flow rate over the sampling period corrected to EPA reference conditions as Q_{std} . When the sampler's flow indicator is calibrated in actual volumetric units (Q_a), Q_{std} is calculated as:

$$Q_{std} = Q_a \times (P_{at}/T_{at}) \times (T_{std}/P_{std})$$

where

Q_{std} —average flow rate at EPA reference conditions, std m^3/min ;

Q_a —average flow rate at ambient conditions, m^3/min ;

P_{at} —average barometric pressure during the sampling period or average barometric pressure for the sampling site, kPa (or mm Hg);

T_{at} —average ambient temperature during the sampling period or seasonal average ambient temperature for the sampling site, K;

T_{std} —standard temperature, defined as 298 K;

P_{std} —standard pressure, defined as 101.3 kPa (or 760 mm Hg).

11.2. Calculate the total volume of air sampled as:

$$V_{std} = Q_{std} \times t$$

where

V_{std} —total air sampled in standard volume units, std m^3 ;

t —sampling time, min.

11.3. Calculate the PM_{10} concentration as:

$$PM_{10} = (W_f - W_i) \times 10^6 / V_{std}$$

where

PM_{10} —mass concentration of PM_{10} , $\mu g/std m^3$;

W_f , W_i —final and initial weights of filter collecting PM_{10} particles, g;

10^6 —conversion of g to μg .

NOTE: If more than one size fraction in the PM_{10} size range is collected by the sampler, the sum of the net weight gain by each collection filter [$\Sigma(W_f - W_i)$] is used to calculate the PM_{10} mass concentration.

12.0 References.

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APPENDIX K TO PART 50—INTERPRETATION OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

1.0 General.

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This appendix explains the computations necessary for analyzing particulate matter data to determine attainment of the 24-hour and annual standards specified in 40 CFR 50.6. For the primary and secondary standards, particulate matter is measured in the ambient air as PM_{10} (particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers) by a reference method based on Appendix J of this part and designated in accordance with part 53 of this chapter, or by an equivalent method designated in accordance with part 53 of this chapter. The required frequency of measurements is specified in part 58 of this chapter.

Several terms used throughout this appendix must be defined. A "daily value" for PM_{10} refers to the 24-hour average concentration of PM_{10} calculated or measured from midnight to midnight (local time). The term "exceedance" means a daily value that is above the level of the 24-hour standard after rounding to the nearest $10 \mu g/m^3$ (i.e., values ending in 5 or greater are to be rounded up). The term "average" refers to an arithmetic mean. All particulate matter standards are expressed in terms of expected annual values: expected number of exceedances per year for the 24-hour standards and expected annual arithmetic mean for the annual standards. The "expected annual value" is the number approached when the annual values from an increasing number of years are averaged, in the absence of long-term trends in emissions or meteorological conditions. The term "year" refers to a calendar year.

Although the discussion in this appendix focuses on monitored data, the same principles apply to modeling data, subject to EPA modeling guidelines.

2.0 Attainment Determinations.

2.1 24-Hour Primary and Secondary Standards.

Under 40 CFR 50.6(a) the 24-hour primary and secondary standards are attained when the expected number of exceedances per year at each monitoring site is less than or equal to one. In the simplest case, the number of expected exceedances at a site is determined by recording the number of exceedances in each calendar year and then averaging them over the past 3 calendar years. Situations in which 3 years of data are not available and possible adjustments for unusual events or trends are discussed in Sections 2.3 and 2.4. Further, when data for a year are incomplete, it is necessary to compute an estimated number of exceedances for that year by adjusting the observed number of exceedances. This procedure, performed by calendar quarter, is described in Section 3. The expected number of exceedances is then estimated by averaging the individual annual estimates for the past 3 years.

The comparison with the allowable expected exceedance rate of one per year is made in terms of a number rounded to the nearest tenth (fractional values equal to or greater than 0.05 are to be rounded up; e.g., an exceedance rate of 1.05 would be rounded to 1.1, which is the lowest rate for nonattainment).

2.2 Annual Primary and Secondary Standards.

Under 40 CFR 50.6(b), the annual primary and secondary standards are attained when the expected annual arithmetic mean PM_{10} concentration is less than or equal to the level of the standard. In the simplest case, the expected annual arithmetic mean is determined by averaging the annual arithmetic mean PM_{10} concentrations for the past 3 calendar years. Because of the potential for incomplete data and the possible seasonality in PM_{10} concentrations, the annual mean shall be calculated by averaging the four quarterly means of PM_{10} concentrations within the calendar year. The formulas for calculating the annual arithmetic mean are given in Section 4. Situations in which 3 years of data are not available and possible adjustments for unusual events or trends are discussed in Sections 2.3 and 2.4. The expected annual arithmetic mean is rounded to the nearest $1 \mu g/m^3$ before comparison with the annual standards (fractional values equal to or greater than 0.5 are to be rounded up).

2.3 Data Requirements.

40 CFR 58.13 specifies the required minimum frequency of sampling for PM_{10} . For the purposes of making comparisons with the particulate matter standards, all data produced by National Air Monitoring Stations (NAMS), State and Local Air Monitoring Stations (SLAMS) and other sites submitted to EPA in accordance with the Part 58 requirements must be used, and a minimum of 75 percent of the scheduled PM_{10} samples per quarter are required.

To demonstrate attainment of either the annual or 24-hour standards at a monitoring site, the monitor must provide sufficient data to perform the required calculations of Sections 3 and 4. The amount of data required varies with the sampling frequency, data capture rate and the number of years of record. In all cases, 3 years of representative monitoring data that meet the 75 percent criterion of the previous paragraph should be utilized, if available, and would suffice. More than 3 years may be considered, if all additional representative years of data meeting the 75 percent criterion are utilized. Data not meeting these criteria may also suffice to show attainment; however, such exceptions will have to be approved by the appropriate Regional Administrator in accordance with EPA guidance.

There are less stringent data requirements for showing that a monitor has failed an attainment test and thus has recorded a violation of the particulate matter standards. Although it is generally necessary to meet the minimum 75 percent data capture requirement per quarter to use the computational formulas described in Sections 3 and 4, this criterion does not apply when less data is sufficient to unambiguously establish nonattainment. The following examples illustrate how nonattainment can be demonstrated when a site fails to meet the completeness criteria. Nonattainment of the 24-hour primary standards can be established by (a) the observed annual number of exceedances (e.g. four observed exceedances in a single year), or by (b) the estimated number of exceedances derived from the observed number of exceedances and the required number of scheduled samples (e.g. two observed exceedances with every other day sampling). Nonattainment of the annual standards can be demonstrated on the basis of quarterly mean concentrations developed from observed data combined with one-half the minimum detectable concentration substituted for missing values. In both cases, expected annual values must exceed the levels allowed by the standards.

2.4 Adjustment for Exceptional Events and Trends

An exceptional event is an uncontrollable event caused by natural sources of particulate matter or an event that is not expected to recur at a given location. Inclusion of such a value in the computation of exceedances or averages could result in inappropriate estimates of their respective expected annual values. To reduce the effect of unusual events, more than 3 years of representative data may be used. Alternatively, other techniques, such as the use of statistical models or the use of historical data could be considered so that the event may be discounted or weighted according to the likelihood that it will recur. The use of such techniques is subject to the approval of the appropriate Regional Administrator in accordance with EPA guidance.

In cases where long-term trends in emissions and air quality are evident, mathematical techniques should be applied to account for the trends to ensure that the expected annual values are not inappropriately biased by unrepresentative data. In the simplest case, if 3 years of data are available under stable emission conditions, this data should be used. In the event of a trend or shift in emission patterns, either the most recent representative years could be used or statistical techniques or models could be used in conjunction with previous years of data to adjust for trends. The use of less than 3 years of data, and any adjustments are subject to the approval of the appropriate

ate Regional Administrator in accordance with EPA guidance.

3.0 Computational formulas for the 24-hour standards

3.1 Estimating Exceedances for a year

If PM₁₀ sampling is scheduled less frequently than every day, or if some scheduled samples are missed, a PM₁₀ value will not be available for each day of the year. To account for the possible effect of incomplete data, an adjustment must be made to the data collected at each monitoring location to estimate the number of exceedances in a calendar year. In this adjustment, the assumption is made that the fraction of missing values that would have exceeded the standard level is identical to the fraction of measured values above this level. This computation is to be made for all sites that are scheduled to monitor throughout the entire year and meet the minimum data requirements of Section 2.3. Because of possible seasonal imbalance, this adjustment shall be applied on a quarterly basis. The estimate of the expected number of exceedances for the quarter is equal to the observed number of exceedances plus an increment associated with the missing data. The following formula must be used for these computations:

$$e_q = v_q + [(v_q/n_q) \times (N_q - n_q)] = v_q \times N_q/n_q \quad [1]$$

where

e_q = the estimated number of exceedances for calendar quarter q .

v_q = the observed number of exceedances for calendar quarter q .

N_q = the number of days in calendar quarter q .

n_q = the number of days in calendar quarter q with PM₁₀ data, and

q = the index for calendar quarter, $q=1, 2, 3$ or 4.

The estimated number of exceedances for a calendar quarter must be rounded to the nearest hundredth (fractional values equal to or greater than 0.005 must be rounded up).

The estimated number of exceedances for the year, e , is the sum of the estimates for each calendar quarter.

$$e = \sum_{q=1}^4 e_q \quad [2]$$

The estimated number of exceedances for a single year must be rounded to one decimal place (fractional values equal to or greater than 0.05 must be rounded up).

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expected number of exceedances is then estimated by averaging the individual annual estimates for the most recent 3 or more representative years of data. The expected number of exceedances must be rounded to one decimal place (fractional values equal to or greater than 0.05 are to be rounded up). The adjustment for incomplete data will not be necessary for monitoring or modeling data which constitutes a complete record, i.e., 365 days per year.

To reduce the potential for overestimating the number of expected exceedances, the correction for missing data will not be required for a calendar quarter in which the first observed exceedance has occurred if: (a) there was only one exceedance in the calendar quarter, (b) everyday sampling is subsequently initiated and maintained for 4 calendar quarters in accordance with 40 CFR 58.13 and (c) data capture of 75 percent is achieved during the required period of everyday sampling. In addition, if the first exceedance is observed in a calendar quarter in which the monitor is already sampling every day, no adjustment for missing data will be made to the first exceedance if a 75 percent data capture rate was achieved in the quarter in which it was observed.

Example 1

During a particular calendar quarter, 39 out of a possible 92 samples were recorded, with one observed exceedance of the 24-hour standard. Using formula [1], the estimated number of exceedances for the quarter is

$$e_q = 1 \times 92/39 = 2.359 \text{ or } 2.36$$

If the estimated exceedances for the other 3 calendar quarters in the year were 2.30, 0.0 and 0.0, then, using formula [2], the estimated number of exceedances for the year is $2.36 + 2.30 + 0.0 + 0.0$ which equals 4.66 or 4.7. If no exceedances were observed for the 2 previous years, then the expected number of exceedances is estimated by:

$$(1/3) \times (4.7 + 0 + 0) = 1.57$$

or 1.6. Since 1.6 exceeds the allowable number of expected exceedances, this monitoring site would fail the attainment test.

Example 2

In this example, everyday sampling was initiated following the first observed exceedance as required by 40 CFR 58.13. Accordingly, the first observed exceedance would not be adjusted for incomplete sampling. During the next three quarters, 1.2 exceedances were estimated. In this case, the estimated exceedances for the year would be $1.0 + 1.2 + 0.0 + 0.0$ which equals 2.2. If, as before, no exceedances were observed for the two previous years, then the expected

then be $(1/3) \times (2.2 + 0.0 + 0.0) = 0.7$, and the monitoring site would not fail the attainment test.

3.2 Adjustments for Non-Scheduled Sampling Days

If a systematic sampling schedule is used and sampling is performed on days in addition to the days specified by the systematic sampling schedule, e.g., during episodes of high pollution, then an adjustment must be made in the formula for the estimation of exceedances. Such an adjustment is needed to eliminate the bias in the estimate of the quarterly and annual number of exceedances that would occur if the chance of an exceedance is different for scheduled than for non-scheduled days, as would be the case with episode sampling.

The required adjustment treats the systematic sampling schedule as a stratified sampling plan. If the period from one scheduled sample until the day preceding the next scheduled sample is defined as a sampling stratum, then there is one stratum for each scheduled sampling day. An average number of observed exceedances is computed for each of these sampling strata. With nonscheduled sampling days, the estimated number of exceedances is defined as

$$e_q = (N_q/m_q) \times \sum_{j=1}^{m_q} (v_j/k_j) \quad [3]$$

where

e_q = the estimated number of exceedances for the quarter.

N_q = the number of days in the quarter.

m_q = the number of strata with samples during the quarter.

v_j = the number of observed exceedances in stratum j , and

k_j = the number of actual samples in stratum j .

Note that if only one sample value is recorded in each stratum, then formula [3] reduces to formula [1].

Example 3

A monitoring site samples according to a systematic sampling schedule of one sample every 6 days, for a total of 15 scheduled samples in a quarter out of a total of 92 possible samples. During one 6-day period, potential episode levels of PM₁₀ were suspected, so 5 additional samples were taken. One of the regular scheduled samples was missed, so a total of 19 samples in 14 sampling strata were measured.

with one sample per stratum recorded zero exceedances. Using formula (3), the estimated number of exceedances for the quarter is $e_q = (92/14) \times (2/6 + 0 + \dots + 0) = 2.19$

4.0 Computational Formulas for Annual Standards.

4.1 Calculation of the Annual Arithmetic Mean.

An annual arithmetic mean value for PM_{10} is determined by averaging the quarterly means for the 4 calendar quarters of the year. The following formula is to be used for calculation of the mean for a calendar quarter:

$$\bar{x}_q = (1/n_q) \times \sum_{i=1}^{n_q} x_i \quad (4)$$

where

\bar{x}_q = the quarterly mean concentration for quarter q , $q=1, 2, 3$, or 4 ,

n_q = the number of samples in the quarter, and

x_i = the i th concentration value recorded in the quarter.

The quarterly mean, expressed in $\mu\text{g}/\text{m}^3$, must be rounded to the nearest tenth (fractional values of 0.05 should be rounded up).

The annual mean is calculated by using the following formula:

$$\bar{x} = (1/4) \times \sum_{q=1}^4 \bar{x}_q \quad (5)$$

where

\bar{x} = the annual mean, and

\bar{x}_q = the mean for calendar quarter q .

The average of quarterly means must be rounded to the nearest tenth (fractional values of 0.05 should be rounded up).

The use of quarterly averages to compute the annual average will not be necessary for monitoring or modeling data which results in a complete record, i.e., 365 days per year.

The expected annual mean is estimated as the average of three or more annual means. This multi-year estimate, expressed in $\mu\text{g}/\text{m}^3$, shall be rounded to the nearest integer for comparison with the annual standard (fractional values of 0.5 should be rounded up).

Example 4

Using formula (4), the quarterly means are calculated for each calendar quarter. If the quarterly means are 52.4, 75.3, 82.1, and 83.2 $\mu\text{g}/\text{m}^3$, then the annual mean is

$$\bar{x} = (1/4) \times (52.4 + 75.3 + 82.1 + 83.2) = 68.25 \text{ or } 68.3$$

4.2 Adjustments for Non-scheduled Sampling Days.

An adjustment in the calculation of the annual mean is needed if sampling is performed on days in addition to the days specified by the systematic sampling schedule. For the same reasons given in the discussion of estimated exceedances (Section 3.2), the quarterly averages would be calculated by using the following formula:

$$\bar{x}_q = (1/m_q) \times \sum_{j=1}^{m_q} \sum_{i=1}^{k_j} (x_{qj}/k_j) \quad (6)$$

where

\bar{x}_q = the quarterly mean concentration for quarter q , $q=1, 2, 3$, or 4 ,

x_{qj} = the i th concentration value recorded in stratum j ,

k_j = the number of actual samples in stratum j , and

m_q = the number of strata with data in the quarter.

If one sample value is recorded in each stratum, formula (6) reduces to a simple arithmetic average of the observed values as described by formula (4).

Example 5

During one calendar quarter, 9 observations were recorded. These samples were distributed among 7 sampling strata, with 3 observations in one stratum. The concentrations of the 3 observations in the single stratum were 202, 242, and 180 $\mu\text{g}/\text{m}^3$. The remaining 6 observed concentrations were 55, 68, 73, 92, 120, and 155 $\mu\text{g}/\text{m}^3$. Applying the weighting factors specified in formula (6), the quarterly mean is

$$\bar{x}_q = (1/7) \times [(1/3) \times (202 + 242 + 180) + 55 + 68 + 73 + 92 + 120 + 155] = 110.1$$

Although 24-hour measurements are rounded to the nearest 10 $\mu\text{g}/\text{m}^3$ for determinations of exceedances of the 24-hour standard, note that these values are rounded to the nearest 1 $\mu\text{g}/\text{m}^3$ for the calculation of means.

Environmental Protection Agency

(52 FR 24667, July 1, 1987; 52 FR 26402, July 14, 1987; 52 FR 29382, Aug. 7, 1987; 52 FR 31701, Aug. 21, 1987)

Sec.

51.104 Revisions.

51.105 Approval of plans.

Subpart G—Control Strategy

- 51.110 Attainment and maintenance of national standards.
- 51.111 Description of control measures.
- 51.112 Demonstration of adequacy.
- 51.113 Time period for demonstration of adequacy.
- 51.114 Emissions data and projections.
- 51.115 Air quality data and projections.
- 51.116 Data availability.
- 51.117 Additional provisions for lead.
- 51.118 Stack height provisions.
- 51.119 Intermittent control systems.

PART 51—REQUIREMENTS FOR PREPARATION, ADOPTION, AND SUBMITTAL OF IMPLEMENTATION PLANS

Subparts A—C—[Reserved]

Subpart D—Maintenance of National Standards

Sec.

51.40 Scope.

AQMA ANALYSIS

- 51.41 AQMA analysis: Submittal date.
- 51.42 AQMA analysis: Analysis period.
- 51.43 AQMA analysis: Guidelines.
- 51.44 AQMA analysis: Projection of emissions.
- 51.45 AQMA analysis: Allocation of emissions.
- 51.46 AQMA analysis: Projection of air quality concentrations.
- 51.47 AQMA analysis: Description of data sources.
- 51.48 AQMA analysis: Data bases.
- 51.49 AQMA analysis: Techniques description.
- 51.50 AQMA analysis: Accuracy factors.
- 51.51 AQMA analysis: Submittal of calculations.

AQMA PLAN

- 51.52 AQMA plan: General.
- 51.53 AQMA plan: Demonstration of adequacy.
- 51.54 AQMA plan: Strategies.
- 51.55 AQMA plan: Legal authority.
- 51.56 AQMA plan: Future strategies.
- 51.57 AQMA plan: Future legal authority.
- 51.58 AQMA plan: Intergovernmental cooperation.
- 51.59 [Reserved]
- 51.60 AQMA plan: Resources.
- 51.61 AQMA plan: Submittal format.
- 51.62 AQMA analysis and plan: Data availability.
- 51.63 AQMA analysis and plan: Alternative procedures.

Subpart E—[Reserved]

Subpart F—Procedural Requirements

- 51.100 Definitions.
- 51.101 Stipulations.
- 51.102 Public hearings.
- 51.103 Submission of plans; preliminary review of plans.

Subpart H—Prevention of Air Pollution Emergency Episodes

- 51.150 Classification of regions for episode plans.
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- 51.152 Contingency plans.
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- 51.160 Legally enforceable procedures.
- 51.161 Public availability of information.
- 51.162 Identification of responsible agency.
- 51.163 Administration procedures.
- 51.164 Stack height procedures.
- 51.165 Permit requirements.
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Subpart J—Ambient Air Quality Surveillance

- 51.190 Ambient air quality monitoring requirements.

Subpart K—Source Surveillance

- 51.210 General.
- 51.211 Emission reports and recordkeeping.
- 51.212 Testing, inspection, enforcement, and complaints.
- 51.213 Transportation control measures.
- 51.214 Continuous emission monitoring.

Subpart L—Legal Authority

- 51.230 Requirements for all plans.
- 51.231 Identification of legal authority.
- 51.232 Assignment of legal authority to local agencies.

Subpart M—Intergovernmental Consultation

AGENCY DESIGNATION

- 51.240 General plan requirements.



U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Atmospheric Research and Exposure
Assessment Laboratory
Methods Research & Development Division (MD-77)
Research Triangle Park, North Carolina 27711
919 541-2622 or 919 541-4599
FTS 629-2622 or FTS 629-4599

Issue Date: February 8, 1993

* Previous Revision: September 28, 1992 *
*
* New Designations: *
* Dasibi Environmental Corporation *
* Model 2108 Oxides of Nitrogen Analyzer *
* Lear Siegler Measurement Controls Corporation *
* Model ML9841 Nitrogen Oxides Analyzer *
* Model ML9810 Ozone Analyzer *
* Model ML9850 Sulfur Dioxide Analyzer *

LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

These methods for measuring ambient concentrations of specified air pollutants have been designated as "reference methods" or "equivalent methods" in accordance with Title 40, Part 53 of the Code of Federal Regulations (40 CFR Part 53). Subject to any limitations (e.g., operating range) specified in the applicable designation, each method is acceptable for use in state or local air quality surveillance systems under 40 CFR Part 58 unless the applicable designation is subsequently canceled. Automated methods are acceptable for use at temperatures between 20°C and 30°C and line voltages between 105 and 125 volts unless wider limits are specified in the method description.

Prospective users of the methods listed should note (1) that each method must be used in strict accordance with the operation or instruction manual and with applicable quality assurance procedures, and (2) that modification of a method by its vendor or user may cause the pertinent designation to be inapplicable to the method as modified. (See Section 2.8 of Appendix C, 40 CFR Part 58 for approval of modifications to any of these methods by users.)

Further information concerning particular designations may be found in the *Federal Register* notice cited for each method or by writing to the Atmospheric Research & Exposure Assessment Laboratory, Methods Research & Development Division (MD-77), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. Technical information concerning the methods should be obtained by writing to the "source" listed for each method. New analyzers or PM₁₀ samplers sold as reference or equivalent methods must carry a label or sticker identifying them as designated methods. For analyzers or PM₁₀ samplers sold prior to the designation, the model number does not necessarily identify an analyzer or sampler as a designated method. Consult the manufacturer or seller to determine if a previously sold analyzer or sampler can be considered a designated method, or if it can be upgraded to designation status. Analyzer users who experience operational or other difficulties with a designated analyzer or sampler and are unable to resolve the problem directly with the instrument manufacturer may contact EPA (preferably in writing) at the above address for assistance.

This list will be revised as necessary to reflect any new designations or any cancellation of a designation currently in effect. The most current revision of the list will be available for inspection at EPA's Regional Offices, and copies may be obtained by writing to the Atmospheric Research & Exposure Assessment Laboratory at the address specified above.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - TSP</u>						
*****	Reference Method for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method)	40 CFR Part 50, Appendix B	Manual	Reference	47 54912 12/06/82 48 17355 04/22/83	
<u>PARTICULATE MATTER - PM₁₀</u>						
*****	Reference Method for the Determination of Particulate Matter as PM ₁₀ in the Atmosphere	40 CFR Part 50, Appendix J	Manual	Reference	52 24664 07/01/87 52 29467 08/07/87	
RFPS-1087-062	"Wedding & Associates' PM ₁₀ Critical Flow High-Volume Sampler," consisting of the following components: Wedding PM ₁₀ Inlet Wedding & Associates' Critical Flow Device Wedding & Associates' Anodized Aluminum Shelter 115, 220 or 240 VAC Motor Blower Assembly Mechanical Timer Or Optional Digital Timer Elapsed Time Indicator Filter Cartridge/Cassette	Wedding & Associates, Inc. P.O. Box 1756 Fort Collins, CO 80522	Manual	Reference	52 37366 10/06/87	

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
RFPS-1287-063	"Sierra-Andersen or General Metal Works Model 1200 PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 1200 PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Cleves, OH 45002	Manual	Reference	52	12/01/87
					53	01/15/88
RFPS-1287-064	"Sierra-Andersen or General Metal Works Model 321-B PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 321-B PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Cleves, OH 45002	Manual	Reference	52	12/01/87
					53	01/15/88

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<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>					
RFPS-1287-065	"Sierra-Andersen or General Metal Works Model 321-C PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 321-C PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	52 45684 12/01/8 53 1062 01/15/81
RFPS-0389-071	"Oregon DEQ Medium Volume PM ₁₀ Sampler" NOTE: This method is not now commercially available.	State of Oregon Department of Environmental Quality Air Quality Division 811 S.W. Sixth Avenue Portland, OR 97204	Manual	Reference	54 12273 03/24/89
RFPS-0789-073	"Sierra-Andersen Models SA241 and SA241M or General Metal Works Models G241 and G241M PM ₁₀ Dichotomous Samplers", consisting of the following components: Sampling Module with SA245h or G245h 10	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works	Manual	Reference	54 31247 07/27/89

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
EQPM-0990-076	<p>"Andersen Instruments Model FH62I-N PM₁₀ Beta Attenuation Monitor," consisting of the following components:</p> <p>FH62I Beta Attenuation 19-inch Control Module SA246b PM₁₀ Inlet (16.7 liter/min) FH101 Vacuum Pump Assembly FH102 Accessory Kit FH107 Roof Flange Kit FH125 Zero and Span PM₁₀ Mass Foil Calibration Kit</p> <p>operated for 24-hour average measurements, with an observing time of 60 minutes, the calibration factor set to 2400, a glass fiber filter tape, an automatic filter advance after each 24-hour sample period, and with or without either of the following options:</p> <p>FHOP1 Indoor Cabinet FHOP2 Outdoor Shelter Assembly</p>	<p>Andersen Instruments, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336</p>	Auto	Equiv.	55 38387	09/18/90
EQPM-1090-079	<p>"Rupprecht & Patashnick TEOM Series 1400 and Series 1400a PM-10 Monitors," consisting of the following components:</p> <p>TEOM Sensor Unit TEOM Control Unit Rupprecht & Patashnick PM-10 Inlet (part number 57-00596) or Sierra-Andersen Model 246b PM-10 Inlet (16.7 liter/min) Flow Splitter Teflon-Coated Glass Fiber Filter Cartridges</p> <p>operated for 24-hour average measurements, with the total mass averaging time set at 300 seconds, the mass rate/mass concentration averaging time set at 300 seconds, the gate time set at 2 seconds, and with or without either of the following options:</p> <p>Tripod Outdoor Enclosure Automatic Cartridge Collection Unit (Series 1400a only)</p>	<p>Rupprecht & Patashnick Co., Inc. 8 Corporate Circle Albany, NY 12203</p>	Auto	Equiv.	55 43406	10/29/90

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
		<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>			
EQPM-0391-081	"Wedding & Associates' PM ₁₀ Beta Gauge Automated Particle Sampler," consisting of the following components: Particle Sampling Module PM ₁₀ Inlet (18.9 liter/min) Inlet Tube and Support Ring Vacuum Pump (115 VAC/60 Hz or 220-240 VAC/50 Hz) operated for 24-hour average measurements with glass fiber filter tape.	Wedding & Associates, Inc. P.O. Box 1756 Fort Collins, CO 80522	Auto	Equiv.	56 9216 03/05/91

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<u>SULFUR DIOXIDE</u>						
*****	Reference Method for the Determination of Sulfur Dioxide in the Atmosphere (Pararosaniline Method)	40 CFR Part 50, Appendix A	Manual	Reference	47 54899 48 17355	12/06/8 04/22/8
EQS-0775-001	"Pararosaniline Method for the Determination of Sulfur Dioxide in the Atmosphere-Technicon I Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	40 34024	08/13/7
EQS-0775-002	"Pararosaniline Method for the Determination of Sulfur Dioxide in the Atmosphere-Technicon II Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv	40 34024	08/13/7
EQSA-1275-005	"Lear Siegler Model SM1000 SO ₂ Ambient Monitor," operated on the 0-0.5 ppm range, at a wavelength of 299.5 nm, with the "slow" (300 second) response time, with or without any of the following options: SM-1 Internal Zero/Span SM-2 Span Timer Card SM-3 0-0.1 Volt Output SM-4 0-5 Volt Output SM-5 Alternate Sample Pump SM-6 Outdoor Enclosure	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	41 3893 41 32946 42 13044 45 1147	01/27/7 08/06/7 03/08/7 01/04/8

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICI VOL. PAGE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-1275-006	"Meloxy Model SA185-2A Sulfur Dioxide Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: S-1 Linearized Output S-2 Modified Recorder Output S-5 Teflon-Coated Block S-6A Reignite Timer Circuit S-7 Press To Read S-11A Manual Zero And Span S-11B Automatic Zero And Span S-13 Status Lights S-14 Output Booster Amplifier S-14B Line Transmitter Board or operated on the 0-1.0 ppm range with either option S-36 or options S-1 and S-24, with or without any of the other options.	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	41 3893 01/27/76 43 38088 08/25/76
	S-18 Rack Mount Conversion S-18A Rack Mount Conversion S-21 Front Panel Digital Volt Meter S-22 Remote Zero/Span Control And Status (Timer) S-22A Remote Zero/Span Control S-23 Automatic Zero Adjust S-23A Automatic/Manual Zero Adjust	S-24 Dual Range Linearized Output S-33 Remote Range Control And Status (Signals) S-34 Remote Control S-35 Front Panel Digital Meter With BCD Output S-36 Dual Range Log-Linear Output S-38 Sampling Mode Status			
EQSA-0276-009	"Thermo Electron Model 43 Pulsed Fluorescent SO ₂ Analyzer," equipped with an aromatic hydrocarbon cutter and operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: 001 Rack Mounting For Standard 19 Inch Relay Rack 002 Automatic Actuation Of Zero And Span Solenoid Valves 003 Type S Flash Lamp Power Supply 004 Low Flow	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	41 8531 02/27/76 41 15363 04/12/76 42 20490 04/20/77 44 21861 04/12/79 45 2700 01/14/80 45 32419 05/16/80

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-0676-010	"Philips PW9755 SO ₂ Analyzer," consisting of the following components: PW9755/02 SO ₂ Monitor with: PW9741/00 SO ₂ Source PW9721/00 Filter Set SO ₂ PW9711/00 Electrolyte SO ₂ PW9750/00 Supply Cabinet PW9750/10 Supply Unit/Coulometric Either PW9731/00 Sampler or PW9731/20 Dust Filter (or vendor-approved alternate particulate filter); operated with a 0-0.5 ppm range and with a reference voltage setting of 760 millivolts; with or without any of the following options: PW9750/30 Frame For MTT PW9750/41 Control Clock 60 Hz	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	41 26252 41 46019 42 28571	06/25/7 10/19/7 06/03/7
EQSA-0876-011	"Philips PW9700 SO ₂ Analyzer," consisting of the following components: PW9710/00 Chemical Unit with: PW9711/00 Electrolyte SO ₂ PW9721/00 Filter Set SO ₂ PW9740/00 SO ₂ Source PW9720/00 Electrical Unit PW9730/00 Sampler Unit (or vendor-approved alternate particulate filter); operated with a 0-0.5 ppm range and with a reference voltage of 760 millivolts.	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	41 34105	08/12/7
EQSA-0876-013	"Monitor Labs Model 8450 Sulfur Monitor," operated on a range of either 0-0.5 or 0-1.0 ppm, with a 5 second time constant, a model 8740 hydrogen sulfide scrubber in the sample line, with or without any of the following options: BP Bipolar Signal Processor CLO Current Loop Output DO Status Remote Interface	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	41 36245 44 33476	08/27/7 06/11/7
		IZS Internal Zero/Span Module TF TFE Sample Particulate Filter		V Zero/Span Valves VT Zero/Span Valves And Timer		

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<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-0877-024	"ASARCO Model 500 Sulfur Dioxide Monitor," operated on a 0-0.5 ppm range; or "ASARCO Model 600 Sulfur Dioxide Monitor," operated on a 0-1.0 ppm range. (Both models are identical except the range.)	ASARCO Incorporated 3422 South 700 West Salt Lake City, UT 84119	Auto	Equiv.	42 44264 44 67522	09/02/77 11/26/79
NOTE: This method is not now commercially available.						
EQSA-0678-029	"Beckman Model 953 Fluorescent Ambient SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a time constant setting of 2, 2.5, or 3 minutes, a 5 to 10 micron membrane filter element installed in the rear-panel filter assembly, with or without any of the following options: a. Remote Operation Kit, Catalog No. 641984 b. Digital Panel Meter, Catalog No. 641710 c. Rack Mount Kit, Catalog No. 641709 d. Panel Mount Kit, Catalog No. 641708	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Equiv.	43 35995	08/14/78
EQSA-1078-030	"Bendix Model 8303 Sulfur Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a Teflon filter installed on the sample inlet of the H ₂ S scrubber assembly.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Equiv.	43 50733	10/31/78

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
SULFUR DIOXIDE (Continued)						
EQSA-1078-032	"Meloy Model SA285E Sulfur Dioxide Analyzer," operated on the following ranges and time constant switch positions:	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	43 50733	10/31/78
	<u>Range, ppb</u> <u>Time Constant Setting</u>	*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.				
	0-50* 1 or 10					
	0-100* 1 or 10					
	0-500 off, 1 or 10					
	0-1000 off, 1 or 10					
The analyzer may be operated at temperatures between 10°C and 40°C and at line voltages between 105 and 130 volts, with or without any of the following options:						
	S-5 Teflon Coated Block	S-22B Remote Zero/Span Control	S-30 Auto Reignite			
	S-14B Line Transmitter Board	And Status (Pulse)	S-32 Remote Range Control And Status			
	S-18 Rack Mount Conversion	S-23 Auto Zero Adjust	S-35 Front Panel Digital Meter With BCD Output			
	S-18A Rack Mount Conversion	S-23A Auto/Manual Zero Adjust	S-37 Temperature Status Lights			
	S-21 Front Panel Digital Meter	S-25 Press To Read	S-38 Sampling Mode Status			
	S-22 Remote Zero/Span Control	S-26 Manual Zero And Span				
	And Status (Timer)	S-27 Auto Manual Zero/Span				
	S-22A Remote Zero/Span Control	S-28 Auto Range And Status				
EQSA-0779-039	"Monitor Labs Model 8850 Fluorescent SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with an internal time constant setting of 55 seconds, a TFE sample filter installed on the sample inlet line, with or without any of the following options:	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	44 44616	07/30/79
	03A Rack	06B,C,D NBS Traceable Permeation Tubes	013 Recorder Output Options			
	03B Slides	08A Pump	014 DAS Output Options			
	05A Valves Zero/Span	09A Rack Mount For Option 08A	017 Low Flow Option			
	06A IZS Internal Zero/Span Source	010 Status Output W/Connector	018 Kicker			

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
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SULFUR DIOXIDE (Continued)

EQSA-0580-046	<p>"Meloxy Model SA 700 Fluorescence Sulfur Dioxide Analyzer," operated on the 0-250 ppb*, the 0-500 ppb, or the 0-1000 ppb range with a time constant switch position of either 2 or 3. The analyzer may be operated at temperatures between 20°C and 30°C and at line voltages between 105 and 130 volts, with or without any of the following options:</p> <ul style="list-style-type: none"> FS-1 Current Output FS-2 Rack Mount Conversion FS-2A Rack Mount Conversion FS-2B Rack Mount Conversion FS-3 Front Panel Mounted Digital Meter FS-5 Auto/Manual Zero/Span With Status FS-6 Remote/Manual Zero/Span With Status FS-7 Auto Zero Adjust 	<p>Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759</p>	Auto	Equiv.	<p>45 31488 05/13/80</p>
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*NOTE: Users should be aware that designation of this analyzer for operation on a range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of this lower range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

EQSA-1280-049	<p>"Lear Siegler Model AM2020 Ambient SO₂ Monitor," operated on a range of either 0-0.5 or 0-1.0 ppm, at a wavelength of 299.5 nm, with a 5 minute integration period, over any 10°C temperature range between 20°C and 45°C, with or without the automatic zero and span correction feature.</p>	<p>Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189</p>	Auto	Equiv.	<p>45 79574 12/01/80 46 9997 01/30/81</p>
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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-0486-060	"Thermo Electron Instruments, Inc. Model 43A Pulsed Fluorescent Ambient SO ₂ Analyzer," operated on the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range with either a high or a low time constant setting and with or without any of the following options: 001 Teflon Particulate Filter Kit 002 Rack Mount	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	51 12390	04/10/86
*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.						
EQSA-1086-061	"Dasibi Model 4108 U.V. Fluorescence SO ₂ Analyzer," operated with a range of 0-100 ppb*, 0-200 ppb*, 0-500 ppb, or 0-1000 ppb, with a Teflon-coated particulate filter and a continuous hydrocarbon removal system, with or without any of the following options: a. Rack Mounting Brackets And Slides	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Equiv.	51 32244	09/10/86
b. RS-232-C Interface c. Temperature Correction						
*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.						
EQSA-0390-075	"Monitor Labs Model 8850S SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	55 5264	02/14/90

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-0990-077	"Advanced Pollution Instrumentation, Inc. Model 100 Fluorescent SO ₂ Analyzer," operated on the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range with a 5-micron TFE filter element installed in the rear-panel filter assembly, either a user- or vendor-supplied vacuum pump capable of providing 20 inches of mercury vacuum at 2.5 L/min, with or without any of the following options: Internal Zero/Span Pump Pack Rack Mount With Slides RS-232 Interface Status Output TFE Zero/Span Valves Zero Air Scrubber	Advanced Pollution Instrumentation, Inc. 8815 Production Avenue San Diego, CA 92121-2219	Auto	Equiv.	55 38149	09/17/90
<p>*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.</p>						
EQSA-0292-084	"Environnement S.A. Model AF21M Sulfur Dioxide Analyzer," operated on a range of 0-0.5 ppm with a response time coefficient setting of 01, a Teflon filter installed in the rear-panel filter assembly, and with or without any of the following options: Rack Mount/Slides RS-232-C Interface	Environnement S.A. 111, bd Robespierre 78300 Poissy, France	Auto	Equiv.	57 5444	02/14/92

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
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SULFUR DIOXIDE (Continued)

EQSA-0193-092	<p>"Lear Siegler Measurement Controls Corporation Model ML9850 Sulfur Dioxide Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i>, at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Background: Not <i>Disabled</i>; Calibration; <i>Manual</i> or <i>Timed</i>; Diagnostic Mode: <i>Operate</i>; Filter Type: <i>Kalman</i>; Pres/Temp/Flow Comp: <i>On</i>; Span Comp: <i>Disabled</i>; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA; and with or without any of the following options: Valve Assembly for External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive.</p>	<p>Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189</p>	Auto	Equiv.	58 6964 02/03/93
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*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>OZONE</u>						
RFOA-1075-003	"Meloy Model OA325-2R Ozone Analyzer," operated with a scale range of 0-0.5 ppm, with or without any of the following options: 0-4 Output Booster Amplifier	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759 0-18 Rack Mount Conversion	Auto	Reference	40 54856	11/26/75
RFOA-1075-004	"Meloy Model OA350-2R Ozone Analyzer," operated with a scale range of 0-0.5 ppm, with or without any of the following options: 0-2 Automatic Zero And Span 0-3 Remote Control Zero And Span	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759 0-4 Output Booster Amplifier 0-18 Rack Mount Conversion	Auto	Reference	40 54856	11/26/75
RFOA-0176-007	Bendix or Combustion Engineering Model 8002 Ozone Analyzer, operated on the 0-0.5 ppm range, with a 40 second time constant, with or without any of the following options: A Rack Mounting With Chassis Slides	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901 B Rack Mounting Without Chassis Slides	Auto	Reference	41 5145 45 18474	02/04/76 03/21/80
RFOA-1076-014	"MEC Model 1100-1 Ozone Meter,"	Columbia Scientific Industries	Auto	Reference	41 46647	10/22/76
RFOA-1076-015	"MEC Model 1100-2 Ozone Meter,"	Columbia Scientific Industries			42 30235	06/13/77
RFOA-1076-016	"MEC Model 1100-3 Ozone Meter," operated on a 0-0.5 ppm range, with or without any of the following options: 0011 Rack Mounting Ears 0012 Instrument Bail	11950 Jollyville Road Austin, TX 78759 0016 Chassis Slide Kit 0026 Alarm Set Feature				
					0033 Local-Remote Sample, Zero, Span Kit 0040 Ethylene/CO ₂ Blend Feature	

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<u>OZONE (Continued)</u>					
RFOA-1176-017	"Monitor Labs Model 8410E Ozone Analyzer," operated on a range of 0-0.5 ppm with a time constant setting of 5 seconds, with or without any of the following options: DO Status Outputs ER Ethylene Regulator Assembly TF TFE Sample Particulate Filter V TFE Zero/Span Valves VT TFE Zero/Span Valves And Timer	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	41 53684 12/08/76
EQOA-0577-019	"Dasibi Model 1003-AH, 1003-PC, or 1003-RS Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: Adjustable Alarm Aluminum Coated Absorption Tubes BCD Digital Output Glass (Pyrex) Absorption Tubes Integrated Output Rack Mounting Ears And Slides Teflon-based Solenoid Valve Vycor-Jacketed U.V. Source Lamp 0-10 mV, 0-100 mV, 0-1 V, or 0-10 V Analog Output	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Equiv.	42 28571 06/03/77
RFOA-0577-020	"Beckman Model 950A Ozone Analyzer," operated on a range of 0-0.5 ppm and with the "SLOW" (60 second) response time, with or without any of the following options: Internal Ozone Generator	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634 Computer Adaptor Kit	Auto	Reference	42 28571 06/3/77 Pure Ethylene Accessory

February 8, 1993

LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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		<u>OZONE (Continued)</u>			
EQOA-0777-023	"Philips PW9771 O3 Analyzer," consisting of the following components: PW9771/00 O3 Monitor with: PW9724/00 Disc.-Set PW9750/00 Supply Cabinet PW9750/20 Supply Unit; operated on a range of 0-0.5 ppm, with or without any of the following accessories: PW9732/00 Sampler Line Heater PW9733/00 Sampler PW9750/30 Frame For MTT PW9750/41 Control Clock 60 Hz PW9752/00 Air Sampler Manifold	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	42 38931 08/01/7 42 57156 11/01/7
RFOA-0279-036	"Columbia Scientific Industries Model 2000 Ozone Meter," when operated on the 0-0.5 ppm range with either AC or battery power: The BCA 952 battery charger/AC adapter M952-0002 (115V) or M952-0003 (230V) is required for AC operation; an internal battery M952-0006 or 12 volt external battery is required for portable non-AC powered operation.	Columbia Scientific Industries 11950 Jollyville Rd. Austin, TX 78759	Auto	Reference	44 10429 02/20/79
EQOA-0880-047	"Thermo Electron Model 49 U.V. Photometric Ambient O ₃ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: 49-001 Teflon Particulate Filter	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	45 57168 08/27/80

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<u>OZONE (Continued)</u>							
EQOA-0881-053	"Monitor Labs Model 8810 Photo-metric Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with selectable electronic time constant settings from 20 through 150 seconds, with or without any of the following options: 05 Pressure Compensation 06 Averaging Option 07 Zero/Span Valves 08 Internal Zero/Span (Valve And Ozone Source) 09 Status 10 Particulate Filter 15 through 20 DAS/REC Output	Lear Siegler Measurement Control Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	46	52224	10/26/81
EQOA-0382-055	"PCI Ozone Corporation Model LC-12 Ozone Analyzer," operated on a range of 0-0.5 ppm.	PCI Ozone Corporation One Fairfield Crescent West Caldwell, NJ 07006	Auto	Equiv.	47	13572	03/31/82
EQOA-0383-056	"Dasibi Model 1008-AH, 1008-PC, or 1008-RS Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: Aluminum Coated Absorption Tubes BCD Digital Output Glass (Pyrex) Absorption Tubes Ozone Generator Photometer Flow Restrictor (2 LPM) Rack Mounting Brackets or Slides RS232 Interface Vycor-Jacketed U.V. Source Lamp Teflon-based Solenoid Valve 4-20 mA, Isolated, or Dual Analog Outputs 20 Second Update Software	Dasibi Environmental Corp. 515 West Colorado St. Glendale, CA 91204-1101	Auto	Equiv.	48	10126	03/10/83

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<u>OZONE (Continued)</u>						
EQOA-0990-078	"Enviro-nics Series 300 Computerized Ozone Analyzer," operated on the 0-0.5 ppm range, with the following parameters entered into the analyzer's computer system: Absorption Coefficient = 308 ± 4 Flush Time = 3 Integration Factor = 1 Offset Adjustment = 0.025 ppm Ozone Average Time = 4 Signal Average = 0 Temp/Press Correction = On and with or without the RS-232 Serial Data Interface.	Enviro-nics, Inc. 165 River Road West Willington, CT 06279	Auto	Equiv.	55 38386	09/18/90
EQOA-0992-087	"Advanced Pollution Instrumentation, Inc. Model 400 Ozone Analyzer," operated on any full scale range between 0-100 ppb* and 0-1000 ppb, at any temperature in the range of 5°C to 40°C, with the dynamic zero and span adjustment features set to OFF, with a 5-micron TFE filter element installed in the rear-panel filter assembly, and with or without any of the following options: Internal Zero/Span (IZS) IZS Reference Adjustment Rack Mount With Slides RS-232 With Status Outputs Zero/Span Valves	Advanced Pollution Instrumentation, Inc. 8815 Production Avenue San Diego, CA 92121-2219	Auto	Equiv.	57 44565	09/28/92

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0-500 ppb is based on meeting the same absolute performance specifications required for the 0-500 ppb range. Thus, designation of any range lower than 0-500 ppb does not imply commensurably better performance than that obtained on the 0-500 ppb range.

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OZONE (Continued)

EQOA-0193-091	<p>"Lear Siegler Measurement Controls Corporation Model ML9810 Ozone Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i>, at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Calibration; <i>Manual</i> or <i>Timed</i>; Diagnostic Mode: <i>Operate</i>; Filter Type: <i>Kalman</i>; Pres/Temp/Flow Comp: <i>On</i>; Span Comp: <i>Disabled</i>;</p> <p>with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings:</p> <p>Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA;</p> <p>and with or without any of the following options:</p> <p>Valve Assembly for External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive.</p>	<p>Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189</p>	Auto	Equiv.	58 6964 02/03/93
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*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>CARBON MONOXIDE</u>						
RFCA-0276-008	Bendix or Combustion Engineering Model 8501-5CA Infrared CO Analyzer, operated on the 0-50 ppm range and with a time constant setting between 5 and 16 seconds, with or without any of the following options: A Rack Mounting With Chassis Slides B Rack Mounting Without Chassis Slides C External Sample Pump	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	41 7450	02/18/76
RFCA-0876-012	"Beckman Model 866 Ambient CO Monitoring System," consisting of the following components: Pump/Sample-Handling Module, Gas Control Panel, Model 865-17 Analyzer Unit, Automatic Zero/Span Standardizer; operated with a 0-50 ppm range, a 13 second electronic response time, with or without any of the following options: Current Output Feature Bench Mounting Kit Linearizer Circuit	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Reference	41 36245	08/27/76
RFCA-0177-018	"LIRA Model 202S Air Quality Carbon Monoxide Analyzer System," consisting of a LIRA Model 202S optical bench (P/N 459839), a regenerative dryer (P/N 464084), and rack-mounted sampling system; operated on a 0-50 ppm range, with the slow response amplifier, with or without any of the following options: Remote Meter Remote Zero And Span Controls 0-1, 5, 20, or 50 mA Output 1-5, 4-20, or 10-50 mA Output 0-10 or 100 mV Output 0-1, 5, or 10 Volt Output	Mine Safety Appliances Co. 600 Penn Center Boulevard Pittsburgh, PA 15208	Auto	Reference	42 5748	01/31/77

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE DATE</u>
<u>CARBON MONOXIDE (Continued)</u>					
RFCA-1278-033	"Horiba Models AQM-10, AQM-11, and AQM-12 Ambient CO Monitoring Systems," operated on the 0-50 ppm range, with a response time setting of 15.5 seconds, with or without any of the following options: a AIC-101 Automatic Indication Corrector b VIT-3 Non-Isolated Current Output c ISO-2 and DCS-3 Isolated Current Output	Horiba Instruments, Inc. 17671 Armstrong Avenue Irvine, CA 92714-5727	Auto	Reference	43 58429 12/14/78
RFCA-0979-041	"Monitor Labs Model 8310 CO Analyzer," operated on the 0-50 ppm range, with a sample inlet filter, with or without any of the following options: 02A Zero/Span Valves 03A Floor Stand 04A Pump (60 Hz)	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	44 54545 09/20/79 45 2700 01/14/80
		04B Pump (50 Hz) 05A CO Regulator 06A CO Cylinder		07A Zero/Span Valve Power Supply 08A Calibration Valves 9A,B,C,D Input Power Transformer	
RFCA-1180-048	"Horiba Model APMA-300E Ambient Carbon Monoxide Monitoring System," operated on the 0-20 ppm*, the 0-50 ppm, or the 0-100 ppm range with a time constant switch setting of No. 5. The monitoring system may be operated at temperatures between 10°C and 40°C.	Horiba Instruments, Inc. 17671 Armstrong Avenue Irvine, CA 92714-5727	Auto	Reference	45 72774 11/03/80

*NOTE: Users should be aware that designation of this analyzer for operation on a range less than 50 ppm is based on meeting the same absolute performance specifications required for the 0-50 ppm range. Thus, designation of this lower range does not imply commensurably better performance than that obtained on the 0-50 ppm range.

(This method was originally designated as "Horiba Model APMA 300E/300SE Ambient Carbon Monoxide Monitoring System".)

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<u>CARBON MONOXIDE (Continued)</u>						
RFCA-1280-050	"MASS-CO, Model 1 Carbon Monoxide Analyzer," operated on a range of 0-50 ppm, with automatic zero and span adjustments at time intervals not to exceed 4 hours, with or without the 100 millivolt and 5 volt output options. The method consists of the following components: (1) Infra-2 (Uras 2) Infrared Analyzer Model 5611-200-35, (2) Automatic Calibrator Model 5869-111, (3) Electric Gas Cooler Model 7865-222 or equivalent with prehumidifier, (4) Diaphragm Pump Model 5861-214 or equivalent, (5) Membrane Filter Model 5862-111 or equivalent, (6) Flow Meter Model SK 1171-U or equivalent, (7) Recorder Model Mini Comp DN 1/192 or equivalent	Commonwealth of Massachusetts Auto Department of Environmental Quality Engineering Tewksberry, MA 01876		Reference	45 81650	12/11/80
NOTE: This method is not now commercially available.						
RFCA-0381-051	"Dasibi Model 3003 Gas Filter Correlation CO Analyzer," operated on the 0-50 ppm range, with a sample particulate filter installed on the sample inlet line, 3-001 Rack Mount 3-002 Remote Zero And Span	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101 with or without any of the following options: 3-003 BCD Digital Output 3-004 4-20 Milliamp Output	Auto	Reference	46 20773	04/07/81
RFCA-0981-054	"Thermo Environmental Instruments Model 48 Gas Filter Correlation Ambient CO Analyzer," operated on the 0-50 ppm range, with a time constant setting of 30 seconds, with or without any of the following options: 48-001 Particulate Filter 48-002 19 Inch Rack Mountable Configuration 48-003 Internal Zero/Span Valves With Remote Activation 48-488 GPIB (General Purpose Interface Bus) IEEE-488 48-010 Internal Zero Air Package	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	46 47002	09/23/81

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<u>CARBON MONOXIDE (Continued)</u>					
RFCA-0388-066	"Monitor Labs Model 8830 CO Analyzer," operated on the 0-50 ppm range, with a five micron Teflon filter element installed in the rear-panel filter assembly, with or without any of the following options: 2 Zero/Span Valve Assembly 3 Rack Assembly 4 Slide Assembly 7 230 VAC, 50/60 Hz	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	53 7233 03/07/88
RFCA-0488-067	"Dasibi Model 3008 Gas Filter Correlation CO Analyzer," operated on the 0-50 ppm range, with a time constant setting of 60 seconds, a particulate filter installed in the analyzer sample inlet line, with or without use of the auto zero or auto zero/span feature, and with or without any of the following options: N-0056-A RS-232-C Interface S-0132-A Rack Mounting Slides Z-0176-S Rack Mounting Brackets	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Reference	53 12073 04/12/88

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CARBON MONOXIDE (Continued)

RFCA-0992-088	<p>"Lear Siegler Measurement Controls Corporation Model ML9830 Carbon Monoxide Analyzer," operated on any full scale range between 0-5.0 ppm* and 0-100 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i>, at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position, with the following menu choices selected: Background: Not <i>Disabled</i>; Calibration: <i>Manual</i> or <i>Timed</i>; Diagnostic Mode: <i>Operate</i>; Filter Type: <i>Kalman</i>; Pres/Temp/Flow Comp: <i>On</i>; Span Comp: <i>Disabled</i>; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V Current, 0-20 mA, 2-20 mA and 4-20 mA; and with or without any of the following options: Valve Assembly For External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive</p>	<p>Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189</p>	Auto	Reference	57 44565 09/28/92
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*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 50 ppm is based on meeting the same absolute performance specifications required for the 0-50 ppm range. Thus, designation of any full scale range lower than the 0-50 ppm range does not imply commensurably better performance than that obtained on the 0-50 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>NITROGEN DIOXIDE</u>						
RFNA-0677-021	"Monitor Labs Model 8440E Nitrogen Oxides Analyzer," operated on a 0-0.5 ppm range (position 2 of range switch) with a time constant setting of 20 seconds, with or without any of the following options: TF Sample Particulate Filter With TFE Filter Element V Zero/Span Valves	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	42 37434 42 46575 46 29986	07/21/77 09/16/77 06/04/81
		DO Status Outputs R Rack Mount FM Flowmeters		018A Ozone Dry Air 018B Ozone Dry Air - No Drierite		
RFNA-0777-022	Bendix or Combustion Engineering Model 8101-C Oxides of Nitrogen Analyzer, operated on a 0-0.5 ppm range with a Teflon sample filter (Bendix P/N 007163) installed on the sample inlet line.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	42 37435	07/21/77
RFNA-0977-025	"CSI Model 1600 Oxides of Nitrogen Analyzer," operated on a 0-0.5 ppm range with a Teflon sample filter (CSI P/N M951-8023) installed on the sample inlet line, with or without any of the following options: 951-0103 Rack Ears 951-0104 Rack Mounting Kit (Ears & Slides) 951-0106 Current Output, 4-20 mA (Non-Insulated) 951-0108 Diagnostic Output Option 951-0111 Recorder Output, 10 V	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Reference	42 46574	09/16/77
		951-0112 Remote Zero/Span Sample Control 951-0114 Recorder Output, 5 V 951-0115 External Pump (115 V, 60 Hz) 951-8072 Molybdenum Converter Assembly (Horizontal)		951-8074 Copper Converter Assembly (Horizontal) 951-8079 Copper Converter Assembly (Vertical) 951-8085 Molybdenum Converter Assembly (Vertical)		

NOTE: The vertical molybdenum converter assembly is standard on all new analyzers as of 1-1-87; however, use of any of the other converter assemblies is optional. Also, the above options reflect new CSI part numbers.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE</u>		
					<u>VOL.</u>	<u>PAGE</u>	<u>DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>							
EQN-1277-026	"Sodium Arsenite Method for the Determination of Nitrogen Dioxide in the Atmosphere"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42	62971	12/14/77
EQN-1277-027	"Sodium Arsenite Method for the Determination of Nitrogen Dioxide in the Atmosphere--Technicon II Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42	62971	12/14/77
EQN-1277-028	"TGS-ANSA Method for the Determination of Nitrogen Dioxide in the Atmosphere"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42	62971	12/14/77

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
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NITROGEN DIOXIDE (Continued)

RFNA-1078-031	"Meloy Model NA530R Nitrogen Oxides Analyzer," operated on the following ranges and time constant switch positions:	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Reference	43 50733 44 8327	10/31/78 02/09/79
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Range, ppm Time Constant Setting

0-0.1*	4
0-0.25*	3 or 4
0-0.5	2, 3, or 4
0-1.0	2, 3, or 4

Operation of the analyzer requires an external vacuum pump, either Meloy Option N-10 or an equivalent pump capable of maintaining a vacuum of 200 torr (22 inches mercury vacuum) or better at the pump connection at the specified sample and ozone-air flow rates of 1200 and 200 cm³/min, respectively. The analyzer may be operated at temperatures between 10°C and 40°C and at line voltages between 105 and 130 volts, with or without any of the following options:

N-1A Automatic Zero And Span	N-6C Remote Zero/Span Control	N-14B Line Transmitter
N-2 Vacuum Gauge	And Status (Timer)	N-18 Rack Mount Conversion
N-4 Digital Panel Meter	N-9 Manual Zero/Span	N-18A Rack Mount Conversion
N-6 Remote Control For Zero And Span	N-10 Vacuum Pump Assembly (See Alternate Requirement Above)	
N-6B Remote Zero/Span Control And Status (Pulse)	N-11 Auto Ranging	

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0179-034	"Beckman Model 952-A NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range with the 5-micron Teflon sample filter (Beckman P/N 861072 supplied with the analyzer) installed on the sample inlet line, with or without the Remote Operation Option (Beckman Cat. No. 635539).	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Reference	44 7806 02/07/79
RFNA-0179-035	"Thermo Electron Model 14 B/E Chemiluminescent NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: 14-001 Teflon Particulate Filter 14-002 Voltage Divider Card 14-003 Long-Time Signal Integrator 14-004 Indicating Temperature Controller 14-005 Sample Flowmeter 14-006 Air Filter	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	44 7805 02/07/79 44 54545 09/20/79
RFNA-0279-037	"Thermo Electron Model 14 D/E Chemiluminescent NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: 14-001 Teflon Particulate Filter 14-002 Voltage Divider Card	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	44 10429 02/20/79

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0479-038	"Bendix Model 8101-B Oxides of Nitrogen Analyzer," operated on a 0-0.5 ppm range with a Teflon sample filter installed on the sample inlet line and with the following post-manufacture modifications: 1. Ozone generator and reaction chamber input-output tubing modification per Bendix Service Bulletin 8101B-2; 2. The approved converter material; 3. The revised and EPA-approved operation and service manual. These items are mandatory and must be obtained from Combustion Engineering, Inc. The analyzer may be operated with or without any of the following optional modifications: a. Perma Pure dryer/ambient air modification; b. Valve cycle time modification; c. Zero potentiometer centering modification per Bendix Service Bulletin 8101B-1; d. Reaction chamber vacuum gauge modification.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	44 26792 05/07/79
RFNA-0879-040	"Philips Model PW9762/02 NO/NO ₂ /NO _x Analyzer," consisting of the following components: PW9762/02 Basic Analyzer PW9729/00 Converter Cartridge PW9731/00 Sampler or PW9731/20 Dust Filter; operated on a range of 0-0.5 ppm, with or without any of the following accessories: PW9752/00 Air Sampler Manifold PW9732/00 Sample Line Heater PW9011/00 Remote Control Set	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Reference	44 51683 09/04/79

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
<u>NITROGEN DIOXIDE (Continued)</u>						
RFNA-0280-042	"Monitor Labs Model 8840 Nitrogen Oxides Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with an internal time constant setting of 60 seconds, a TFE sample filter installed on the sample inlet line, with or without any of the following options:	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	45 9100	02/11/80
					46 29986	06/04/81
	02 Flowmeter	08A Pump Pac Assembly With 09A (115 VAC)			011A Recorder Output 1 Volt	
	03A Rack Ears				011B Recorder Output 100 mV	
	03B Slides	08B Pump Pac Assembly With 09B (100 VAC)			011C Recorder Output 10 mV	
	05A Zero/Span Valves				012A DAS Output 1 Volt	
	05B Valve/Relay	08C Pump Pac Assembly With 09C (220/240 VAC)			012B DAS Output 100 mV	
	06 Status				012C DAS Output 10 mV	
	07A Input Power Transformer 100 VAC, 50/60 Hz	08D Rack Mount Panel Assembly			013A Ozone Dry Air	
	07B Input Power Transformer 220/240 VAC, 50 Hz	09A Pump 115 VAC 50/60 Hz			013B Ozone Dry Air - No Drierite	
		09B Pump 100 VAC 50/60 Hz				
		09C Pump 220/240 VAC 50 Hz				
RFNA-1289-074	"Thermo Environmental Instruments Inc. Model 42 NO/NO ₂ /NO _x Analyzer," operated on the 0-0.05 ppm*, the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range, with any time average setting from 10 to 300 seconds. The analyzer may be operated at temperatures between 15°C and 35°C and at line voltages between 105 and 125 volts, with or without any of the following options:	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	54 50820	12/11/89
	42-002 Rack Mounts	42-004 Sample/Ozone Flowmeters			42-007 Ozone Particulate Filter	
	42-003 Internal Zero/Span And Sample Valves With Remote Activation	42-005 4-20 mA Current Output			42-008 RS-232 Interface	
		42-006 Pressure Transducer			42-009 Permeation Dryer	

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>						
RFNA-0691-082	"Advanced Pollution Instrumentation, Inc. Model 200 Nitrogen Oxides Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a 5-micron TFE filter element installed in the rear-panel filter assembly, with either a user- or vendor-supplied vacuum pump capable of providing 5 inches mercury absolute pressure at 5 slpm, with either a user- or vendor-supplied dry air source capable of providing air at a dew point of 0°C or lower, with the following settings of the adjustable setup variables: Adaptive Filter = ON Dwell Time = 7 seconds Dynamic Span = OFF Dynamic Zero = OFF PMT Temperature Set Point = 15°C Rate of Change(ROC) Threshold = 10% Reaction Cell Temperature = 50°C Sample Time = 8 seconds Normal Filter Size = 12 samples; and with or without any of the following options: 180 Stainless Steel Valves 184 Pump Pack 280 Rack Mount With Slides	Advanced Pollution Instrumentation, Inc 8815 Production Avenue San Diego, CA 92121-2219	Auto	Reference	56 27014	06/12/91
		283 Internal Zero/Span With Valves (IZS) 325 RS-232/Status Output 355 Expendables			356 Level One Spares Kit 357 Level Two Spares Kit PE5 Permeation Tube for IZS	
RFNA-0991-083	"Monitor Labs Model 8841 Nitrogen Oxides Analyzer," operated on the 0-0.05 ppm*, 0-0.1 ppm*, 0-0.2 ppm*, 0-0.5 ppm, or 0-1.0 ppm range, with manufacturer-supplied vacuum pump or alternative user-supplied vacuum pump capable of providing 200 torr or better absolute vacuum while operating with the analyzer.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	56 47473	09/19/91

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE											
NITROGEN DIOXIDE (Continued)																	
RFNA-1192-089	"Dasibi Model 2108 Oxides of Nitrogen Analyzer," operated on the 0-500 ppb range, with software revision 3.6 installed in the analyzer, with the Auto thumbwheel switch and the Diag thumbwheel switch settings at 0, with the following internal CPU dipswitch settings: <table><tr><td>switch</td><td>position</td><td>function</td></tr><tr><td>1</td><td>open (down)</td><td>Recorder outputs are NO & NO₂</td></tr><tr><td>5</td><td>open (down)</td><td>3 minute time constant</td></tr><tr><td>6</td><td>closed (up)</td><td>3 minute time constant;</td></tr></table> with a 5-micron Teflon filter element installed in the filter holder, and with or without any of the following options: Built-in Permeation Oven RS-232 Interface	switch	position	function	1	open (down)	Recorder outputs are NO & NO ₂	5	open (down)	3 minute time constant	6	closed (up)	3 minute time constant;	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Reference 57 55530	11/25/92
switch	position	function															
1	open (down)	Recorder outputs are NO & NO ₂															
5	open (down)	3 minute time constant															
6	closed (up)	3 minute time constant;															
		Rack Mounting 4-20 mA Output		Three-Channel Recorder Output													

RFNA-1292-090	"Lear Siegler Measurement Controls Corporation Model ML9841 Nitrogen Oxides Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i> , at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Calibration: <i>Manual</i> or <i>Timed</i> ; Diagnostic Mode: <i>Operate</i> ; Filter Type: <i>Kalman</i> ; Pres/Temp/Flow Comp: <i>On</i> ; Span Comp: <i>Disabled</i> ; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA; and with or without any of the following options: Internal Floppy Disk Drive	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference 57 60198	12/18/92
	Rack Mount Assembly			Valve Assembly for External Zero/Span (EVS)	

*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
		<u>LEAD</u>				
*****	Reference Method for the Determination of Lead in Suspended Particulate Matter Collected from Ambient Air	40 CFR Part 50, Appendix G	Manual	Reference	43 46258	10/05/78
EQL-0380-043	"Determination of Lead Concentration in Ambient Particulate Matter by Flame Atomic Absorption Spectrometry Following Ultrasonic Extraction with Heated HNO ₃ -HCl"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648	03/06/80
EQL-0380-044	"Determination of Lead Concentration in Ambient Particulate Matter by Flameless Atomic Absorption Spectrometry (EPA/RTP,N.C.)"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648	03/06/80
EQL-0380-045	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (EPA/RTP,N.C.)"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648	03/06/80
EQL-0581-052	"Determination of Lead Concentration in Ambient Particulate Matter by Wavelength Dispersive X-Ray Fluorescence Spectrometry"	California Department of Health Services Air & Industrial Hygiene Laboratory 2151 Berkeley Way Berkeley, CA 94704	Manual	Equiv.	46 29986	06/04/81

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>LEAD (Continued)</u>					
EQL-0483-057	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Montana)"	State of Montana Department of Health and Environmental Sciences Cogswell Building Helena, MT 59620	Manual	Equiv.	48 14748 04/05/83
EQL-0783-058	"Determination of Lead Concentration in Ambient Particulate Matter by Energy-Dispersive X-Ray Fluorescence Spectrometry (Texas Air Control Board)"	Texas Air Control Board 6330 Highway 290 East Austin, TX 78723	Manual	Equiv.	48 29742 06/28/83
EQL-0785-059	"Determination of Lead Concentration in Ambient Particulate Matter by Flameless Atomic Absorption Spectrometry (Omaha-Douglas County Health Department)"	Omaha-Douglas County Health Department 1819 Farnam Street Omaha, NE 68183	Manual	Equiv.	50 37909 09/18/85
EQL-0888-068	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Rhode Island)"	State of Rhode Island Department of Health Air Pollution Laboratory 50 Orms Street Providence, RI 02904	Manual	Equiv.	53 30866 08/16/88
EQL-1188-069	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Northern Engineering and Testing, Inc.)"	Northern Engineering and Testing, Inc. P.O. Box 30615 Billings, MT 59107	Manual	Equiv.	53 44947 11/07/88

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<u>LEAD (Continued)</u>						
EQL-1288-070	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Silver Valley Laboratories)"	Silver Valley Laboratories, Inc. P.O. Box 929 Kellogg, ID 83837	Manual	Equiv.	53 48974	12/05/88
EQL-0589-072	"Determination of Lead Concentration in Ambient Particulate Matter by Energy Dispersive X-Ray Fluorescence Spectrometry (NEA, Inc.)"	Nuclear Environmental Analysis, Inc. 10950 SW 5th Street, Suite 260 Beaverton, OR 97005	Manual	Equiv.	54 20193	05/10/89
EQL-1290-080	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of New Hampshire)"	State of New Hampshire Department of Environmental Services Laboratory Service Unit 6 Hazen Drive (P.O. Box 95) Concord, NH 03302-0095	Manual	Equiv.	55 49119	11/26/90
EQL-0592-085	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Kansas)"	State of Kansas Department of Health and Environment Forbes Field, Building 740 Topeka, KS 66620-0001	Manual	Equiv.	57 20823	05/15/92
EQL-0592-086	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Commonwealth of Pennsylvania)"	Commonwealth of Pennsylvania Department of Environmental Resources P.O. Box 2357 Harrisburg, PA 17105-2357	Manual	Equiv.	57 20823	05/15/92

February 8, 1993

METHOD CODES

Method	Designation Number	Method Code	Method	Designation Number	Method Code
<u>SO₂ Manual Methods</u>			<u>NO_x Manual Methods</u>		
Ref. method (pararosaniline)	-	097	Sodium arsenite (orifice)	EQN-1277-026	084
Technicon I (pararosaniline)	EQS-0775-001	097	Sodium arsenite/Technicon II	EQN-1277-027	084
Technicon II (Pararosaniline)	EQS-0775-002	097	TGS-ANSA (orifice)	EQN-1277-028	098
<u>SO₂ Analyzers</u>			<u>NO_x Analyzers</u>		
Advanced Pollution Instr. 100	EQSA-0990-077	077	Advanced Pollution Instr. 200	RFNA-0691-082	082
Aasroco 500	EQSA-0877-024	024	Beckman 952A	RFNA-0179-034	034
Beckman 953	EQSA-0678-029	029	Bendix 8101-B	RFNA-0479-038	038
Bendix 8303	EQSA-1078-030	030	Bendix 8101-C	RFNA-0777-022	022
Dasibi 4108	EQSA-1086-061	061	Dasibi 2108	RFNA-1192-089	089
Environnement S.A. AF21M	EQSA-0292-084	084	CSI 1600	RFNA-0977-025	025
Lear Siegler AM2020	EQSA-1280-049	049	Lear Siegler ML9841	RFNA-1292-090	090
Lear Siegler SM1000	EQSA-1275-005	005	Meloy NA530R	RFNA-1078-031	031
Lear Siegler ML9850	EQSA-0193-092	092	Monitor Labs 8440E	RFNA-0677-021	021
Meloy SA185-2A	EQSA-1275-006	006	Monitor Labs 8840	RFNA-0280-042	042
Meloy SA285E	EQSA-1078-032	032	Monitor Labs 8841	RFNA-0991-083	083
Meloy SA700	EQSA-0580-046	046	Philips PW9762/02	RFNA-0879-040	040
Monitor Labs 8450	EQSA-0876-013	513	Thermo Electron 14B/E	RFNA-0179-035	035
Monitor Labs 8850	EQSA-0779-039	039	Thermo Electron 14D/E	RFNA-0279-037	037
Monitor Labs 8850S	EQSA-0390-075	075	Thermo Environmental Inst. 42	RFNA-1289-074	074
Philips PW9700	EQSA-0876-011	511			
Philips PW9755	EQSA-0676-010	010			
Thermo Electron 43	EQSA-0276-009	009			
Thermo Electron 43A	EQSA-0486-060	060			
<u>O₃ Analyzers</u>			<u>Pb Manual Methods</u>		
Advanced Pollution Instr. 400	EQOA-0992-087	087	Ref. method (hi-vol/AA spect.)	-	803
Beckman 950A	RFOA-0577-020	020	Hi-vol/AA spect. (alt. extr.)	EQL-0380-043	043
Bendix 8002	RFOA-0176-007	007	Hi-vol/Energy-disp XRF (TX ACB)	EQL-0783-058	058
CSI 2000	RFOA-0279-036	036	Hi-vol/Energy-disp XRF (NEA)	EQL-0589-072	072
Dasibi 1003-AH,-PC,-RS	EQOA-0577-019	019	Hi-vol/Flameless AA (EMSL/EPA)	EQL-0380-044	044
Dasibi 1008-AH	EQOA-0383-056	056	Hi-vol/Flameless AA (Omaha)	EQL-0785-059	059
Enviro-nics 300	EQOA-0990-078	078	Hi-vol/ICAP spect. (EMSL/EPA)	EQL-0380-045	045
Lear Siegler ML9810	EQOA-0193-091	091	Hi-vol/ICAP spect. (Kansas)	EQL-0592-085	085
McMillan 1100-1	RFOA-1076-014	514	Hi-vol/ICAP spect. (Montana)	EQL-0483-057	057
McMillan 1100-2	RFOA-1076-015	515	Hi-vol/ICAP spect. (NE&T)	EQL-1188-069	069
McMillan 1100-3	RFOA-1076-016	016	Hi-vol/ICAP spect. (N. Hampshire)	EQL-1290-080	080
Meloy OA325-2R	RFOA-1075-003	003	Hi-vol/ICAP spect. (Pennsylvania)	EQL-0592-086	086
Meloy OA350-2R	RFOA-1075-004	004	Hi-vol/ICAP spect. (Rhode Is.)	EQL-0888-068	068
Monitor Labs 8410E	RFOA-1176-017	017	Hi-vol/ICAP spect. (S.V. Labs)	EQL-1288-070	070
Monitor Labs 8810	EQOA-0881-053	053	Hi-vol/WL-disp. XRF (CA A&IHL)	EQL-0581-052	052
PCI Ozone Corp. LC-12	EQOA-0382-055	055			
Philips PW9771	EQOA-0777-023	023			
Thermo Electron 49	EQOA-0880-047	047			
<u>CO Analyzers</u>			<u>PM₁₀ Samplers</u>		
Beckman 866	RFCA-0876-012	012	Oregon DEQ Med. vol. sampler	RFPS-0389-071	071
Bendix 8501-SCA	RFCA-0276-008	008	Sierra-Andersen/GMW 1200	RFPS-1287-063	063
Dasibi 3003	RFCA-0381-051	051	Sierra-Andersen/GMW 321-B	RFPS-1287-064	064
Dasibi 3008	RFCA-0488-067	067	Sierra-Andersen/GMW 321-C	RFPS-1287-065	065
Horiba AQM-10, -11, -12	RFCA-1278-033	033	Sierra-Andersen/GMW 241 Dichot	RFPS-0789-073	073
Horiba 300E/300SE	RFCA-1180-048	048	Wedding & Assoc. high volume	RFPS-1087-062	062
Lear Siegler ML 9830	RFCA-0992-088	088			
MASS - CO 1 (Massachusetts)	RFCA-1280-050	050			
Monitor Labs 8310	RFCA-0979-041	041			
Monitor Labs 8830	RFCA-0388-066	066			
MSA 202S	RFCA-0177-018	018			
Thermo Electron 48	RFCA-0981-054	054			
			<u>PM₁₀ Analyzers</u>		
			Andersen Instr. Beta FH621-N	EQPM-0990-076	076
			R & P TEOM 1400, 1400a	EQPM-1090-079	079
			Wedding & Assoc. Beta Gauge	EQPM-0391-081	081
			<u>TSP Manual Method</u>		
			Reference method (high-volume)	-	802

APPROVED METHODS AS OF FEBRUARY 8, 1993

	MANUAL		AUTOMATED	
	REFERENCE	EQUIVALENT	REFERENCE	EQUIVALENT
CO			<ol style="list-style-type: none"> 1. CE (Beckman) 8501-SCA (50) 2. Beckman 864 (50) 3. MSA 2025 (50) 4. Horiba AQM-10,11,12 (50) 5. Monitor Labs 8310 (50) 6. Horiba APMA-300E (20, 50, 100) 7. MARS-CO I (50) 8. Dunham 3003 (50) 9. TEI 46 (50) 10. Monitor Labs 8830 (50) 11. Dunham 3008 (50) 12. Lear Singler ML 9830 (5-100) 	
NO ₂		<ol style="list-style-type: none"> 1. Sodium Arsenite 2. Sodium Arsenite/Tetrasodium II 3. TOB-ANSA 	<ol style="list-style-type: none"> 1. Monitor Labs 8440E (.5) 2. CE (Beckman) 8101-C (.5) 3. CEI 1600 (.5) 4. Moly NA30R (.1, .25, .5, 1.0) 5. Beckman 952-A (.5) 6. TEI 14 B/E (.5) 7. TEI 14 D/E (.5) 8. Buntax 8101-B (.5) 9. Philips PW7762/02 (.5) 10. Monitor Labs 8840 (.5, 1.0) 11. TEI 42 (.05, .1, .2, .5, 1.0) 12. API 200 (.5, 1.0) 13. Monitor Labs 8841 (.05, .1, .2, .5, 1.0) 14. Dunham 2108 (.5) 15. Lear Singler ML 9841 (.05-1.0) 	
O ₃			<ol style="list-style-type: none"> 1. Moly OA325-2R (.5) 2. Moly OA350-2R (.5) 3. CE (Beckman) 8002 (.5) 4. McMillan 1100-1 (.5) 5. McMillan 1100-2 (.5) 6. McMillan 1100-3 (.5) 7. Monitor Labs 8410E (.5) 8. Beckman 950A (.5) 9. CSI 2000 (.5) 	<ol style="list-style-type: none"> 1. Dunham 1003-AH, PC, RS (.5, 1.0) 2. Philips PW7771 (.5) 3. TEI 49 (.5, 1.0) 4. Monitor Labs 8810 (.5, 1.0) 5. PCI Ocean Corp. LC-12 (.5) 6. Dunham 1008-AH, PC, RS (.5, 1.0) 7. Biorrecom 300 (.5) 8. API 400 (.1, .5, 1.0) 9. Lear Singler ML 9810 (.05-1.0)
Pb	HV with Flame AA	<ol style="list-style-type: none"> 1. HV/Flame AA (EPA) 2. HV/Flameless AA (EPA) 3. HV/ICAP (EPA) 4. HV/WDXRF (ADL, CA) 5. HV/ICAP (MT) 6. HV/EDXRF (TX) 7. HV/Flameless AA (Omaha-Douglas Co.) 8. HV/ICAP (RJ) 9. HV/ICAP (NET) 10. HV/ICAP (SVL) 11. HV/EDXRF (NEA) 12. HV/ICAP (NH) 13. HV/ICAP (KS) 14. HV/ICAP (PA) 		
PM ₁₀	<ol style="list-style-type: none"> 1. W & A PM₁₀ Critical Flow HV Sampler 2. SA/GMW 1200 3. SA/GMW 321-B 4. SA/GMW 321-C 5. Oregon DBQ HV Special Sampler 6. SA/GMW 241 & 241M Direct Sampler 			<ol style="list-style-type: none"> 1. Andersen Inst. FM621-N PM₁₀ Beta Attenuation Monitor 2. Rappaport & Patachuck TBCM[®] Series 1400 and 1400a PM₁₀ Monitors 3. Wadding & Associates' PM-10 Beta Gauge Automated Purline Sampler
SO ₂	Potassiumiodide Method	<ol style="list-style-type: none"> 1. Testimony I 2. Testimony II 		<ol style="list-style-type: none"> 1. Lear Singler SM1000 (.5) 2. Moly SA185-2A (.5, 1.0) 3. TEI 43 (.5, 1.0) 4. Philips PW7755 (.5) 5. Philips PW7700 (.5) 6. Monitor Labs 8450 (.5, 1.0) 7. ASARCO 500 (.5), 600 (1.0) 8. Beckman 953 (.5, 1.0) 9. Buntax 8303 (.5, 1.0) 10. Moly SA285E (.05, .1, .5, 1.0) 11. Monitor Labs 8850 (.5, 1.0) 12. Moly SA700 (.25, .5, 1.0) 13. Lear Singler AM2020 (.5, 1.0) 14. TEI 43A (.1, .2, .5, 1.0) 15. Dunham 4108 (.1, .2, .5, 1.0) 16. Monitor Labs 88508 (.5, 1.0) 17. API 100 (.5) 18. Environment S.A. AP21M (.5) 19. Lear Singler ML 9850 (.05-1.0)
TSP	High Volume Method (HV)			

NOTE: The numbers in parentheses that follow the manufacturer name i.e., (.05), (.1), (.2), (.5), (1.0), or (50) indicate the full scale range(s) approved for that method. Ranges that are specified as (.05-1.0) or (5-100) indicate any full scale range between the indicated values.

DEPT E MD-77

**UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY**
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Atmospheric Research and Exposure
Assessment Laboratory
Methods Research & Development Division (MD-77)
Research Triangle Park, North Carolina 27711
919 541-2622 or 919 541-4599
FTS 629-2622 or FTS 629-4599

Issue Date: February 8, 1993

* Previous Revision: September 28, 1992 *
*
* New Designations: *
* Dasibi Environmental Corporation *
* Model 2108 Oxides of Nitrogen Analyzer *
* Lear Siegler Measurement Controls Corporation *
* Model ML9841 Nitrogen Oxides Analyzer *
* Model ML9810 Ozone Analyzer *
* Model ML9850 Sulfur Dioxide Analyzer *

LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

These methods for measuring ambient concentrations of specified air pollutants have been designated as "reference methods" or "equivalent methods" in accordance with Title 40, Part 53 of the Code of Federal Regulations (40 CFR Part 53). Subject to any limitations (e.g., operating range) specified in the applicable designation, each method is acceptable for use in state or local air quality surveillance systems under 40 CFR Part 58 unless the applicable designation is subsequently canceled. Automated methods are acceptable for use at temperatures between 20°C and 30°C and line voltages between 105 and 125 volts unless wider limits are specified in the method description.

Prospective users of the methods listed should note (1) that each method must be used in strict accordance with the operation or instruction manual and with applicable quality assurance procedures, and (2) that modification of a method by its vendor or user may cause the pertinent designation to be inapplicable to the method as modified. (See Section 2.8 of Appendix C, 40 CFR Part 58 for approval of modifications to any of these methods by users.)

Further information concerning particular designations may be found in the *Federal Register* notice cited for each method or by writing to the Atmospheric Research & Exposure Assessment Laboratory, Methods Research & Development Division (MD-77), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. Technical information concerning the methods should be obtained by writing to the "source" listed for each method. New analyzers or PM₁₀ samplers sold as reference or equivalent methods must carry a label or sticker identifying them as designated methods. For analyzers or PM₁₀ samplers sold prior to the designation, the model number does not necessarily identify an analyzer or sampler as a designated method. Consult the manufacturer or seller to determine if a previously sold analyzer or sampler can be considered a designated method, or if it can be upgraded to designation status. Analyzer users who experience operational or other difficulties with a designated analyzer or sampler and are unable to resolve the problem directly with the instrument manufacturer may contact EPA (preferably in writing) at the above address for assistance.

This list will be revised as necessary to reflect any new designations or any cancellation of a designation currently in effect. The most current revision of the list will be available for inspection at EPA's Regional Offices, and copies may be obtained by writing to the Atmospheric Research & Exposure Assessment Laboratory at the address

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - TSP</u>						
*****	Reference Method for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method)	40 CFR Part 50, Appendix B	Manual	Reference	47 54912 48 17355	12/06/82 04/22/83
<u>PARTICULATE MATTER - PM₁₀</u>						
*****	Reference Method for the Determination of Particulate Matter as PM ₁₀ in the Atmosphere	40 CFR Part 50, Appendix J	Manual	Reference	52 24664 52 29467	07/01/87 08/07/87
RFPS-1087-062	"Wedding & Associates' PM ₁₀ Critical Flow High-Volume Sampler," consisting of the following components: Wedding PM ₁₀ Inlet Wedding & Associates' Critical Flow Device Wedding & Associates' Anodized Aluminum Shelter 115, 220 or 240 VAC Motor Blower Assembly Mechanical Timer Or Optional Digital Timer Elapsed Time Indicator Filter Cartridge/Cassette	Wedding & Associates, Inc. P.O. Box 1756 Fort Collins, CO 80522	Manual	Reference	52 37366	10/06/87

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
RFPS-1287-063	"Sierra-Andersen or General Metal Works Model 1200 PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 1200 PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	52 45684 53 1062	12/01/87 01/15/88
RFPS-1287-064	"Sierra-Andersen or General Metal Works Model 321-B PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 321-B PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	52 45684 53 1062	12/01/87 01/15/88

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<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
RFPS-1287-065	"Sierra-Andersen or General Metal Works Model 321-C PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 321-C PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	52 45684 53 1062	12/01/87 01/15/88
RFPS-0389-071	"Oregon DEQ Medium Volume PM ₁₀ Sampler" NOTE: This method is not now commercially available.	State of Oregon Department of Environmental Quality Air Quality Division 811 S.W. Sixth Avenue Portland, OR 97204	Manual	Reference	54 12273	03/24/89
RFPS-0789-073	"Sierra-Andersen Models SA241 and SA241M or General Metal Works Models G241 and G241M PM ₁₀ Dichotomous Samplers", consisting of the following components: Sampling Module with SA246b or G246b 10 µm inlet, 2.5 µm virtual impactor assembly, 37 mm coarse and fine particulate filter holders, and tripod mount; Control Module with diaphragm vacuum pump, pneumatic constant flow controller, total and coarse flow rotameters and vacuum gauges, pressure switch (optional), 24-hour flow/event recorder, digital	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	54 31247	07/27/89

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
EQPM-0990-076	"Andersen Instruments Model FH62I-N PM ₁₀ Beta Attenuation Monitor," consisting of the following components: FH62I Beta Attenuation 19-inch Control Module SA246b PM ₁₀ Inlet (16.7 liter/min) FH101 Vacuum Pump Assembly FH102 Accessory Kit FH107 Roof Flange Kit FH125 Zero and Span PM ₁₀ Mass Foil Calibration Kit operated for 24-hour average measurements, with an observing time of 60 minutes, the calibration factor set to 2400, a glass fiber filter tape, an automatic filter advance after each 24-hour sample period, and with or without either of the following options: FHOP1 Indoor Cabinet FHOP2 Outdoor Shelter Assembly	Andersen Instruments, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336	Auto	Equiv.	55 38387	09/18/90
EQPM-1090-079	"Rupprecht & Patashnick TEOM Series 1400 and Series 1400a PM-10 Monitors," consisting of the following components: TEOM Sensor Unit TEOM Control Unit Rupprecht & Patashnick PM-10 Inlet (part number 57-00596) or Sierra-Andersen Model 246b PM-10 Inlet (16.7 liter/min) Flow Splitter Teflon-Coated Glass Fiber Filter Cartridges operated for 24-hour average measurements, with the total mass averaging time set at 300 seconds, the mass rate/mass concentration averaging time set at 300 seconds, the gate time set at 2 seconds, and with or without either of the following options: Tripod Outdoor Enclosure Automatic Cartridge Collection Unit (Series 1400a only)	Rupprecht & Patashnick Co., Inc. 8 Corporate Circle Albany, NY 12203	Auto	Equiv.	55 43406	10/29/90

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		<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>			
EQPM-0391-081	"Wedding & Associates' PM ₁₀ Beta Gauge Automated Particle Sampler," consisting of the following components: Particle Sampling Module PM ₁₀ Inlet (18.9 liter/min) Inlet Tube and Support Ring Vacuum Pump (115 VAC/60 Hz or 220-240 VAC/50 Hz) operated for 24-hour average measurements with glass fiber filter tape.	Wedding & Associates, Inc. P.O. Box 1756 Fort Collins, CO 80522	Auto	Equiv.	56 9216 03/05/91

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					<u>VOL.</u>	<u>PAGE</u> <u>DATE</u>
<u>SULFUR DIOXIDE</u>						
*****	Reference Method for the Determination of Sulfur Dioxide in the Atmosphere (Pararosaniline Method)	40 CFR Part 50, Appendix A	Manual	Reference	47 48	54899 17355 12/06/8 04/22/8
EQS-0775-001	"Pararosaniline Method for the Determination of Sulfur Dioxide in the Atmosphere-Technicon I Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	40	34024 08/13/7
EQS-0775-002	"Pararosaniline Method for the Determination of Sulfur Dioxide in the Atmosphere-Technicon II Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv	40	34024 08/13/7
EQSA-1275-005	"Lear Siegler Model SM1000 SO ₂ Ambient Monitor," operated on the 0-0.5 ppm range, at a wavelength of 299.5 nm, with the "slow" (300 second) response time; with or without any of the following options: SM-1 Internal Zero/Span SM-2 Span Timer Card SM-3 0-0.1 Volt Output SM-4 0-5 Volt Output SM-5 Alternate Sample Pump SM-6 Outdoor Enclosure	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	41 41 42 45	3893 32946 01/27/7 08/06/7 13044 03/08/7 1147 01/04/8

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-1275-006	"Meloxy Model SA185-2A Sulfur Dioxide Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: S-1 Linearized Output S-2 Modified Recorder Output S-5 Teflon-Coated Block S-6A Reignite Timer Circuit S-7 Press To Read S-11A Manual Zero And Span S-11B Automatic Zero And Span S-13 Status Lights S-14 Output Booster Amplifier S-14B Line Transmitter Board or operated on the 0-1.0 ppm range with either option S-36 or options S-1 and S-24, with or without any of the other options.	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	41 3893 43 38088	01/27/76 08/25/76
	S-18 Rack Mount Conversion S-18A Rack Mount Conversion S-21 Front Panel Digital Volt Meter S-22 Remote Zero/Span Control And Status (Timer) S-22A Remote Zero/Span Control S-23 Automatic Zero Adjust S-23A Automatic/Manual Zero Adjust			S-24 Dual Range Linearized Output S-33 Remote Range Control And Status (Signals) S-34 Remote Control S-35 Front Panel Digital Meter With BCD Output S-36 Dual Range Log-Linear Output S-38 Sampling Mode Status		
EQSA-0276-009	"Thermo Electron Model 43 Pulsed Fluorescent SO ₂ Analyzer," equipped with an aromatic hydrocarbon cutter and operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: 001 Rack Mounting For Standard 19 Inch Relay Rack 002 Automatic Actuation Of Zero And Span Solenoid Valves 003 Type S Flash Lamp Power Supply 004 Low Flow	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	41 8531 41 15363 42 20490 44 21861 45 2700 45 32419	02/27/76 04/12/76 04/20/76 04/12/76 01/14/77 05/16/77

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-0676-010	"Philips PW9755 SO ₂ Analyzer," consisting of the following components: PW9755/02 SO ₂ Monitor with: PW9741/00 SO ₂ Source PW9721/00 Filter Set SO ₂ PW9711/00 Electrolyte SO ₂ PW9750/00 Supply Cabinet PW9750/10 Supply Unit/Coulometric Either PW9731/00 Sampler or PW9731/20 Dust Filter (or vendor-approved alternate particulate filter); operated with a 0-0.5 ppm range and with a reference voltage setting of 760 millivolts; with or without an of the following options: PW9750/30 Frame For MTT PW9750/41 Control Clock 60 Hz	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	41 26252 41 46019 42 28571	06/25/7 10/19/7 06/03/7
EQSA-0876-011	"Philips PW9700 SO ₂ Analyzer," consisting of the following components: PW9710/00 Chemical Unit with: PW9711/00 Electrolyte SO ₂ PW9721/00 Filter Set SO ₂ PW9740/00 SO ₂ Source PW9720/00 Electrical Unit PW9730/00 Sampler Unit (or vendor-approved alternate particulate filter); operated with a 0-0.5 ppm range and with a reference voltage of 760 millivolts.	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	41 34105	08/12/7
EQSA-0876-013	"Monitor Labs Model 8450 Sulfur Monitor," operated on a range of either 0-0.5 or 0-1.0 ppm, with a 5 second time constant, a model 8740 hydrogen sulfide scrubber in the sample line, with or without any of the following options: BP Bipolar Signal Processor CLO Current Loop Output	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	41 36245 44 33476	08/27/7 06/11/7
		IZS Internal Zero/Span Module TF TFE Sample Particulate Filter		V Zero/Span Valves VT Zero/Span Valves And Timer		

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-0877-024	"ASARCO Model 500 Sulfur Dioxide Monitor," operated on a 0-0.5 ppm range; or "ASARCO Model 600 Sulfur Dioxide Monitor," operated on a 0-1.0 ppm range. (Both models are identical except the range.)	ASARCO Incorporated 3422 South 700 West Salt Lake City, UT 84119	Auto	Equiv.	42 44264 09/02/77 44 67522 11/26/79
NOTE: This method is not now commercially available.					
EQSA-0678-029	"Beckman Model 953 Fluorescent Ambient SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a time constant setting of 2, 2.5, or 3 minutes, a 5 to 10 micron membrane filter element installed in the rear-panel filter assembly, with or without any of the following options: a. Remote Operation Kit, Catalog No. 641984 b. Digital Panel Meter, Catalog No. 641710 c. Rack Mount Kit, Catalog No. 641709 d. Panel Mount Kit, Catalog No. 641708	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Equiv.	43 35995 08/14/78
EQSA-1078-030	"Bendix Model 8303 Sulfur Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a Teflon filter installed on the sample inlet of the H ₂ S scrubber assembly.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Equiv.	43 50733 10/31/78

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-1078-032	"Meloxy Model SA285E Sulfur Dioxide Analyzer," operated on the following ranges and time constant switch positions:	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	43 50733	10/31/78
	<u>Range, ppb</u> <u>Time Constant Setting</u>	*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.				
	0-50* 1 or 10					
	0-100* 1 or 10					
	0-500 off, 1 or 10					
	0-1000 off, 1 or 10					
The analyzer may be operated at temperatures between 10°C and 40°C and at line voltages between 105 and 130 volts, with or without any of the following options:						
	S-5 Teflon Coated Block	S-22B Remote Zero/Span Control	S-30 Auto Reignite			
	S-14B Line Transmitter Board	And Status (Pulse)	S-32 Remote Range Control And Status			
	S-18 Rack Mount Conversion	S-23 Auto Zero Adjust	S-35 Front Panel Digital Meter With BCD Output			
	S-18A Rack Mount Conversion	S-23A Auto/Manual Zero Adjust	S-37 Temperature Status Lights			
	S-21 Front Panel Digital Meter	S-25 Press To Read	S-38 Sampling Mode Status			
	S-22 Remote Zero/Span Control	S-26 Manual Zero And Span				
	And Status (Timer)	S-27 Auto Manual Zero/Span				
	S-22A Remote Zero/Span Control	S-28 Auto Range And Status				
EQSA-0779-039	"Monitor Labs Model 8850 Fluorescent SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with an internal time constant setting of 55 seconds, a TFE sample filter installed on the sample inlet line, with or without any of the following options:	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	44 44616	07/30/79
	03A Rack	06B,C,D NBS Traceable Permeation Tubes	013 Recorder Output Options			
	03B Slides	08A Pump	014 DAS Output Options			
	05A Valves Zero/Span	09A Rack Mount For Option 08A	017 Low Flow Option			
	06A IZS Internal Zero/Span Source	010 Status Output W/Connector	018 Kicker			

<u>DESIGNATION</u> <u>NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL</u> <u>OR AUTO</u>	<u>REF. OR</u> <u>EQUIV.</u>	<u>FED. REGISTER NOTICE</u> <u>VOL. PAGE DATE</u>
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SULFUR DIOXIDE (Continued)

EQSA-0580-046	"Melo y Model SA 700 Fluorescence Sulfur Dioxide Analyzer," operated on the 0-250 ppb*, the 0-500 ppb, or the 0-1000 ppb range with a time constant switch position of either 2 or 3. The analyzer may be operated at temperatures between 20°C and 30°C and at line voltages between 105 and 130 volts, with or without any of the following options: FS-1 Current Output FS-2 Rack Mount Conversion FS-2A Rack Mount Conversion FS-2B Rack Mount Conversion FS-3 Front Panel Mounted Digital Meter FS-5 Auto/Manual Zero/Span With Status FS-6 Remote/Manual Zero/Span With Status FS-7 Auto Zero Adjust	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	45 31488 05/13/80
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*NOTE: Users should be aware that designation of this analyzer for operation on a range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of this lower range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

EQSA-1280-049	"Lear Siegler Model AM2020 Ambient SO ₂ Monitor," operated on a range of either 0-0.5 or 0-1.0 ppm, at a wavelength of 299.5 nm, with a 5 minute integration period, over any 10°C temperature range between 20°C and 45°C, with or without the automatic zero and span correction feature.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	45 79574 12/01/80 46 9997 01/30/81
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DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-0486-060	"Thermo Electron Instruments, Inc. Model 43A Pulsed Fluorescent Ambient SO ₂ Analyzer," operated on the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range with either a high or a low time constant setting and with or without any of the following options: 001 Teflon Particulate Filter Kit 002 Rack Mount	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	51 12390	04/10/86
*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.						
EQSA-1086-061	"Dasibi Model 4108 U.V. Fluorescence SO ₂ Analyzer," operated with a range of 0-100 ppb*, 0-200 ppb*, 0-500 ppb, or 0-1000 ppb, with a Teflon-coated particulate filter and a continuous hydrocarbon removal system, with or without any of the following options: a. Rack Mounting Brackets And Slides	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Equiv.	51 32244	09/10/86
b. RS-232-C Interface c. Temperature Correction						
*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.						
EQSA-0390-075	"Monitor Labs Model 8850S SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	55 5264	02/14/91

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-0990-077	"Advanced Pollution Instrumentation, Inc. Model 100 Fluorescent SO ₂ Analyzer," operated on the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range with a 5-micron TFE filter element installed in the rear-panel filter assembly, either a user- or vendor-supplied vacuum pump capable of providing 20 inches of mercury vacuum at 2.5 L/min, with or without any of the following options: Internal Zero/Span Pump Pack Rack Mount With Slides RS-232 Interface Status Output TFE Zero/Span Valves Zero Air Scrubber	Advanced Pollution Instrumentation, Inc. 8815 Production Avenue San Diego, CA 92121-2219	Auto	Equiv.	55 38149 09/17/90
<p>*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.</p>					
EQSA-0292-084	"Environnement S.A. Model AF21M Sulfur Dioxide Analyzer," operated on a range of 0-0.5 ppm with a response time coefficient setting of 01, a Teflon filter installed in the rear-panel filter assembly, and with or without any of the following options: Rack Mount/Slides RS-232-C Interface	Environnement S.A. 111, bd Robespierre 78300 Poissy, France	Auto	Equiv.	57 5444 02/14/92

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER NOTICE VOL. PAGE DATE
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SULFUR DIOXIDE (Continued)

EQSA-0193-092	"Lear Siegler Measurement Controls Corporation Model ML9850 Sulfur Dioxide Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i> , at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Background: Not <i>Disabled</i> ; Calibration; <i>Manual</i> or <i>Timed</i> ; Diagnostic Mode: <i>Operate</i> ; Filter Type: <i>Kalman</i> ; Pres/Temp/Flow Comp: <i>On</i> ; Span Comp: <i>Disabled</i> ; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA; and with or without any of the following options: Valve Assembly for External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	58 6964 02/03/93
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*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

February 8, 1993

LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER NOTIC VOL. PAGE DATE
		<u>OZONE</u>			
RFOA-1075-003	"Melo Model OA325-2R Ozone Analyzer," operated with a scale range of 0-0.5 ppm, with or without any of the following options: 0-4 Output Booster Amplifier	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759 0-18 Rack Mount Conversion	Auto	Reference	40 54856 11/26/7
RFOA-1075-004	"Melo Model OA350-2R Ozone Analyzer," operated with a scale range of 0-0.5 ppm, with or without any of the following options: 0-2 Automatic Zero And Span 0-3 Remote Control Zero And Span	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759 0-4 Output Booster Amplifier 0-18 Rack Mount Conversion	Auto	Reference	40 54856 11/26/75
RFOA-0176-007	Bendix or Combustion Engineering Model 8002 Ozone Analyzer, operated on the 0-0.5 ppm range, with a 40 second time constant, with or without any of the following options: A Rack Mounting With Chassis Slides	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901 B Rack Mounting Without Chassis Slides	Auto	Reference	41 5145 02/04/76 45 18474 03/21/80
RFOA-1076-014	"MEC Model 1100-1 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-015	"MEC Model 1100-2 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-016	"MEC Model 1100-3 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-017	"MEC Model 1100-4 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-018	"MEC Model 1100-5 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-019	"MEC Model 1100-6 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-020	"MEC Model 1100-7 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-021	"MEC Model 1100-8 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-022	"MEC Model 1100-9 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-023	"MEC Model 1100-10 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-024	"MEC Model 1100-11 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-025	"MEC Model 1100-12 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-026	"MEC Model 1100-13 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-027	"MEC Model 1100-14 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-028	"MEC Model 1100-15 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-029	"MEC Model 1100-16 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-030	"MEC Model 1100-17 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-031	"MEC Model 1100-18 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-032	"MEC Model 1100-19 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-033	"MEC Model 1100-20 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-034	"MEC Model 1100-21 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-035	"MEC Model 1100-22 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-036	"MEC Model 1100-23 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-037	"MEC Model 1100-24 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-038	"MEC Model 1100-25 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-039	"MEC Model 1100-26 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-040	"MEC Model 1100-27 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-041	"MEC Model 1100-28 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-042	"MEC Model 1100-29 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-043	"MEC Model 1100-30 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-044	"MEC Model 1100-31 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-045	"MEC Model 1100-32 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-046	"MEC Model 1100-33 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-047	"MEC Model 1100-34 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-048	"MEC Model 1100-35 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-049	"MEC Model 1100-36 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-050	"MEC Model 1100-37 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-051	"MEC Model 1100-38 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-052	"MEC Model 1100-39 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-053	"MEC Model 1100-40 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-054	"MEC Model 1100-41 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-055	"MEC Model 1100-42 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-056	"MEC Model 1100-43 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-057	"MEC Model 1100-44 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-058	"MEC Model 1100-45 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-059	"MEC Model 1100-46 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-060	"MEC Model 1100-47 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-061	"MEC Model 1100-48 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-062	"MEC Model 1100-49 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-063	"MEC Model 1100-50 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-064	"MEC Model 1100-51 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-065	"MEC Model 1100-52 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-066	"MEC Model 1100-53 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-067	"MEC Model 1100-54 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-068	"MEC Model 1100-55 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-069	"MEC Model 1100-56 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-070	"MEC Model 1100-57 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-071	"MEC Model 1100-58 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-072	"MEC Model 1100-59 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-073	"MEC Model 1100-60 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-074	"MEC Model 1100-61 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-075	"MEC Model 1100-62 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-076	"MEC Model 1100-63 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-077	"MEC Model 1100-64 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-078	"MEC Model 1100-65 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-079	"MEC Model 1100-66 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-080	"MEC Model 1100-67 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-081	"MEC Model 1100-68 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-082	"MEC Model 1100-69 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-083	"MEC Model 1100-70 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-084	"MEC Model 1100-71 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-085	"MEC Model 1100-72 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-086	"MEC Model 1100-73 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-087	"MEC Model 1100-74 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-088	"MEC Model 1100-75 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-089	"MEC Model 1100-76 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-090	"MEC Model 1100-77 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-091	"MEC Model 1100-78 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-092	"MEC Model 1100-79 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-093	"MEC Model 1100-80 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-094	"MEC Model 1100-81 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-095	"MEC Model 1100-82 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-096	"MEC Model 1100-83 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-097	"MEC Model 1100-84 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-098	"MEC Model 1100-85 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-099	"MEC Model 1100-86 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-100	"MEC Model 1100-87 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-101	"MEC Model 1100-88 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-102	"MEC Model 1100-89 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-103	"MEC Model 1100-90 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-104	"MEC Model 1100-91 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-105	"MEC Model 1100-92 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-106	"MEC Model 1100-93 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-107	"MEC Model 1100-94 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-108	"MEC Model 1100-95 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-109	"MEC Model 1100-96 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-110	"MEC Model 1100-97 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-111	"MEC Model 1100-98 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-112	"MEC Model 1100-99 Ozone Meter,"	Columbia Scientific Industries			
RFOA-1076-113	"MEC Model 1100-100 Ozone Meter,"	Columbia Scientific Industries			

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>OZONE (Continued)</u>						
RFOA-1176-017	"Monitor Labs Model 8410E Ozone Analyzer," operated on a range of 0-0.5 ppm with a time constant setting of 5 seconds, with or without any of the following options: DO Status Outputs ER Ethylene Regulator Assembly TF TFE Sample Particulate Filter V TFE Zero/Span Valves VT TFE Zero/Span Valves And Timer	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	41 53684	12/08/76
EQOA-0577-019	"Dasibi Model 1003-AH, 1003-PC, or 1003-RS Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: Adjustable Alarm Aluminum Coated Absorption Tubes BCD Digital Output Glass (Pyrex) Absorption Tubes Integrated Output Rack Mounting Ears And Slides Teflon-based Solenoid Valve Vycor-Jacketed U.V. Source Lamp 0-10 mV, 0-100 mV, 0-1 V, or 0-10 V Analog Output	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Equiv.	42 28571	06/03/77
RFOA-0577-020	"Beckman Model 950A Ozone Analyzer," operated on a range of 0-0.5 ppm and with the "SLOW" (60 second) response time, with or without any of the following options: Internal Ozone Generator	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634 Computer Adaptor Kit	Auto	Reference	42 28571	06/3/77 Pure Ethylene Accessory

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>OZONE (Continued)</u>						
EQOA-0777-023	"Philips PW9771 03 Analyzer," consisting of the following components: PW9771/00 03 Monitor with: PW9724/00 Disc.-Set PW9750/00 Supply Cabinet PW9750/20 Supply Unit; operated on a range of 0-0.5 ppm, with or without any of the following accessories: PW9732/00 Sampler Line Heater PW9733/00 Sampler PW9750/30 Frame For MTT PW9750/41 Control Clock 60 Hz PW9752/00 Air Sampler Manifold	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	42 38931 08/01/77 42 57156 11/01/77	
RFOA-0279-036	"Columbia Scientific Industries Model 2000 Ozone Meter," when operated on the 0-0.5 ppm range with either AC or battery power: The BCA 952 battery charger/AC adapter M952-0002 (115V) or M952-0003 (230V) is required for AC operation; an internal battery M952-0006 or 12 volt external battery is required for portable non-AC powered operation.	Columbia Scientific Industries 11950 Jollyville Rd. Austin, TX 78759	Auto	Reference	44 10429 02/20/79	
EQOA-0880-047	"Thermo Electron Model 49 U.V. Photometric Ambient O ₃ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: 49-001 Teflon Particulate Filter 49-002 19 Inch Rack Mountable Configuration 49-100 Internal Ozone Generator For Zero, Precision, And Level 1 Span Checks 49-103 Internal Ozone Generator For Zero, Precision, And Level 1 Span Checks With Remote Activation 49-488 GPIB (General Purpose Interface Bus) IEEE-488	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	45 57168 08/27/80	

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER</u>	<u>NOTICE</u>
					<u>VOL.</u>	<u>PAGE</u> <u>DATE</u>
<u>OZONE (Continued)</u>						
EQOA-0881-053	"Monitor Labs Model 8810 Photo-metric Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with selectable electronic time constant settings from 20 through 150 seconds, with or without any of the following options: 05 Pressure Compensation 06 Averaging Option 07 Zero/Span Valves 08 Internal Zero/Span (Valve And Ozone Source) 09 Status 10 Particulate Filter 15 through 20 DAS/REC Output	Lear Siegler Measurement Control Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	46	52224 10/26/81
EQOA-0382-055	"PCI Ozone Corporation Model LC-12 Ozone Analyzer," operated on a range of 0-0.5 ppm.	PCI Ozone Corporation One Fairfield Crescent West Caldwell, NJ 07006	Auto	Equiv.	47	13572 03/31/82
EQOA-0383-056	"Dasibi Model 1008-AH, 1008-PC, or 1008-RS Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: Aluminum Coated Absorption Tubes BCD Digital Output Glass (Pyrex) Absorption Tubes Ozone Generator Photometer Flow Restrictor (2 LPM) Rack Mounting Brackets or Slides RS232 Interface Vycor-Jacketed U.V. Source Lamp Teflon-based Solenoid Valve 4-20 mA, Isolated, or Dual Analog Outputs 20 Second Update Software	Dasibi Environmental Corp. 515 West Colorado St. Glendale, CA 91204-1101	Auto	Equiv.	48	10126 03/10/83

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>OZONE (Continued)</u>						
EQOA-0990-078	"Enviro-nics Series 300 Computerized Ozone Analyzer," operated on the 0-0.5 ppm range, with the following parameters entered into the analyzer's computer system: Absorption Coefficient = 308 ± 4 Flush Time = 3 Integration Factor = 1 Offset Adjustment = 0.025 ppm Ozone Average Time = 4 Signal Average = 0 Temp/Press Correction = On and with or without the RS-232 Serial Data Interface.	Enviro-nics, Inc. 165 River Road West Willington, CT 06279	Auto	Equiv.	55 38386	09/18/90
EQOA-0992-087	"Advanced Pollution Instrumentation, Inc. Model 400 Ozone Analyzer," operated on any full scale range between 0-100 ppb* and 0-1000 ppb, at any temperature in the range of 5°C to 40°C, with the dynamic zero and span adjustment features set to OFF, with a 5-micron TFE filter element installed in the rear-panel filter assembly, and with or without any of the following options: Internal Zero/Span (IZS) IZS Reference Adjustment Rack Mount With Slides RS-232 With Status Outputs Zero/Span Valves	Advanced Pollution Instrumentation, Inc. 8815 Production Avenue San Diego, CA 92121-2219	Auto	Equiv.	57 44565	09/28/92

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0-500 ppb is based on meeting the same absolute performance specifications required for the 0-500 ppb range. Thus, designation of any range lower than 0-500 ppb does not imply commensurably better performance than that obtained on the 0-500 ppb range.

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>OZONE (Continued)</u>					
EQOA-0193-091	"Lear Siegler Measurement Controls Corporation Model ML9810 Ozone Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i> , at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Calibration; <i>Manual</i> or <i>Timed</i> : Diagnostic Mode: <i>Operate</i> ; Filter Type: <i>Kalman</i> ; Pres/Temp/Flow Comp: <i>On</i> ; Span Comp: <i>Disabled</i> ; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA; and with or without any of the following options: Valve Assembly for External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	58 6964 02/03/93

*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
<u>CARBON MONOXIDE</u>						
RFCA-0276-008	Bendix or Combustion Engineering Model 8501-5CA Infrared CO Analyzer, operated on the 0-50 ppm range and with a time constant setting between 5 and 16 seconds, with or without any of the following options: A Rack Mounting With Chassis Slides B Rack Mounting Without Chassis Slides C External Sample Pump	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	41 7450	02/18/76
RFCA-0876-012	"Beckman Model 866 Ambient CO Monitoring System," consisting of the following components: Pump/Sample-Handling Module, Gas Control Panel, Model 865-17 Analyzer Unit, Automatic Zero/Span Standardizer; operated with a 0-50 ppm range, a 13 second electronic response time, with or without any of the following options: Current Output Feature Bench Mounting Kit Linearizer Circuit	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Reference	41 36245	08/27/76
RFCA-0177-018	"LIRA Model 202S Air Quality Carbon Monoxide Analyzer System," consisting of a LIRA Model 202S optical bench (P/N 459839), a regenerative dryer (P/N 464084), and rack-mounted sampling system; operated on a 0-50 ppm range, with the slow response amplifier, with or without any of the following options: Remote Meter Remote Zero And Span Controls 0-1, 5, 20, or 50 mA Output 1-5, 4-20, or 10-50 mA Output 0-10 or 100 mV Output 0-1, 5, or 10 Volt Output	Mine Safety Appliances Co. 600 Penn Center Boulevard Pittsburgh, PA 15208	Auto	Reference	42 5748	01/31/77

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>CARBON MONOXIDE (Continued)</u>					
RFCA-1278-033	"Horiba Models AQM-10, AQM-11, and AQM-12 Ambient CO Monitoring Systems," operated on the 0-50 ppm range, with a response time setting of 15.5 seconds, with or without any of the following options: a AIC-101 Automatic Indication Corrector b VIT-3 Non-Isolated Current Output c ISO-2 and DCS-3 Isolated Current Output	Horiba Instruments, Inc. 17671 Armstrong Avenue Irvine, CA 92714-5727	Auto	Reference	43 58429 12/14/78
RFCA-0979-041	"Monitor Labs Model 8310 CO Analyzer," operated on the 0-50 ppm range, with a sample inlet filter, with or without any of the following options: 02A Zero/Span Valves 03A Floor Stand 04A Pump (60 Hz)	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189 04B Pump (50 Hz) 05A CO Regulator 06A CO Cylinder	Auto	Reference	44 54545 09/20/79 45 2700 01/14/80 07A Zero/Span Valve Power Supply 08A Calibration Valves 9A,B,C,D Input Power Transformer
RFCA-1180-048	"Horiba Model APMA-300E Ambient Carbon Monoxide Monitoring System," operated on the 0-20 ppm*, the 0-50 ppm, or the 0-100 ppm range with a time constant switch setting of No. 5. The monitoring system may be operated at temperatures between 10°C and 40°C.	Horiba Instruments, Inc. 17671 Armstrong Avenue Irvine, CA 92714-5727	Auto	Reference	45 72774 11/03/80

*NOTE: Users should be aware that designation of this analyzer for operation on a range less than 50 ppm is based on meeting the same absolute performance specifications required for the 0-50 ppm range. Thus, designation of this lower range does not imply commensurably better performance than that obtained on the 0-50 ppm range.

(This method was originally designated as "Horiba Model APMA 300E/300SE Ambient Carbon Monoxide Monitoring System".)

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE DATE
<u>CARBON MONOXIDE (Continued)</u>					
RFCA-1280-050	"MASS-CO, Model 1 Carbon Monoxide Analyzer," operated on a range of 0-50 ppm, with automatic zero and span adjustments at time intervals not to exceed 4 hours, with or without the 100 millivolt and 5 volt output options. The method consists of the following components: (1) Infra-2 (Uras 2) Infrared Analyzer Model 5611-200-35, (2) Automatic Calibrator Model 5869-111, (3) Electric Gas Cooler Model 7865-222 or equivalent with prehumidifier, (4) Diaphragm Pump Model 5861-214 or equivalent, (5) Membrane Filter Model 5862-111 or equivalent, (6) Flow Meter Model SK 1171-U or equivalent, (7) Recorder Model Mini Comp DN 1/192 or equivalent	Commonwealth of Massachusetts Department of Environmental Quality Engineering Tewksberry, MA 01876	Auto	Reference	45 81650 12/11/80
NOTE: This method is not now commercially available.					
RFCA-0381-051	"Dasibi Model 3003 Gas Filter Correlation CO Analyzer," operated on the 0-50 ppm range, with a sample particulate filter installed on the sample inlet line, with or without any of the following options: 3-001 Rack Mount 3-002 Remote Zero And Span	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Reference	46 20773 04/07/81
3-003 BCD Digital Output 3-004 4-20 Milliamp Output 3-007 Zero/Span Module Panel					
RFCA-0981-054	"Thermo Environmental Instruments Model 48 Gas Filter Correlation Ambient CO Analyzer," operated on the 0-50 ppm range, with a time constant setting of 30 seconds, with or without any of the following options: 48-001 Particulate Filter 48-002 19 Inch Rack Mountable Configuration 48-003 Internal Zero/Span Valves With Remote Activation 48-488 GPIB (General Purpose Interface Bus) IEEE-488 48-010 Internal Zero Air Package	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	46 47002 09/23/81

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
		<u>CARBON MONOXIDE (Continued)</u>			
RFCA-0388-066	"Monitor Labs Model 8830 CO Analyzer," operated on the 0-50 ppm range, with a five micron Teflon filter element installed in the rear-panel filter assembly, with or without any of the following options: 2 Zero/Span Valve Assembly 3 Rack Assembly 4 Slide Assembly 7 230 VAC, 50/60 Hz	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	53 7233 03/07/88
RFCA-0488-067	"Dasibi Model 3008 Gas Filter Correlation CO Analyzer," operated on the 0-50 ppm range, with a time constant setting of 60 seconds, a particulate filter installed in the analyzer sample inlet line, with or without use of the auto zero or auto zero/span feature, and with or without any of the following options: N-0056-A RS-232-C Interface S-0132-A Rack Mounting Slides Z-0176-S Rack Mounting Brackets	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Reference	53 12073 04/12/88

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>CARBON MONOXIDE (Continued)</u>						
RFCA-0992-088	"Lear Siegler Measurement Controls Corporation Model ML9830 Carbon Monoxide Analyzer," operated on any full scale range between 0-5.0 ppm* and 0-100 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i> , at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position, with the following menu choices selected: Background: Not <i>Disabled</i> ; Calibration: <i>Manual</i> or <i>Timed</i> ; Diagnostic Mode: <i>Operate</i> ; Filter Type: <i>Kalman</i> ; Pres/Temp/Flow Comp: <i>On</i> ; Span Comp: <i>Disabled</i> ; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V Current, 0-20 mA, 2-20 mA and 4-20 mA; and with or without any of the following options: Valve Assembly For External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	57 44565	09/28/92

*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 50 ppm is based on meeting the same absolute performance specifications required for the 0-50 ppm range. Thus, designation of any full scale range lower than the 0-50 ppm range does not imply commensurably better performance than that obtained on the 0-50 ppm range.

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<u>NITROGEN DIOXIDE</u>						
RFNA-0677-021	"Monitor Labs Model 8440E Nitrogen Oxides Analyzer," operated on a 0-0.5 ppm range (position 2 of range switch) with a time constant setting of 20 seconds, with or without any of the following options: TF Sample Particulate Filter With TFE Filter Element V Zero/Span Valves	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	42 37434 42 46575 46 29986	07/21/77 09/16/77 06/04/81
				018A Ozone Dry Air 018B Ozone Dry Air - No Drierite		
RFNA-0777-022	Bendix or Combustion Engineering Model 8101-C Oxides of Nitrogen Analyzer, operated on a 0-0.5 ppm range with a Teflon sample filter (Bendix P/N 007163) installed on the sample inlet line.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	42 37435	07/21/77
RFNA-0977-025	"CSI Model 1600 Oxides of Nitrogen Analyzer," operated on a 0-0.5 ppm range with a Teflon sample filter (CSI P/N M951-8023) installed on the sample inlet line, with or without any of the following options: 951-0103 Rack Ears 951-0104 Rack Mounting Kit (Ears & Slides) 951-0106 Current Output, 4-20 mA (Non-Insulated) 951-0108 Diagnostic Output Option 951-0111 Recorder Output, 10 V	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Reference	42 46574	09/16/77
		951-0112 Remote Zero/Span Sample Control 951-0114 Recorder Output, 5 V 951-0115 External Pump (115 V, 60 Hz) 951-8072 Molybdenum Converter Assembly (Horizontal)		951-8074 Copper Converter Assembly (Horizontal) 951-8079 Copper Converter Assembly (Vertical) 951-8085 Molybdenum Converter Assembly (Vertical)		

NOTE: The vertical molybdenum converter assembly is standard on all new analyzers as of 1-1-87; however, use of any of the other converter assemblies is optional. Also, the above options reflect new CSI part numbers.

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<u>NITROGEN DIOXIDE (Continued)</u>						
EQN-1277-026	"Sodium Arsenite Method for the Determination of Nitrogen Dioxide in the Atmosphere"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42 62971	12/14/77
EQN-1277-027	"Sodium Arsenite Method for the Determination of Nitrogen Dioxide in the Atmosphere--Technicon II Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42 62971	12/14/77
EQN-1277-028	"TGS-ANSA Method for the Determination of Nitrogen Dioxide in the Atmosphere"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42 62971	12/14/77

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE</u>	<u>DATE</u>
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NITROGEN DIOXIDE (Continued)

RFNA-1078-031	"Melay Model NA530R Nitrogen Oxides Analyzer," operated on the following ranges and time constant switch positions:	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Reference	43 44	50733 8327	10/31/78 02/09/79
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Range, ppm Time Constant Setting

0-0.1*	4
0-0.25*	3 or 4
0-0.5	2, 3, or 4
0-1.0	2, 3, or 4

Operation of the analyzer requires an external vacuum pump, either Melay Option N-10 or an equivalent pump capable of maintaining a vacuum of 200 torr (22 inches mercury vacuum) or better at the pump connection at the specified sample and ozone-air flow rates of 1200 and 200 cm³/min, respectively. The analyzer may be operated at temperatures between 10°C and 40°C and at line voltages between 105 and 130 volts, with or without any of the following options:

N-1A Automatic Zero And Span	N-6C Remote Zero/Span Control	N-14B Line Transmitter
N-2 Vacuum Gauge	And Status (Timer)	N-18 Rack Mount Conversion
N-4 Digital Panel Meter	N-9 Manual Zero/Span	N-18A Rack Mount Conversion
N-6 Remote Control For Zero And Span	N-10 Vacuum Pump Assembly (See Alternate Requirement Above)	
N-6B Remote Zero/Span Control And Status (Pulse)	N-11 Auto Ranging	

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0179-034	"Beckman Model 952-A NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range with the 5-micron Teflon sample filter (Beckman P/N 861072 supplied with the analyzer) installed on the sample inlet line, with or without the Remote Operation Option (Beckman Cat. No. 635539).	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Reference	44 7806 02/07/79
RFNA-0179-035	"Thermo Electron Model 14 B/E Chemiluminescent NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: 14-001 Teflon Particulate Filter 14-002 Voltage Divider Card 14-003 Long-Time Signal Integrator 14-004 Indicating Temperature Controller 14-005 Sample Flowmeter 14-006 Air Filter	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	44 7805 02/07/79 44 54545 09/20/79
RFNA-0279-037	"Thermo Electron Model 14 D/E Chemiluminescent NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: 14-001 Teflon Particulate Filter 14-002 Voltage Divider Card	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	44 10429 02/20/79

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<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0479-038	"Bendix Model 8101-B Oxides of Nitrogen Analyzer," operated on a 0-0.5 ppm range with a Teflon sample filter installed on the sample inlet line and with the following post-manufacture modifications: 1. Ozone generator and reaction chamber input-output tubing modification per Bendix Service Bulletin 8101B-2; 2. The approved converter material; 3. The revised and EPA-approved operation and service manual. These items are mandatory and must be obtained from Combustion Engineering, Inc. The analyzer may be operated with or without any of the following optional modifications: a. Perma Pure dryer/ambient air modification; b. Valve cycle time modification; c. Zero potentiometer centering modification per Bendix Service Bulletin 8101B-1; d. Reaction chamber vacuum gauge modification.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	44 26792 05/07/79
RFNA-0879-040	"Philips Model PW9762/02 NO/NO ₂ /NO _x Analyzer," consisting of the following components: PW9762/02 Basic Analyzer PW9729/00 Converter Cartridge PW9731/00 Sampler or PW9731/20 Dust Filter; operated on a range of 0-0.5 ppm, with or without any of the following accessories: PW9752/00 Air Sampler Manifold PW9732/00 Sample Line Heater PW9011/00 Remote Control Set	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Reference	44 51683 09/04/79

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<u>NITROGEN DIOXIDE (Continued)</u>						
RFNA-0280-042	"Monitor Labs Model 8840 Nitrogen Oxides Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with an internal time constant setting of 60 seconds, a TFE sample filter installed on the sample inlet line, with or without any of the following options:	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	45 9100 46 29986	02/11/80 06/04/81
	02 Flowmeter	08A Pump Pac Assembly With 09A (115 VAC)			011A Recorder Output 1 Volt	
	03A Rack Ears				011B Recorder Output 100 mV	
	03B Slides	08B Pump Pac Assembly With 09B (100 VAC)			011C Recorder Output 10 mV	
	05A Zero/Span Valves				012A DAS Output 1 Volt	
	05B Valve/Relay	08C Pump Pac Assembly With 09C (220/240 VAC)			012B DAS Output 100 mV	
	06 Status				012C DAS Output 10 mV	
	07A Input Power Transformer 100 VAC, 50/60 Hz	08D Rack Mount Panel Assembly			013A Ozone Dry Air	
	07B Input Power Transformer 220/240 VAC, 50 Hz	09A Pump 115 VAC 50/60 Hz 09B Pump 100 VAC 50/60 Hz 09C Pump 220/240 VAC 50 Hz			013B Ozone Dry Air - No Drierite	
RFNA-1289-074	"Thermo Environmental Instruments Inc. Model 42 NO/NO ₂ /NO _x Analyzer," operated on the 0-0.05 ppm*, the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range, with any time average setting from 10 to 300 seconds. The analyzer may be operated at temperatures between 15°C and 35°C and at line voltages between 105 and 125 volts, with or without any of the following options:	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	54 50820	12/11/89
	42-002 Rack Mounts	42-004 Sample/Ozone Flowmeters			42-007 Ozone Particulate Filter	
	42-003 Internal Zero/Span And Sample Valves With Remote Activation	42-005 4-20 mA Current Output 42-006 Pressure Transducer			42-008 RS-232 Interface 42-009 Permeation Dryer	

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0.05 ppm range.

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<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0691-082	<p>*Advanced Pollution Instrumentation, Inc. Model 200 Nitrogen Oxides Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a 5-micron TFE filter element installed in the rear-panel filter assembly, with either a user- or vendor-supplied vacuum pump capable of providing 5 inches mercury absolute pressure at 5 slpm, with either a user- or vendor-supplied dry air source capable of providing air at a dew point of 0°C or lower, with the following settings of the adjustable setup variables:</p> <p>Adaptive Filter = ON Dwell Time = 7 seconds Dynamic Span = OFF Dynamic Zero = OFF PMT Temperature Set Point = 15°C Rate of Change(ROC) Threshold = 10% Reaction Cell Temperature = 50°C Sample Time = 8 seconds Normal Filter Size = 12 samples; and with or without any of the following options:</p> <p>180 Stainless Steel Valves 184 Pump Pack 280 Rack Mount With Slides</p>	<p>Advanced Pollution Instrumentation, Inc 8815 Production Avenue San Diego, CA 92121-2219</p>	Auto	Reference	56 27014 06/12/91
		<p>283 Internal Zero/Span With Valves (IZS) 325 RS-232/Status Output 355 Expendables</p>			<p>356 Level One Spares Kit 357 Level Two Spares Kit PE5 Permeation Tube for IZS</p>
RFNA-0991-083	<p>*Monitor Labs Model 8841 Nitrogen Oxides Analyzer," operated on the 0-0.05 ppm*, 0-0.1 ppm*, 0-0.2 ppm*, 0-0.5 ppm, or 0-1.0 ppm range, with manufacturer-supplied vacuum pump or alternative user-supplied vacuum pump capable of providing 200 torr or better absolute vacuum while operating with the analyzer.</p>	<p>Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189</p>	Auto	Reference	56 47473 09/19/91

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on

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NITROGEN DIOXIDE (Continued)

RFNA-1192-089 "Dasibi Model 2108 Oxides of Nitrogen Analyzer," operated on the 0-500 ppb range, with software revision 3.6 installed in the analyzer, with the Auto thumbwheel switch and the Diag thumbwheel switch settings at 0, with the following internal CPU dipswitch settings:

switch	position	function
1	open (down)	Recorder outputs are NO & NO ₂
5	open (down)	3 minute time constant
6	closed (up)	3 minute time constant;

with a 5-micron Teflon filter element installed in the filter holder, and with or without any of the following options:

Built-in Permeation Oven
RS-232 Interface

Rack Mounting
4-20 mA Output

Three-Channel Recorder Output

RFNA-1292-090 "Lear Siegler Measurement Controls Corporation Model ML9841 Nitrogen Oxides Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging *enabled or disabled*, at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the *In* position; with the following menu choices selected:

Calibration: *Manual or Timed*; Diagnostic Mode: *Operate*; Filter Type: *Kalman*; Pres/Temp/Flow Comp: *On*; Span Comp: *Disabled*;

with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings:

Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA;

and with or without any of the following options:

Internal Floppy Disk Drive

Rack Mount Assembly

Valve Assembly for External Zero/Span (EVS)

*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

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		<u>LEAD</u>			
*****	Reference Method for the Determination of Lead in Suspended Particulate Matter Collected from Ambient Air	40 CFR Part 50, Appendix G	Manual	Reference	43 46258 10/05/78
EQL-0380-043	"Determination of Lead Concentration in Ambient Particulate Matter by Flame Atomic Absorption Spectrometry Following Ultrasonic Extraction with Heated HNO ₃ -HCl"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648 03/06/80
EQL-0380-044	"Determination of Lead Concentration in Ambient Particulate Matter by Flameless Atomic Absorption Spectrometry (EPA/RTP,N.C.)"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648 03/06/80
EQL-0380-045	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (EPA/RTP,N.C.)"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648 03/06/80
EQL-0581-052	"Determination of Lead Concentration in Ambient Particulate Matter by Wavelength Dispersive X-Ray Fluorescence Spectrometry"	California Department of Health Services Air & Industrial Hygiene Laboratory 2151 Berkeley Way Berkeley, CA 94704	Manual	Equiv.	46 29986 06/04/81

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<u>LEAD (Continued)</u>						
EQL-0483-057	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Montana)"	State of Montana Department of Health and Environmental Sciences Cogswell Building Helena, MT 59620	Manual	Equiv.	48 14748	04/05/83
EQL-0783-058	"Determination of Lead Concentration in Ambient Particulate Matter by Energy-Dispersive X-Ray Fluorescence Spectrometry (Texas Air Control Board)"	Texas Air Control Board 6330 Highway 290 East Austin, TX 78723	Manual	Equiv.	48 29742	06/28/83
EQL-0785-059	"Determination of Lead Concentration in Ambient Particulate Matter by Flameless Atomic Absorption Spectrometry (Omaha-Douglas County Health Department)"	Omaha-Douglas County Health Department 1819 Farnam Street Omaha, NE 68183	Manual	Equiv.	50 37909	09/18/85
EQL-0888-068	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Rhode Island)"	State of Rhode Island Department of Health Air Pollution Laboratory 50 Orms Street Providence, RI 02904	Manual	Equiv.	53 30866	08/16/88
EQL-1188-069	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Northern Engineering and Testing, Inc.)"	Northern Engineering and Testing, Inc. P.O. Box 30615 Billings, MT 59107	Manual	Equiv.	53 44947	11/07/88

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<u>LEAD (Continued)</u>					
EQL-1288-070	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Silver Valley Laboratories)"	Silver Valley Laboratories, Inc. P.O. Box 929 Kellogg, ID 83837	Manual	Equiv.	53 48974 12/05/88
EQL-0589-072	"Determination of Lead Concentration in Ambient Particulate Matter by Energy Dispersive X-Ray Fluorescence Spectrometry (NEA, Inc.)"	Nuclear Environmental Analysis, Inc. 10950 SW 5th Street, Suite 260 Beaverton, OR 97005	Manual	Equiv.	54 20193 05/10/89
EQL-1290-080	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of New Hampshire)"	State of New Hampshire Department of Environmental Services Laboratory Service Unit 6 Hazen Drive (P.O. Box 95) Concord, NH 03302-0095	Manual	Equiv.	55 49119 11/26/90
EQL-0592-085	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Kansas)"	State of Kansas Department of Health and Environment Forbes Field, Building 740 Topeka, KS 66620-0001	Manual	Equiv.	57 20823 05/15/92
EQL-0592-086	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Commonwealth of Pennsylvania)"	Commonwealth of Pennsylvania Department of Environmental Resources P.O. Box 2357 Harrisburg, PA 17105-2357	Manual	Equiv.	57 20823 05/15/92

February 8, 1993

METHOD CODES

Method	Designation Number	Method Code	Method	Designation Number	Method Code
<u>SO₂ Manual Methods</u>			<u>NO_x Manual Methods</u>		
Ref. method (pararosaniline)	-	097	Sodium arsenite (orifice)	EQN-1277-026	084
Technicon I (pararosaniline)	EQS-0775-001	097	Sodium arsenite/Technicon II	EQN-1277-027	084
Technicon II (Pararosaniline)	EQS-0775-002	097	TGS-ANSA (orifice)	EQN-1277-028	098
<u>SO₂ Analyzers</u>			<u>NO_x Analyzers</u>		
Advanced Pollution Instr. 100	EQSA-0990-077	077	Advanced Pollution Instr. 200	RFNA-0691-082	082
Ameco 500	EQSA-0877-024	024	Beckman 952A	RFNA-0179-034	034
Beckman 953	EQSA-0678-029	029	Bendix 8101-B	RFNA-0479-038	038
Bendix 8303	EQSA-1078-030	030	Bendix 8101-C	RFNA-0777-022	022
Dasibi 4106	EQSA-1086-061	061	Dasibi 2108	RFNA-1192-089	089
Environmental S.A. AF21M	EQSA-0292-084	084	CSI 1600	RFNA-0977-025	025
Lear Siegler AM2020	EQSA-1280-049	049	Lear Siegler ML9841	RFNA-1292-090	090
Lear Siegler SM1000	EQSA-1275-005	005	Meloy NA530R	RFNA-1078-031	031
Lear Siegler ML9850	EQSA-0193-092	092	Monitor Labs 8440E	RFNA-0677-021	021
Meloy SA185-2A	EQSA-1275-006	006	Monitor Labs 8840	RFNA-0280-042	042
Meloy SA285E	EQSA-1078-032	032	Monitor Labs 8841	RFNA-0991-083	083
Meloy SA700	EQSA-0580-046	046	Philips PW9762/02	RFNA-0879-040	040
Monitor Labs 8450	EQSA-0876-013	513	Thermo Electron 14B/E	RFNA-0179-035	035
Monitor Labs 8850	EQSA-0779-039	039	Thermo Electron 14D/E	RFNA-0279-037	037
Monitor Labs 8850S	EQSA-0390-075	075	Thermo Environmental Inst. 42	RFNA-1289-074	074
Philips PW9700	EQSA-0876-011	511			
Philips PW9755	EQSA-0676-010	010			
Thermo Electron 43	EQSA-0276-009	009			
Thermo Electron 43A	EQSA-0486-060	060			
<u>O₃ Analyzers</u>			<u>Pb Manual Methods</u>		
Advanced Pollution Instr. 400	EQOA-0992-087	087	Ref. method (hi-vol/AA spect.)	-	803
Beckman 950A	RFOA-0577-020	020	Hi-vol/AA spect. (alt. extr.)	EQL-0380-043	043
Bendix 8002	RFOA-0176-007	007	Hi-vol/Energy-disp XRF (TX ACB)	EQL-0783-058	058
CSI 2000	RFOA-0279-036	036	Hi-vol/Energy-disp XRF (NEA)	EQL-0589-072	072
Dasibi 1003-AH,-PC,-RS	EQOA-0577-019	019	Hi-vol/Flameless AA (EMSL/EPA)	EQL-0380-044	044
Dasibi 1008-AH	EQOA-0383-056	056	Hi-vol/Flameless AA (Omaha)	EQL-0785-059	059
Enviroconics 300	EQOA-0990-078	078	Hi-vol/ICAP spect. (EMSL/EPA)	EQL-0380-045	045
Lear Siegler ML9810	EQOA-0193-091	091	Hi-vol/ICAP spect. (Kansas)	EQL-0592-085	085
McMillan 1100-1	RFOA-1076-014	514	Hi-vol/ICAP spect. (Montana)	EQL-0483-057	057
McMillan 1100-2	RFOA-1076-015	515	Hi-vol/ICAP spect. (NE&T)	EQL-1188-069	069
McMillan 1100-3	RFOA-1076-016	016	Hi-vol/ICAP spect. (N. Hampshir)	EQL-1290-080	080
Meloy OA325-2R	RFOA-1075-003	003	Hi-vol/ICAP spect. (Pennsylvania)	EQL-0592-086	086
Meloy OA350-2R	RFOA-1075-004	004	Hi-vol/ICAP spect. (Rhode Is.)	EQL-0888-068	068
Monitor Labs 8410E	RFOA-1176-017	017	Hi-vol/ICAP spect. (S.V. Labs)	EQL-1288-070	070
Monitor Labs 8810	EQOA-0881-053	053	Hi-vol/WL-disp. XRF (CA A&IHL)	EQL-0581-052	052
PCI Ozone Corp. LC-12	EQOA-0382-055	055			
Philips PW9771	EQOA-0777-023	023			
Thermo Electron 49	EQOA-0880-047	047			
<u>CO Analyzers</u>			<u>PM₁₀ Samplers</u>		
Beckman 866	RFCA-0876-012	012	Oregon DEQ Med. vol. sampler	RFPS-0389-071	071
Bendix 8501-SCA	RFCA-0276-008	008	Sierra-Andersen/GMW 1200	RFPS-1287-063	063
Dasibi 3003	RFCA-0381-051	051	Sierra-Andersen/GMW 321-B	RFPS-1287-064	064
Dasibi 3008	RFCA-0488-067	067	Sierra-Andersen/GMW 321-C	RFPS-1287-065	065
Horiba AQM-10, -11, -12	RFCA-1278-033	033	Sierra-Andersen/GMW 241 Dichot	RFPS-0789-073	073
Horiba 300E/300SE	RFCA-1180-048	048	Wedding & Assoc. high volume	RFPS-1087-062	062
Lear Siegler ML 9830	RFCA-0992-088	088			
MASS - CO 1 (Massachusetts)	RFCA-1280-050	050			
Monitor Labs 8310	RFCA-0979-041	041			
Monitor Labs 8830	RFCA-0388-066	066			
MSA 202S	RFCA-0177-018	018			
Thermo Electron 48	RFCA-0981-054	054			
			<u>PM₁₀ Analyzers</u>		
			Andersen Instr. Beta FH621-N	EQPM-0990-076	076
			R & P TEOM 1400, 1400a	EQPM-1090-079	079
			Wedding & Assoc. Beta Gauge	EQPM-0391-081	081
			<u>TSP Manual Method</u>		
			Reference method (high-volume)	-	802

APPROVED METHODS AS OF FEBRUARY 8, 1993

	MANUAL		AUTOMATED	
	REFERENCE	EQUIVALENT	REFERENCE	EQUIVALENT
CO			<ol style="list-style-type: none"> 1. CE (Beckman) 8501-5CA (50) 2. Beckman 846 (50) 3. MSA 2025 (50) 4. Beutels AOM-10,11,12 (50) 5. Monitor Labs 8310 (50) 6. Beutels APMA-300E (20, 50, 100) 7. MARS-CD 1 (50) 8. Daelhi 3003 (50) 9. TED 48 (50) 10. Monitor Labs 8830 (50) 11. Daelhi 3008 (50) 12. Lear Sampler ML 9830 (5-100) 	
NO ₂		<ol style="list-style-type: none"> 1. Sadtler Aromat 2. Sadtler Aromat/Techmate II 3. TOS-ANSA 	<ol style="list-style-type: none"> 1. Monitor Labs 8400E (.5) 2. CE (Beckman) 8101-C (.5) 3. CSI 1600 (.5) 4. Molloy NA30E (.1, .25, .5, 1.0) 5. Beckman 952-A (.5) 6. TED 14 D/E (.5) 7. TED 14 D/E (.5) 8. Beutels 8101-B (.5) 9. Philips PW7762/02 (.5) 10. Monitor Labs 8840 (.5, 1.0) 11. TED 42 (.05, .1, .2, .5, 1.0) 12. API 200 (.5, 1.0) 13. Monitor Labs 8841 (.05, .1, .2, .5, 1.0) 14. Daelhi 2108 (.5) 15. Lear Sampler ML 9841 (.05-1.0) 	
O ₃			<ol style="list-style-type: none"> 1. Molloy OA325-2R (.5) 2. Molloy OA350-2R (.5) 3. CE (Beckman) 8002 (.5) 4. McGillem 1100-1 (.5) 5. McGillem 1100-2 (.5) 6. McGillem 1100-3 (.5) 7. Monitor Labs 8410E (.5) 8. Beckman 950A (.5) 9. CSI 2000 (.5) 	<ol style="list-style-type: none"> 1. Daelhi 1000-AH, PC, RS (.5, 1.0) 2. Philips PW7771 (.5) 3. TED 49 (.5, 1.0) 4. Monitor Labs 8810 (.5, 1.0) 5. PCT Ocean Corp. LC-12 (.5) 6. Daelhi 1000-AH, PC, RS (.5, 1.0) 7. Beutels 300 (.5) 8. API 400 (.1, .5, 1.0) 9. Lear Sampler ML 9810 (.05-1.0)
Pb	HV with Photo AA	<ol style="list-style-type: none"> 1. HV/Photo AA (EPA) 2. HV/Fluorescence AA (EPA) 3. HV/ICAP (EPA) 4. HV/EDXRF (ADL, CA) 5. HV/ICAP (MT) 6. HV/EDXRF (TX) 7. HV/Fluorescence AA (Omaha-Douglas Co.) 8. HV/ICAP (BJ) 9. HV/ICAP (NET) 10. HV/ICAP (SVL) 11. HV/EDXRF (NEA) 12. HV/ICAP (NH) 13. HV/ICAP (KS) 14. HV/ICAP (PA) 		
PM ₁₀	<ol style="list-style-type: none"> 1. W & A PM₁₀ Critical Flow HV Sampler 2. SA/GM/W 1200 3. SA/GM/W 321-B 4. SA/GM/W 321-C 5. Oregon DBQ HV Special Sampler 6. SA/GM/W 241 & 241M Direct Sampler 			<ol style="list-style-type: none"> 1. Anderson Int. PM10-N PM₁₀ Beta Attenuation Monitor 2. Rappaport & Pennebaker TROOP Series 1400 and 1400n PM-10 Monitors 3. Working & Associates' PM-10 Beta Gauge Automated Particle Sampler
SO ₂	Permanence Method	<ol style="list-style-type: none"> 1. Techmate I 2. Techmate II 		<ol style="list-style-type: none"> 1. Lear Sampler SM1000 (.5) 2. Molloy SA185-2A (.5, 1.0) 3. TED 43 (.5, 1.0) 4. Philips PW7755 (.5) 5. Philips PW7700 (.5) 6. Monitor Labs 8450 (.5, 1.0) 7. ASARCO 500 (.5), 600 (1.0) 8. Beckman 953 (.5, 1.0) 9. Beutels 8303 (.5, 1.0) 10. Molloy SA285E (.05, .1, .5, 1.0) 11. Monitor Labs 8850 (.5, 1.0) 12. Molloy SA700 (.25, .5, 1.0) 13. Lear Sampler AM0300 (.5, 1.0) 14. TED 43A (.1, .2, .5, 1.0) 15. Daelhi 4108 (.1, .2, .5, 1.0) 16. Monitor Labs 8650E (.5, 1.0) 17. API 100 (.5) 18. Beutels S.A. AF21M (.5) 19. Lear Sampler ML 9850 (.05-1.0)
TSP	High Volume Method (HV)			

NOTE: The numbers in parentheses that follow the manufacturer name i.e., (.05), (.1), (.2), (.5), (1.0), or (50) indicate the full scale range(s) approved for that method. Ranges that are qualified as (.05-1.0) or (5-100) indicate any full scale range between the indicated values.

DEPT E MD-77

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Research Triangle Park, North Carolina 27711
919 541-2622 or 919 541-4599
FTS 629-2622 or FTS 629-4599

Issue Date: February 8, 1993

* Previous Revision: September 28, 1992 *
*
* New Designations: *
* Dasibi Environmental Corporation *
* Model 2108 Oxides of Nitrogen Analyzer *
* Lear Siegler Measurement Controls Corporation *
* Model ML9841 Nitrogen Oxides Analyzer *
* Model ML9810 Ozone Analyzer *
* Model ML9850 Sulfur Dioxide Analyzer *

LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

These methods for measuring ambient concentrations of specified air pollutants have been designated as "reference methods" or "equivalent methods" in accordance with Title 40, Part 53 of the Code of Federal Regulations (40 CFR Part 53). Subject to any limitations (e.g., operating range) specified in the applicable designation, each method is acceptable for use in state or local air quality surveillance systems under 40 CFR Part 58 unless the applicable designation is subsequently canceled. Automated methods are acceptable for use at temperatures between 20°C and 30°C and line voltages between 105 and 125 volts unless wider limits are specified in the method description.

Prospective users of the methods listed should note (1) that each method must be used in strict accordance with the operation or instruction manual and with applicable quality assurance procedures, and (2) that modification of a method by its vendor or user may cause the pertinent designation to be inapplicable to the method as modified. (See Section 2.8 of Appendix C, 40 CFR Part 58 for approval of modifications to any of these methods by users.)

Further information concerning particular designations may be found in the *Federal Register* notice cited for each method or by writing to the Atmospheric Research & Exposure Assessment Laboratory, Methods Research & Development Division (MD-77), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. Technical information concerning the methods should be obtained by writing to the "source" listed for each method. New analyzers or PM₁₀ samplers sold as reference or equivalent methods must carry a label or sticker identifying them as designated methods. For analyzers or PM₁₀ samplers sold prior to the designation, the model number does not necessarily identify an analyzer or sampler as a designated method. Consult the manufacturer or seller to determine if a previously sold analyzer or sampler can be considered a designated method, or if it can be upgraded to designation status. Analyzer users who experience operational or other difficulties with a designated analyzer or sampler and are unable to resolve the problem directly with the instrument manufacturer may contact EPA (preferably in writing) at the above address for assistance.

This list will be revised as necessary to reflect any new designations or any cancellation of a designation currently in effect. The most current revision of the list will be available for inspection at EPA's Regional Offices, and copies may be obtained by writing to the Atmospheric Research & Exposure Assessment Laboratory at the address specified above.

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE DATE</u>
<u>PARTICULATE MATTER - TSP</u>					
*****	Reference Method for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method)	40 CFR Part 50, Appendix B	Manual	Reference	47 54912 12/06/82 48 17355 04/22/83
<u>PARTICULATE MATTER - PM₁₀</u>					
*****	Reference Method for the Determination of Particulate Matter as PM ₁₀ in the Atmosphere	40 CFR Part 50, Appendix J	Manual	Reference	52 24664 07/01/87 52 29467 08/07/87
RFPS-1087-062	"Wedding & Associates' PM ₁₀ Critical Flow High-Volume Sampler," consisting of the following components: Wedding PM ₁₀ Inlet Wedding & Associates' Critical Flow Device Wedding & Associates' Anodized Aluminum Shelter 115, 220 or 240 VAC Motor Blower Assembly Mechanical Timer Or Optional Digital Timer Elapsed Time Indicator Filter Cartridge/Cassette	Wedding & Associates, Inc. P.O. Box 1756 Fort Collins, CO 80522	Manual	Reference	52 37366 10/06/87

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
RFPS-1287-063	"Sierra-Andersen or General Metal Works Model 1200 PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 1200 PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	52 45684 53 1062	12/01/87 01/15/88
RFPS-1287-064	"Sierra-Andersen or General Metal Works Model 321-B PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 321-B PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	52 45684 53 1062	12/01/87 01/15/88

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE	NOTICE DATE
<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
RFPS-1287-065	"Sierra-Andersen or General Metal Works Model 321-C PM ₁₀ High-Volume Air Sampler System," consisting of a Sierra-Andersen or General Metal Works Model 321-C PM ₁₀ Size-Selective Inlet and any of the high-volume air samplers identified as SAUV-10H, SAUV-11H, GMW-IP-10, GMW-IP-10-70, GMW-IP-10-801, or GMW-IP-10-8000, which include the following components: Anodized aluminum high-volume shelter with either acrylonitrile butadiene styrene plastic filter holder and motor/blower housing or stainless steel filter holder and phenolic plastic motor/blower housing; 0.6 hp motor/blower; pressure transducer flow recorder; either an electronic mass flow controller or a volumetric flow controller; either a digital timer/programmer, seven-day mechanical timer, six-day timer/programmer, or solid-state timer/programmer; elapsed time indicator; and filter cartridge.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	52 45684 53 1062	12/01/87 01/15/88
RFPS-0389-071	"Oregon DEQ Medium Volume PM ₁₀ Sampler" NOTE: This method is not now commercially available.	State of Oregon Department of Environmental Quality Air Quality Division 811 S.W. Sixth Avenue Portland, OR 97204	Manual	Reference	54 12273	03/24/89
RFPS-0789-073	"Sierra-Andersen Models SA241 and SA241M or General Metal Works Models G241 and G241M PM ₁₀ Dichotomous Samplers", consisting of the following components: Sampling Module with SA246b or G246b 10 µm inlet, 2.5 µm virtual impactor assembly, 37 mm coarse and fine particulate filter holders, and tripod mount; Control Module with diaphragm vacuum pump, pneumatic constant flow controller, total and coarse flow rotameters and vacuum gauges, pressure switch (optional), 24-hour flow/event recorder, digital timer/programmer or 7-day skip timer, and elapsed time indicator.	Andersen Samplers, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336 or General Metal Works, Inc. 145 South Miami Clevs, OH 45002	Manual	Reference	54 31247	07/27/89

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
EQPM-0990-076	<p>"Andersen Instruments Model FH62I-N PM₁₀ Beta Attenuation Monitor," consisting of the following components:</p> <p>FH62I Beta Attenuation 19-inch Control Module SA246b PM₁₀ Inlet (16.7 liter/min) FH101 Vacuum Pump Assembly FH102 Accessory Kit FH107 Roof Flange Kit FH125 Zero and Span PM₁₀ Mass Foil Calibration Kit</p> <p>operated for 24-hour average measurements, with an observing time of 60 minutes, the calibration factor set to 2400, a glass fiber filter tape, an automatic filter advance after each 24-hour sample period, and with or without either of the following options:</p> <p>FHOP1 Indoor Cabinet FHOP2 Outdoor Shelter Assembly</p>	<p>Andersen Instruments, Inc. 4801 Fulton Industrial Blvd. Atlanta, GA 30336</p>	Auto	Equiv.	55 38387	09/18/90
EQPM-1090-079	<p>"Rupprecht & Patashnick TEOM Series 1400 and Series 1400a PM-10 Monitors," consisting of the following components:</p> <p>TEOM Sensor Unit TEOM Control Unit Rupprecht & Patashnick PM-10 Inlet (part number 57-00596) or Sierra-Andersen Model 246b PM-10 Inlet (16.7 liter/min) Flow Splitter Teflon-Coated Glass Fiber Filter Cartridges</p> <p>operated for 24-hour average measurements, with the total mass averaging time set at 300 seconds, the mass rate/mass concentration averaging time set at 300 seconds, the gate time set at 2 seconds, and with or without either of the following options:</p> <p>Tripod Outdoor Enclosure Automatic Cartridge Collection Unit (Series 1400a only)</p>	<p>Rupprecht & Patashnick Co., Inc. 8 Corporate Circle Albany, NY 12203</p>	Auto	Equiv.	55 43406	10/29/90

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>PARTICULATE MATTER - PM₁₀ (Continued)</u>						
EQPM-0391-081	"Wedding & Associates' PM ₁₀ Beta Gauge Automated Particle Sampler," consisting of the following components: Particle Sampling Module PM ₁₀ Inlet (18.9 liter/min) Inlet Tube and Support Ring Vacuum Pump (115 VAC/60 Hz or 220-240 VAC/50 Hz) operated for 24-hour average measurements with glass fiber filter tape.	Wedding & Associates, Inc. P.O. Box 1756 Fort Collins, CO 80522	Auto	Equiv.	56 9216	03/05/91

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>SULFUR DIOXIDE</u>					
*****	Reference Method for the Determination of Sulfur Dioxide in the Atmosphere (Pararosaniline Method)	40 CFR Part 50, Appendix A	Manual	Reference	47 54899 12/06/8 48 17355 04/22/8
EQS-0775-001	"Pararosaniline Method for the Determination of Sulfur Dioxide in the Atmosphere-Technicon I Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	40 34024 08/13/7
EQS-0775-002	"Pararosaniline Method for the Determination of Sulfur Dioxide in the Atmosphere-Technicon II Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv	40 34024 08/13/7
EQSA-1275-005	"Lear Siegler Model SM1000 SO ₂ Ambient Monitor," operated on the 0-0.5 ppm range, at a wavelength of 299.5 nm, with the "slow" (300 second) response time, with or without any of the following options: SM-1 Internal Zero/Span SM-2 Span Timer Card SM-3 0-0.1 Volt Output SM-4 0-5 Volt Output SM-5 Alternate Sample Pump SM-6 Outdoor Enclosure	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	41 3893 01/27/ 41 32946 08/06/ 42 13044 03/08/ 45 1147 01/04/

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER NOTICI VOL. PAGE DATE
<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-1275-006	"Melooy Model SA185-2A Sulfur Dioxide Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: S-1 Linearized Output S-2 Modified Recorder Output S-5 Teflon-Coated Block S-6A Reignite Timer Circuit S-7 Press To Read S-11A Manual Zero And Span S-11B Automatic Zero And Span S-13 Status Lights S-14 Output Booster Amplifier S-14B Line Transmitter Board or operated on the 0-1.0 ppm range with either option S-36 or options S-1 and S-24, with or without any of the other options.	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	41 3893 01/27/71 43 38088 08/25/71
	S-18 Rack Mount Conversion S-18A Rack Mount Conversion S-21 Front Panel Digital Volt Meter S-22 Remote Zero/Span Control And Status (Timer) S-22A Remote Zero/Span Control S-23 Automatic Zero Adjust S-23A Automatic/Manual Zero Adjust		S-24 Dual Range Linearized Output S-33 Remote Range Control And Status (Signals) S-34 Remote Control S-35 Front Panel Digital Meter With BCD Output S-36 Dual Range Log-Linear Output S-38 Sampling Mode Status		
EQSA-0276-009	"Thermo Electron Model 43 Pulsed Fluorescent SO ₂ Analyzer," equipped with an aromatic hydrocarbon cutter and operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: 001 Rack Mounting For Standard 19 Inch Relay Rack 002 Automatic Actuation Of Zero And Span Solenoid Valves 003 Type S Flash Lamp Power Supply 004 Low Flow	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	41 8531 02/27/71 41 15363 04/12/71 42 20490 04/20/71 44 21861 04/12/71 45 2700 01/14/81 45 32419 05/16/81

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<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-0676-010	"Philips PW9755 SO ₂ Analyzer," consisting of the following components: PW9755/02 SO ₂ Monitor with: PW9741/00 SO ₂ Source PW9721/00 Filter Set SO ₂ PW9711/00 Electrolyte SO ₂ PW9750/00 Supply Cabinet PW9750/10 Supply Unit/Coulometric Either PW9731/00 Sampler or PW9731/20 Dust Filter (or vendor-approved alternate particulate filter); operated with a 0-0.5 ppm range and with a reference voltage setting of 760 millivolts; with or without an of the following options: PW9750/30 Frame For MTT PW9750/41 Control Clock 60 Hz	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	41 26252 06/25/7 41 46019 10/19/7 42 28571 06/03/7
EQSA-0876-011	"Philips PW9700 SO ₂ Analyzer," consisting of the following components: PW9710/00 Chemical Unit with: PW9711/00 Electrolyte SO ₂ PW9721/00 Filter Set SO ₂ PW9740/00 SO ₂ Source PW9720/00 Electrical Unit PW9730/00 Sampler Unit (or vendor-approved alternate particulate filter); operated with a 0-0.5 ppm range and with a reference voltage of 760 millivolts.	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	41 34105 08/12/7
EQSA-0876-013	"Monitor Labs Model 8450 Sulfur Monitor," operated on a range of either 0-0.5 or 0-1.0 ppm, with a 5 second time constant, a model 8740 hydrogen sulfide scrubber in the sample line, with or without any of the following options: BP Bipolar Signal Processor CLO Current Loop Output DO Status Remote Interface	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	41 36245 08/27/7 44 33476 06/11/7
		IZS Internal Zero/Span Module TF TFE Sample Particulate Filter		V Zero/Span Valves VT Zero/Span Valves And Timer	

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>						
EQSA-0877-024	"ASARCO Model 500 Sulfur Dioxide Monitor," operated on a 0-0.5 ppm range; or "ASARCO Model 600 Sulfur Dioxide Monitor," operated on a 0-1.0 ppm range. (Both models are identical except the range.)	ASARCO Incorporated 3422 South 700 West Salt Lake City, UT 84119	Auto	Equiv.	42 44264 44 67522	09/02/77 11/26/79
NOTE: This method is not now commercially available.						
EQSA-0678-029	"Beckman Model 953 Fluorescent Ambient SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a time constant setting of 2, 2.5, or 3 minutes, a 5 to 10 micron membrane filter element installed in the rear-panel filter assembly, with or without any of the following options: a. Remote Operation Kit, Catalog No. 641984 b. Digital Panel Meter, Catalog No. 641710 c. Rack Mount Kit, Catalog No. 641709 d. Panel Mount Kit, Catalog No. 641708	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Equiv.	43 35995	08/14/71
EQSA-1078-030	"Bendix Model 8303 Sulfur Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a Teflon filter installed on the sample inlet of the H ₂ S scrubber assembly.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Equiv.	43 50733	10/31/7

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-1078-032	"Melo Model SA285E Sulfur Dioxide Analyzer," operated on the following ranges and time constant switch positions:	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	43 50733 10/31/78
	<u>Range, ppb</u> <u>Time Constant Setting</u>				
	0-50* 1 or 10	*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.			
	0-100* 1 or 10				
	0-500 off, 1 or 10				
	0-1000 off, 1 or 10				
The analyzer may be operated at temperatures between 10°C and 40°C and at line voltages between 105 and 130 volts, with or without any of the following options:					
	S-5 Teflon Coated Block	S-22B Remote Zero/Span Control	S-30 Auto Reignite		
	S-14B Line Transmitter Board	And Status (Pulse)	S-32 Remote Range Control And Status		
	S-18 Rack Mount Conversion	S-23 Auto Zero Adjust	S-35 Front Panel Digital Meter With BCD Output		
	S-18A Rack Mount Conversion	S-23A Auto/Manual Zero Adjust	S-37 Temperature Status Lights		
	S-21 Front Panel Digital Meter	S-25 Press To Read	S-38 Sampling Mode Status		
	S-22 Remote Zero/Span Control	S-26 Manual Zero And Span			
	And Status (Timer)	S-27 Auto Manual Zero/Span			
	S-22A Remote Zero/Span Control	S-28 Auto Range And Status			
EQSA-0779-039	"Monitor Labs Model 8850 Fluorescent SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with an internal time constant setting of 55 seconds, a TFE sample filter installed on the sample inlet line, with or without any of the following options:	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	44 44616 07/30/79
	03A Rack	06B,C,D NBS Traceable Permeation Tubes	013 Recorder Output Options		
	03B Slides	08A Pump	014 DAS Output Options		
	05A Valves Zero/Span	09A Rack Mount For Option 08A	017 Low Flow Option		
	06A 17S Internal Zero/Span		018 Kicker		

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					VOL.	PAGE	DATE
<u>SULFUR DIOXIDE (Continued)</u>							
EQSA-0580-046	"Melo Model SA 700 Fluorescence Sulfur Dioxide Analyzer," operated on the 0-250 ppb*, the 0-500 ppb, or the 0-1000 ppb range with a time constant switch position of either 2 or 3. The analyzer may be operated at temperatures between 20°C and 30°C and at line voltages between 105 and 130 volts, with or without any of the following options: FS-1 Current Output FS-2 Rack Mount Conversion FS-2A Rack Mount Conversion FS-2B Rack Mount Conversion FS-3 Front Panel Mounted Digital Meter FS-5 Auto/Manual Zero/Span With Status FS-6 Remote/Manual Zero/Span With Status FS-7 Auto Zero Adjust	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Equiv.	45	31488	05/13/80
*NOTE: Users should be aware that designation of this analyzer for operation on a range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of this lower range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.							
EQSA-1280-049	"Lear Siegler Model AM2020 Ambient SO ₂ Monitor," operated on a range of either 0-0.5 or 0-1.0 ppm, at a wavelength of 299.5 nm, with a 5 minute integration period, over any 10°C temperature range between 20°C and 45°C, with or without the automatic zero and span correction feature.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	45 46	79574 9997	12/01/80 01/30/81

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<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-0486-060	"Thermo Electron Instruments, Inc. Model 43A Pulsed Fluorescent Ambient SO ₂ Analyzer," operated on the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range with either a high or a low time constant setting and with or without any of the following options: 001 Teflon Particulate Filter Kit 002 Rack Mount	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	51 12390 04/10/86
*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.					
EQSA-1086-061	"Dasibi Model 4108 U.V. Fluorescence SO ₂ Analyzer," operated with a range of 0-100 ppb*, 0-200 ppb*, 0-500 ppb, or 0-1000 ppb, with a Teflon-coated particulate filter and a continuous hydrocarbon removal system, with or without any of the following options: a. Rack Mounting Brackets And Slides	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Equiv.	51 32244 09/10/86
b. RS-232-C Interface c. Temperature Correction					
*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.					
EQSA-0390-075	"Monitor Labs Model 8850S SO ₂ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	55 5264 02/14/90

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>SULFUR DIOXIDE (Continued)</u>					
EQSA-0990-077	"Advanced Pollution Instrumentation, Inc. Model 100 Fluorescent SO ₂ Analyzer," operated on the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range with a 5-micron TFE filter element installed in the rear-panel filter assembly, either a user- or vendor-supplied vacuum pump capable of providing 20 inches of mercury vacuum at 2.5 L/min, with or without any of the following options: Internal Zero/Span Pump Pack Rack Mount With Slides RS-232 Interface Status Output TFE Zero/Span Valves Zero Air Scrubber	Advanced Pollution Instrumentation, Inc. 8815 Production Avenue San Diego, CA 92121-2219	Auto	Equiv.	55 38149 09/17/90
*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.					
EQSA-0292-084	"Environnement S.A. Model AF21M Sulfur Dioxide Analyzer," operated on a range of 0-0.5 ppm with a response time coefficient setting of 01, a Teflon filter installed in the rear-panel filter assembly, and with or without any of the following options: Rack Mount/Slides RS-232-C Interface	Environnement S.A. 111, bd Robespierre 78300 Poissy, France	Auto	Equiv.	57 5444 02/14/92

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SULFUR DIOXIDE (Continued)

EQSA-0193-092	"Lear Siegler Measurement Controls Corporation Model ML9850 Sulfur Dioxide Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i> , at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Background: Not <i>Disabled</i> ; Calibration; <i>Manual</i> or <i>Timed</i> ; Diagnostic Mode: <i>Operate</i> ; Filter Type: <i>Kalman</i> ; Pres/Temp/Flow Comp: <i>On</i> ; Span Comp: <i>Disabled</i> ; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA; and with or without any of the following options: Valve Assembly for External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	58 6964	02/03/93
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*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE DATE</u>
<u>OZONE</u>					
RFOA-1075-003	"Melo Model OA325-2R Ozone Analyzer," operated with a scale range of 0-0.5 ppm, with or without any of the following options: 0-4 Output Booster Amplifier	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759 0-18 Rack Mount Conversion	Auto	Reference	40 54856 11/26/75
RFOA-1075-004	"Melo Model OA350-2R Ozone Analyzer," operated with a scale range of 0-0.5 ppm, with or without any of the following options: 0-2 Automatic Zero And Span 0-3 Remote Control Zero And Span	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759 0-4 Output Booster Amplifier 0-18 Rack Mount Conversion	Auto	Reference	40 54856 11/26/75
RFOA-0176-007	Bendix or Combustion Engineering Model 8002 Ozone Analyzer, operated on the 0-0.5 ppm range, with a 40 second time constant, with or without any of the following options: A Rack Mounting With Chassis Slides	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901 B Rack Mounting Without Chassis Slides	Auto	Reference	41 5145 02/04/76 45 18474 03/21/80
RFOA-1076-014	"MEC Model 1100-1 Ozone Meter,"	Columbia Scientific Industries	Auto	Reference	41 46647 10/22/76
RFOA-1076-015	"MEC Model 1100-2 Ozone Meter,"	Industries			42 30235 06/13/77
RFOA-1076-016	"MEC Model 1100-3 Ozone Meter," operated on a 0-0.5 ppm range, with or without any of the following options: 0011 Rack Mounting Ears 0012 Instrument Bail	11950 Jollyville Road Austin, TX 78759 0016 Chassis Slide Kit 0026 Alarm Set Feature			0033 Local-Remote Sample, Zero, Span Kit 0040 Ethylene/CO ₂ Blend Feature

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<u>OZONE (Continued)</u>						
RFOA-1176-017	"Monitor Labs Model 8410E Ozone Analyzer," operated on a range of 0-0.5 ppm with a time constant setting of 5 seconds, with or without any of the following options: DO Status Outputs ER Ethylene Regulator Assembly TF TFE Sample Particulate Filter V TFE Zero/Span Valves VT TFE Zero/Span Valves And Timer	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	41 53684	12/08/76
EQOA-0577-019	"Dasibi Model 1003-AH, 1003-PC, or 1003-RS Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: Adjustable Alarm Aluminum Coated Absorption Tubes BCD Digital Output Glass (Pyrex) Absorption Tubes Integrated Output Rack Mounting Ears And Slides Teflon-based Solenoid Valve Vycor-Jacketed U.V. Source Lamp 0-10 mV, 0-100 mV, 0-1 V, or 0-10 V Analog Output	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Equiv.	42 28571	06/03/77
RFOA-0577-020	"Beckman Model 950A Ozone Analyzer," operated on a range of 0-0.5 ppm and with the "SLOW" (60 second) response time, with or without any of the following options: Internal Ozone Generator	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634 Computer Adaptor Kit	Auto	Reference	42 28571	06/3/77 Pure Ethylene Accessory

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<u>OZONE (Continued)</u>						
EQOA-0777-023	"Philips PW9771 O3 Analyzer," consisting of the following components: PW9771/00 O3 Monitor with: PW9724/00 Disc.-Set PW9750/00 Supply Cabinet PW9750/20 Supply Unit; operated on a range of 0-0.5 ppm, with or without any of the following accessories: PW9732/00 Sampler Line Heater PW9733/00 Sampler PW9750/30 Frame For MTT PW9750/41 Control Clock 60 Hz PW9752/00 Air Sampler Manifold	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Equiv.	42 38931 42 57156	08/01/77 11/01/77
RFOA-0279-036	"Columbia Scientific Industries Model 2000 Ozone Meter," when operated on the 0-0.5 ppm range with either AC or battery power: The BCA 952 battery charger/AC adapter M952-0002 (115V) or M952-0003 (230V) is required for AC operation; an internal battery M952-0006 or 12 volt external battery is required for portable non-AC powered operation.	Columbia Scientific Industries 11950 Jollyville Rd. Austin, TX 78759	Auto	Reference	44 10429	02/20/79
EQOA-0880-047	"Thermo Electron Model 49 U.V. Photometric Ambient O ₃ Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: 49-001 Teflon Particulate Filter 49-002 19 Inch Rack Mountable Configuration 49-100 Internal Ozone Generator For Zero, Precision, And Level 1 Span Checks 49-103 Internal Ozone Generator For Zero, Precision, And Level 1 Span Checks With Remote Activation 49-100 0010 (General Purpose Interface Bus) IFFB-488	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Equiv.	45 57168	08/27/80

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<u>OZONE (Continued)</u>					
EQOA-0881-053	"Monitor Labs Model 8810 Photo-metric Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with selectable electronic time constant settings from 20 through 150 seconds, with or without any of the following options: 05 Pressure Compensation 06 Averaging Option 07 Zero/Span Valves 08 Internal Zero/Span (Valve And Ozone Source) 09 Status 10 Particulate Filter 15 through 20 DAS/REC Output	Lear Siegler Measurement Control Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Equiv.	46 52224 10/26/81
EQOA-0382-055	"PCI Ozone Corporation Model LC-12 Ozone Analyzer," operated on a range of 0-0.5 ppm.	PCI Ozone Corporation One Fairfield Crescent West Caldwell, NJ 07006	Auto	Equiv.	47 13572 03/31/82
EQOA-0383-056	"Dasibi Model 1008-AH, 1008-PC, or 1008-RS Ozone Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with or without any of the following options: Aluminum Coated Absorption Tubes BCD Digital Output Glass (Pyrex) Absorption Tubes Ozone Generator Photometer Flow Restrictor (2 LPM) Rack Mounting Brackets or Slides RS232 Interface Vycor-Jacketed U.V. Source Lamp Teflon-based Solenoid Valve 4-20 mA, Isolated, or Dual Analog Outputs 20 Second Update Software	Dasibi Environmental Corp. 515 West Colorado St. Glendale, CA 91204-1101	Auto	Equiv.	48 10126 03/10/83

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>OZONE (Continued)</u>					
EQOA-0990-078	"EnviroNics Series 300 Computerized Ozone Analyzer," operated on the 0-0.5 ppm range, with the following parameters entered into the analyzer's computer system: Absorption Coefficient = 308 ± 4 Flush Time = 3 Integration Factor = 1 Offset Adjustment = 0.025 ppm Ozone Average Time = 4 Signal Average = 0 Temp/Press Correction = On and with or without the RS-232 Serial Data Interface.	EnviroNics, Inc. 165 River Road West Willington, CT 06279	Auto	Equiv.	55 38386 09/18/90
EQOA-0992-087	"Advanced Pollution Instrumentation, Inc. Model 400 Ozone Analyzer," operated on any full scale range between 0-100 ppb* and 0-1000 ppb, at any temperature in the range of 5°C to 40°C, with the dynamic zero and span adjustment features set to OFF, with a 5-micron TFE filter element installed in the rear-panel filter assembly, and with or without any of the following options: Internal Zero/Span (IZS) IZS Reference Adjustment Rack Mount With Slides RS-232 With Status Outputs Zero/Span Valves	Advanced Pollution Instrumentation, Inc. 8815 Production Avenue San Diego, CA 92121-2219	Auto	Equiv.	57 44565 09/28/92

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0-500 ppb is based on meeting the same absolute performance specifications required for the 0-500 ppb range. Thus, designation of any range lower than 0-500 ppb does not imply commensurably better performance than that obtained on the 0-500 ppb range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
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OZONE (Continued)

EQOA-0193-091	<p>"Lear Siegler Measurement Controls Corporation Model ML9810 Ozone Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i>, at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Calibration; <i>Manual</i> or <i>Timed</i>; Diagnostic Mode: <i>Operate</i>; Filter Type: <i>Kalman</i>; Pres/Temp/Flow Comp: <i>On</i>; Span Comp: <i>Disabled</i>;</p> <p>with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings:</p> <p>Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA; and with or without any of the following options: Valve Assembly for External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive.</p>	<p>Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189</p>	Auto	Equiv.	58 6964	02/03/93
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*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

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<u>CARBON MONOXIDE</u>						
RFCA-0276-008	Bendix or Combustion Engineering Model 8501-5CA Infrared CO Analyzer, operated on the 0-50 ppm range and with a time constant setting between 5 and 16 seconds, with or without any of the following options: A Rack Mounting With Chassis Slides B Rack Mounting Without Chassis Slides C External Sample Pump	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	41 7450	02/18/76
RFCA-0876-012	"Beckman Model 866 Ambient CO Monitoring System," consisting of the following components: Pump/Sample-Handling Module, Gas Control Panel, Model 865-17 Analyzer Unit, Automatic Zero/Span Standardizer; operated with a 0-50 ppm range, a 13 second electronic response time, with or without any of the following options: Current Output Feature Bench Mounting Kit Linearizer Circuit	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Reference	41 36245	08/27/76
RFCA-0177-018	"LIRA Model 202S Air Quality Carbon Monoxide Analyzer System," consisting of a LIRA Model 202S optical bench (P/N 459839), a regenerative dryer (P/N 464084), and rack-mounted sampling system; operated on a 0-50 ppm range, with the slow response amplifier, with or without any of the following options: Remote Meter Remote Zero And Span Controls 0-1, 5, 20, or 50 mA Output 1-5, 4-20, or 10-50 mA Output 0-10 or 100 mV Output	Mine Safety Appliances Co. 600 Penn Center Boulevard Pittsburgh, PA 15208	Auto	Reference	42 5748	01/31/77

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>CARBON MONOXIDE (Continued)</u>						
RFCA-1278-033	"Horiba Models AQM-10, AQM-11, and AQM-12 Ambient CO Monitoring Systems," operated on the 0-50 ppm range, with a response time setting of 15.5 seconds, with or without any of the following options: a AIC-101 Automatic Indication Corrector b VIT-3 Non-Isolated Current Output c ISO-2 and DCS-3 Isolated Current Output	Horiba Instruments, Inc. 17671 Armstrong Avenue Irvine, CA 92714-5727	Auto	Reference	43 58429	12/14/78
RFCA-0979-041	"Monitor Labs Model 8310 CO Analyzer," operated on the 0-50 ppm range, with a sample inlet filter, with or without any of the following options: 02A Zero/Span Valves 03A Floor Stand 04A Pump (60 Hz)	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189 04B Pump (50 Hz) 05A CO Regulator 06A CO Cylinder	Auto	Reference	44 54545 45 2700	09/20/79 01/14/80
RFCA-1180-048	"Horiba Model APMA-300E Ambient Carbon Monoxide Monitoring System," operated on the 0-20 ppm*, the 0-50 ppm, or the 0-100 ppm range with a time constant switch setting of No. 5. The monitoring system may be operated at temperatures between 10°C and 40°C.	Horiba Instruments, Inc. 17671 Armstrong Avenue Irvine, CA 92714-5727	Auto	Reference	45 72774	11/03/80

*NOTE: Users should be aware that designation of this analyzer for operation on a range less than 50 ppm is based on meeting the same absolute performance specifications required for the 0-50 ppm range. Thus, designation of this lower range does not imply commensurably better performance than that obtained on the 0-50 ppm range.

(This method was originally designated as "Horiba Model APMA 300E/300SE Ambient Carbon Monoxide Monitoring System".)

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>CARBON MONOXIDE (Continued)</u>						
RFCA-1280-050	"MASS-CO, Model 1 Carbon Monoxide Analyzer," operated on a range of 0-50 ppm, with automatic zero and span adjustments at time intervals not to exceed 4 hours, with or without the 100 millivolt and 5 volt output options. The method consists of the following components: (1) Infra-2 (Uras 2) Infrared Analyzer Model 5611-200-35, (2) Automatic Calibrator Model 5869-111, (3) Electric Gas Cooler Model 7865-222 or equivalent with prehumidifier, (4) Diaphragm Pump Model 5861-214 or equivalent, (5) Membrane Filter Model 5862-111 or equivalent, (6) Flow Meter Model SK 1171-U or equivalent, (7) Recorder Model Mini Comp DN 1/192 or equivalent	Commonwealth of Massachusetts Auto Department of Environmental Quality Engineering Tewksberry, MA 01876		Reference	45 81650	12/11/80
NOTE: This method is not now commercially available.						
RFCA-0381-051	"Dasibi Model 3003 Gas Filter Correlation CO Analyzer," operated on the 0-50 ppm range, with a sample particulate filter installed on the sample inlet line, with or without any of the following options: 3-001 Rack Mount 3-002 Remote Zero And Span	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101 3-003 BCD Digital Output 3-004 4-20 Milliamp Output	Auto	Reference	46 20773	04/07/81
RFCA-0981-054	"Thermo Environmental Instruments Model 48 Gas Filter Correlation Ambient CO Analyzer," operated on the 0-50 ppm range, with a time constant setting of 30 seconds, with or without any of the following options: 48-001 Particulate Filter 48-002 19 Inch Rack Mountable Configuration 48-003 Internal Zero/Span Valves With Remote Activation 48-488 GPIB (General Purpose Interface Bus) IEEE-488 48-010 Internal Zero Air Package	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	46 47002	09/23/81

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
		<u>CARBON MONOXIDE (Continued)</u>			
RFCA-0388-066	"Monitor Labs Model 8830 CO Analyzer," operated on the 0-50 ppm range, with a five micron Teflon filter element installed in the rear-panel filter assembly, with or without any of the following options: 2 Zero/Span Valve Assembly 3 Rack Assembly 4 Slide Assembly 7 230 VAC, 50/60 Hz	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	53 7233 03/07/88
RFCA-0488-067	"Dasibi Model 3008 Gas Filter Correlation CO Analyzer," operated on the 0-50 ppm range, with a time constant setting of 60 seconds, a particulate filter installed in the analyzer sample inlet line, with or without use of the auto zero or auto zero/span feature, and with or without any of the following options: N-0056-A RS-232-C Interface S-0132-A Rack Mounting Slides Z-0176-S Rack Mounting Brackets	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Reference	53 12073 04/12/88

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>CARBON MONOXIDE (Continued)</u>					
RFCA-0992-088	"Lear Siegler Measurement Controls Corporation Model ML9830 Carbon Monoxide Analyzer," operated on any full scale range between 0-5.0 ppm* and 0-100 ppm, with auto-ranging <i>enabled</i> or <i>disabled</i> , at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position, with the following menu choices selected: Background: Not <i>Disabled</i> ; Calibration: <i>Manual</i> or <i>Timed</i> ; Diagnostic Mode: <i>Operate</i> ; Filter Type: <i>Kalman</i> ; Pres/Temp/Flow Comp: <i>On</i> ; Span Comp: <i>Disabled</i> ; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings: Voltage, 0.1 V, 1 V, 5 V, 10 V Current, 0-20 mA, 2-20 mA and 4-20 mA; and with or without any of the following options: Valve Assembly For External Zero/Span (EVS) Rack Mount Assembly Internal Floppy Disk Drive	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	57 44565 09/28/92

*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 50 ppm is based on meeting the same absolute performance specifications required for the 0-50 ppm range. Thus, designation of any full scale range lower than the 0-50 ppm range does not imply commensurably better performance than that obtained on the 0-50 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>NITROGEN DIOXIDE</u>						
RFNA-0677-021	"Monitor Labs Model 8440E Nitrogen Oxides Analyzer," operated on a 0-0.5 ppm range (position 2 of range switch) with a time constant setting of 20 seconds, with or without any of the following options: TF Sample Particulate Filter With TFE Filter Element V Zero/Span Valves	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	42 37434 42 46575 46 29986	07/21/77 09/16/77 06/04/81
		the following options: DO Status Outputs R Rack Mount FM Flowmeters		018A Ozone Dry Air 018B Ozone Dry Air - No Drierite		
RFNA-0777-022	Bendix or Combustion Engineering Model 8101-C Oxides of Nitrogen Analyzer, operated on a 0-0.5 ppm range with a Teflon sample filter (Bendix P/N 007163) installed on the sample inlet line.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	42 37435	07/21/77
RFNA-0977-025	"CSI Model 1600 Oxides of Nitrogen Analyzer," operated on a 0-0.5 ppm range with a Teflon sample filter (CSI P/N M951-8023) installed on the sample inlet line, with or without any of the following options: 951-0103 Rack Ears 951-0104 Rack Mounting Kit (Ears & Slides) 951-0106 Current Output, 4-20 mA (Non-Insulated) 951-0108 Diagnostic Output Option 951-0111 Recorder Output, 10 V	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759 951-0112 Remote Zero/Span Sample Control 951-0114 Recorder Output, 5 V 951-0115 External Pump (115 V, 60 Hz) 951-8072 Molybdenum Converter Assembly (Horizontal)	Auto	Reference	42 46574	09/16/77
		951-8074 Copper Converter Assembly (Horizontal) 951-8079 Copper Converter Assembly (Vertical) 951-8085 Molybdenum Converter Assembly (Vertical)				

NOTE: The vertical molybdenum converter assembly is standard on all new analyzers as of 1-1-87; however, use of this is optional. Also, the above options reflect new CSI part numbers.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>					
EQN-1277-026	"Sodium Arsenite Method for the Determination of Nitrogen Dioxide in the Atmosphere"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42 62971 12/14/77
EQN-1277-027	"Sodium Arsenite Method for the Determination of Nitrogen Dioxide in the Atmosphere--Technicon II Automated Analysis System"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42 62971 12/14/77
EQN-1277-028	"TGS-ANSA Method for the Determination of Nitrogen Dioxide in the Atmosphere"	Atmospheric Research and Exposure Assessment Laboratory Department E (MD-77) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	42 62971 12/14/77

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
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NITROGEN DIOXIDE (Continued)

RFNA-1078-031	"Meloxy Model NA530R Nitrogen Oxides Analyzer," operated on the following ranges and time constant switch positions:	Columbia Scientific Industries 11950 Jollyville Road Austin, TX 78759	Auto	Reference	43 50733 44 8327	10/31/78 02/09/79
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Range, ppm Time Constant Setting

0-0.1*	4
0-0.25*	3 or 4
0-0.5	2, 3, or 4
0-1.0	2, 3, or 4

Operation of the analyzer requires an external vacuum pump, either Meloy Option N-10 or an equivalent pump capable of maintaining a vacuum of 200 torr (22 inches mercury vacuum) or better at the pump connection at the specified sample and ozone-air flow rates of 1200 and 200 cm³/min, respectively. The analyzer may be operated at temperatures between 10°C and 40°C and at line voltages between 105 and 130 volts, with or without any of the following options:

N-1A Automatic Zero And Span	N-6C Remote Zero/Span Control And Status (Timer)	N-14B Line Transmitter
N-2 Vacuum Gauge	N-9 Manual Zero/Span	N-18 Rack Mount Conversion
N-4 Digital Panel Meter	N-10 Vacuum Pump Assembly (See Alternate Requirement Above)	N-18A Rack Mount Conversion
N-6 Remote Control For Zero And Span	N-11 Auto Ranging	
N-6B Remote Zero/Span Control And Status (Pulse)		

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0179-034	"Beckman Model 952-A NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range with the 5-micron Teflon sample filter (Beckman P/N 861072 supplied with the analyzer) installed on the sample inlet line, with or without the Remote Operation Option (Beckman Cat. No. 635539).	Beckman Instruments, Inc. Process Instruments Division 2500 Harbor Boulevard Fullerton, CA 92634	Auto	Reference	44 7806 02/07/79
RFNA-0179-035	"Thermo Electron Model 14 B/E Chemiluminescent NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: 14-001 Teflon Particulate Filter 14-002 Voltage Divider Card 14-003 Long-Time Signal Integrator 14-004 Indicating Temperature Controller 14-005 Sample Flowmeter 14-006 Air Filter	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	44 7805 02/07/79 44 54545 09/20/79
RFNA-0279-037	"Thermo Electron Model 14 D/E Chemiluminescent NO/NO ₂ /NO _x Analyzer," operated on the 0-0.5 ppm range, with or without any of the following options: 14-001 Teflon Particulate Filter 14-002 Voltage Divider Card	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	44 10429 02/20/79

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0479-038	"Bendix Model 8101-B Oxides of Nitrogen Analyzer," operated on a 0-0.5 ppm range with a Teflon sample filter installed on the sample inlet line and with the following post-manufacture modifications: 1. Ozone generator and reaction chamber input-output tubing modification per Bendix Service Bulletin 8101B-2; 2. The approved converter material; 3. The revised and EPA-approved operation and service manual. These items are mandatory and must be obtained from Combustion Engineering, Inc. The analyzer may be operated with or without any of the following optional modifications: a. Perma Pure dryer/ambient air modification; b. Valve cycle time modification; c. Zero potentiometer centering modification per Bendix Service Bulletin 8101B-1; d. Reaction chamber vacuum gauge modification.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	Auto	Reference	44 26792 05/07/79
RFNA-0879-040	"Philips Model PW9762/02 NO/NO ₂ /NO _x Analyzer," consisting of the following components: PW9762/02 Basic Analyzer PW9729/00 Converter Cartridge PW9731/00 Sampler or PW9731/20 Dust Filter; operated on a range of 0-0.5 ppm, with or without any of the following accessories: PW9752/00 Air Sampler Manifold PW9732/00 Sample Line Heater PW9011/00 Remote Control Set	Philips Electronic Instruments, Inc. 85 McKee Drive Mahwah, NJ 07430	Auto	Reference	44 51683 09/04/79

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE DATE
<u>NITROGEN DIOXIDE (Continued)</u>					
RFNA-0280-042	"Monitor Labs Model 8840 Nitrogen Oxides Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with an internal time constant setting of 60 seconds, a TFE sample filter installed on the sample inlet line, with or without any of the following options:	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	45 9100 02/11/80
					46 29986 06/04/81
	02 Flowmeter	08A Pump Pac Assembly With 09A (115 VAC)			011A Recorder Output 1 Volt
	03A Rack Ears	08B Pump Pac Assembly With 09B (100 VAC)			011B Recorder Output 100 mV
	03B Slides	08C Pump Pac Assembly With 09C (220/240 VAC)			011C Recorder Output 10 mV
	05A Zero/Span Valves	08D Rack Mount Panel Assembly			012A DAS Output 1 Volt
	05B Valve/Relay	09A Pump 115 VAC 50/60 Hz			012B DAS Output 100 mV
	06 Status	09B Pump 100 VAC 50/60 Hz			012C DAS Output 10 mV
	07A Input Power Transformer 100 VAC, 50/60 Hz	09C Pump 220/240 VAC 50 Hz			013A Ozone Dry Air
	07B Input Power Transformer 220/240 VAC, 50 Hz				013B Ozone Dry Air - No Drierite
RFNA-1289-074	"Thermo Environmental Instruments Inc. Model 42 NO/NO ₂ /NO _x Analyzer," operated on the 0-0.05 ppm*, the 0-0.1 ppm*, the 0-0.2 ppm*, the 0-0.5 ppm, or the 0-1.0 ppm range, with any time average setting from 10 to 300 seconds. The analyzer may be operated at temperatures between 15°C and 35°C and at line voltages between 105 and 125 volts, with or without any of the following options:	Thermo Environmental Instruments, Inc. 8 West Forge Parkway Franklin, MA 02038	Auto	Reference	54 50820 12/11/89
	42-002 Rack Mounts	42-004 Sample/Ozone Flowmeters			42-007 Ozone Particulate Filter
	42-003 Internal Zero/Span And Sample Valves With Remote Activation	42-005 4-20 mA Current Output			42-008 RS-232 Interface
		42-006 Pressure Transducer			42-009 Permeation Dryer

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>NITROGEN DIOXIDE (Continued)</u>						
RFNA-0691-082	"Advanced Pollution Instrumentation, Inc. Model 200 Nitrogen Oxides Analyzer," operated on a range of either 0-0.5 or 0-1.0 ppm, with a 5-micron TFE filter element installed in the rear-panel filter assembly, with either a user- or vendor-supplied vacuum pump capable of providing 5 inches mercury absolute pressure at 5 slpm, with either a user- or vendor-supplied dry air source capable of providing air at a dew point of 0°C or lower, with the following settings of the adjustable setup variables: Adaptive Filter = ON Dwell Time = 7 seconds Dynamic Span = OFF Dynamic Zero = OFF PMT Temperature Set Point = 15°C Rate of Change(ROC) Threshold = 10% Reaction Cell Temperature = 50°C Sample Time = 8 seconds Normal Filter Size = 12 samples; and with or without any of the following options: 180 Stainless Steel Valves 184 Pump Pack 280 Rack Mount With Slides	Advanced Pollution Instrumentation, Inc 8815 Production Avenue San Diego, CA 92121-2219	Auto	Reference	56 27014	06/12/91
		283 Internal Zero/Span With Valves (IZS) 325 RS-232/Status Output 355 Expendables			356 Level One Spares Kit 357 Level Two Spares Kit PE5 Permeation Tube for IZS	
RFNA-0991-083	"Monitor Labs Model 8841 Nitrogen Oxides Analyzer," operated on the 0-0.05 ppm*, 0-0.1 ppm*, 0-0.2 ppm*, 0-0.5 ppm, or 0-1.0 ppm range, with manufacturer-supplied vacuum pump or alternative user-supplied vacuum pump capable of providing 200 torr or better absolute vacuum while operating with the analyzer.	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	56 47473	09/19/91

*NOTE: Users should be aware that designation of this analyzer for operation on ranges less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of these lower ranges does not imply commensurably better performance than that obtained on the 0-0.5 ppm range.

DESIGNATION NUMBER	IDENTIFICATION	SOURCE	MANUAL OR AUTO	REF. OR EQUIV.	FED. REGISTER VOL. PAGE DATE	NOTICE
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NITROGEN DIOXIDE (Continued)

RFNA-1192-089	"Dasibi Model 2108 Oxides of Nitrogen Analyzer," operated on the 0-500 ppb range, with software revision 3.6 installed in the analyzer, with the Auto thumbwheel switch and the Diag thumbwheel switch settings at 0, with the following internal CPU dipswitch settings:	Dasibi Environmental Corp. 515 West Colorado Street Glendale, CA 91204-1101	Auto	Reference	57	55530	11/25/92
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switch	position	function
1	open (down)	Recorder outputs are NO & NO ₂
5	open (down)	3 minute time constant
6	closed (up)	3 minute time constant;

with a 5-micron Teflon filter element installed in the filter holder, and with or without any of the following options:

Built-in Permeation Oven
RS-232 Interface

Rack Mounting
4-20 mA Output

Three-Channel Recorder Output

RFNA-1292-090	"Lear Siegler Measurement Controls Corporation Model ML9841 Nitrogen Oxides Analyzer," operated on any full scale range between 0-0.050 ppm* and 0-1.0 ppm, with auto-ranging enabled or disabled, at any temperature in the range of 15°C to 35°C, with a five-micron Teflon filter element installed in the filter assembly behind the secondary panel, the service switch on the secondary panel set to the <i>In</i> position; with the following menu choices selected: Calibration: <i>Manual</i> or <i>Timed</i> ; Diagnostic Mode: <i>Operate</i> ; Filter Type: <i>Kalman</i> ; Pres/Temp/Flow Comp: <i>On</i> ; Span Comp: <i>Disabled</i> ; with the 50-pin I/O board installed on the rear panel configured at any of the following output range settings:	Lear Siegler Measurement Controls Corporation 74 Inverness Drive East Englewood, CO 80112-5189	Auto	Reference	57	60198	12/18/92
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Voltage, 0.1 V, 1 V, 5 V, 10 V; Current, 0-20 mA, 2-20 mA, 4-20 mA;

and with or without any of the following options:

Internal Floppy Disk Drive

Rack Mount Assembly

Valve Assembly for External Zero/Span (EVS)

*NOTE: Users should be aware that designation of this analyzer for operation on any full scale range less than 0.5 ppm is based on meeting the same absolute performance specifications required for the 0-0.5 ppm range. Thus, designation of any full scale range lower than the 0-0.5 ppm range does not imply

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LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS

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<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
		<u>LEAD</u>				
*****	Reference Method for the Determination of Lead in Suspended Particulate Matter Collected from Ambient Air	40 CFR Part 50, Appendix G	Manual	Reference	43 46258	10/05/78
EQL-0380-043	"Determination of Lead Concentration in Ambient Particulate Matter by Flame Atomic Absorption Spectrometry Following Ultrasonic Extraction with Heated HNO ₃ -HCl"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648	03/06/80
EQL-0380-044	"Determination of Lead Concentration in Ambient Particulate Matter by Flameless Atomic Absorption Spectrometry (EPA/RTP,N.C.)"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648	03/06/80
EQL-0380-045	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (EPA/RTP,N.C.)"	Atmospheric Research and Exposure Assessment Laboratory U.S. Environmental Protection Agency Research Triangle Park, NC 27711	Manual	Equiv.	45 14648	03/06/80
EQL-0581-052	"Determination of Lead Concentration in Ambient Particulate Matter by Wavelength Dispersive X-Ray Fluorescence Spectrometry"	California Department of Health Services Air & Industrial Hygiene Laboratory 2151 Berkeley Way Berkeley, CA 94704	Manual	Equiv.	46 29986	06/04/81

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER VOL. PAGE</u>	<u>NOTICE DATE</u>
<u>LEAD (Continued)</u>						
EQL-0483-057	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Montana)"	State of Montana Department of Health and Environmental Sciences Cogswell Building Helena, MT 59620	Manual	Equiv.	48 14748	04/05/83
EQL-0783-058	"Determination of Lead Concentration in Ambient Particulate Matter by Energy-Dispersive X-Ray Fluorescence Spectrometry (Texas Air Control Board)"	Texas Air Control Board 6330 Highway 290 East Austin, TX 78723	Manual	Equiv.	48 29742	06/28/83
EQL-0785-059	"Determination of Lead Concentration in Ambient Particulate Matter by Flameless Atomic Absorption Spectrometry (Omaha-Douglas County Health Department)"	Omaha-Douglas County Health Department 1819 Farnam Street Omaha, NE 68183	Manual	Equiv.	50 37909	09/18/85
EQL-0888-068	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Rhode Island)"	State of Rhode Island Department of Health Air Pollution Laboratory 50 Orms Street Providence, RI 02904	Manual	Equiv.	53 30866	08/16/88
EQL-1188-069	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Northern Engineering and Testing, Inc.)"	Northern Engineering and Testing, Inc. P.O. Box 30615 Billings, MT 59107	Manual	Equiv.	53 44947	11/07/88

<u>DESIGNATION NUMBER</u>	<u>IDENTIFICATION</u>	<u>SOURCE</u>	<u>MANUAL OR AUTO</u>	<u>REF. OR EQUIV.</u>	<u>FED. REGISTER NOTICE VOL. PAGE DATE</u>
<u>LEAD (Continued)</u>					
EQL-1288-070	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Silver Valley Laboratories)"	Silver Valley Laboratories, Inc. P.O. Box 929 Kellogg, ID 83837	Manual	Equiv.	53 48974 12/05/88
EQL-0589-072	"Determination of Lead Concentration in Ambient Particulate Matter by Energy Dispersive X-Ray Fluorescence Spectrometry (NEA, Inc.)"	Nuclear Environmental Analysis, Inc. 10950 SW 5th Street, Suite 260 Beaverton, OR 97005	Manual	Equiv.	54 20193 05/10/89
EQL-1290-080	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of New Hampshire)"	State of New Hampshire Department of Environmental Services Laboratory Service Unit 6 Hazen Drive (P.O. Box 95) Concord, NH 03302-0095	Manual	Equiv.	55 49119 11/26/90
EQL-0592-085	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (State of Kansas)"	State of Kansas Department of Health and Environment Forbes Field, Building 740 Topeka, KS 66620-0001	Manual	Equiv.	57 20823 05/15/92
EQL-0592-086	"Determination of Lead Concentration in Ambient Particulate Matter by Inductively Coupled Argon Plasma Optical Emission Spectrometry (Commonwealth of Pennsylvania)"	Commonwealth of Pennsylvania Department of Environmental Resources P.O. Box 2357 Harrisburg, PA 17105-2357	Manual	Equiv.	57 20823 05/15/92

METHOD CODES

<u>Method</u>	<u>Designation Number</u>	<u>Method Code</u>	<u>Method</u>	<u>Designation Number</u>	<u>Method Code</u>
<u>SO₂ Manual Methods</u>			<u>NO_x Manual Methods</u>		
Ref. method (pararosaniline)	-	097	Sodium arsenite (orifice)	EQN-1277-026	084
Technicon I (pararosaniline)	EQS-0775-001	097	Sodium arsenite/Technicon II	EQN-1277-027	084
Technicon II (Pararosaniline)	EQS-0775-002	097	TGS-ANSA (orifice)	EQN-1277-028	098
<u>SO₂ Analyzers</u>			<u>NO_x Analyzers</u>		
Advanced Pollution Instr. 100	EQSA-0990-077	077	Advanced Pollution Instr. 200	RFNA-0691-082	082
Ameco 500	EQSA-0877-024	024	Beckman 952A	RFNA-0179-034	034
Beckman 953	EQSA-0678-029	029	Bendix 8101-B	RFNA-0479-038	038
Bendix 8303	EQSA-1078-030	030	Bendix 8101-C	RFNA-0777-022	022
Dasibi 4108	EQSA-1086-061	061	Dasibi 2108	RFNA-1192-089	089
Environmental S.A. AF21M	EQSA-0292-084	084	CSI 1600	RFNA-0977-025	025
Lear Siegler AM2020	EQSA-1280-049	049	Lear Siegler ML9841	RFNA-1292-090	090
Lear Siegler SM1000	EQSA-1275-005	005	Meloy NA530R	RFNA-1078-031	031
Lear Siegler ML9850	EQSA-0193-092	092	Monitor Labs 8440E	RFNA-0677-021	021
Meloy SA185-2A	EQSA-1275-006	006	Monitor Labs 8840	RFNA-0280-042	042
Meloy SA285E	EQSA-1078-032	032	Monitor Labs 8841	RFNA-0991-083	083
Meloy SA700	EQSA-0580-046	046	Philips PW9762/02	RFNA-0879-040	040
Monitor Labs 8450	EQSA-0876-013	013	Thermo Electron 14B/E	RFNA-0179-035	035
Monitor Labs 8850	EQSA-0779-039	039	Thermo Electron 14D/E	RFNA-0279-037	037
Monitor Labs 8850S	EQSA-0390-075	075	Thermo Environmental Inst. 42	RFNA-1289-074	074
Philips PW9700	EQSA-0876-011	011			
Philips PW9755	EQSA-0676-010	010			
Thermo Electron 43	EQSA-0276-009	009			
Thermo Electron 43A	EQSA-0486-060	060			
<u>O₃ Analyzers</u>			<u>Pb Manual Methods</u>		
Advanced Pollution Instr. 400	EQOA-0992-087	087	Ref. method (hi-vol/AA spect.)	-	803
Beckman 950A	RFOA-0577-020	020	Hi-vol/AA spect. (alt. extr.)	EQL-0380-043	043
Bendix 8002	RFOA-0176-007	007	Hi-vol/Energy-disp XRF (TX ACB)	EQL-0783-058	058
CSI 2000	RFOA-0279-036	036	Hi-vol/Energy-disp XRF (NEA)	EQL-0589-072	072
Dasibi 1003-AH,-PC,-RS	EQOA-0577-019	019	Hi-vol/Flameless AA (EMSL/EPA)	EQL-0380-044	044
Dasibi 1008-AH	EQOA-0383-056	056	Hi-vol/Flameless AA (Omaha)	EQL-0785-059	059
Enviroconics 300	EQOA-0990-078	078	Hi-vol/ICAP spect. (EMSL/EPA)	EQL-0380-045	045
Lear Siegler ML9810	EQOA-0193-091	091	Hi-vol/ICAP spect. (Kansas)	EQL-0592-085	085
McMillan 1100-1	RFOA-1076-014	014	Hi-vol/ICAP spect. (Montana)	EQL-0483-057	057
McMillan 1100-2	RFOA-1076-015	015	Hi-vol/ICAP spect. (NE&T)	EQL-1188-069	069
McMillan 1100-3	RFOA-1076-016	016	Hi-vol/ICAP spect. (N. Hampshir)	EQL-1290-080	080
Meloy OA325-2R	RFOA-1075-003	003	Hi-vol/ICAP spect. (Pennsylvania)	EQL-0592-086	086
Meloy OA350-2R	RFOA-1075-004	004	Hi-vol/ICAP spect. (Rhode Is.)	EQL-0888-068	068
Monitor Labs 8410E	RFOA-1176-017	017	Hi-vol/ICAP spect. (S.V. Labs)	EQL-1288-070	070
Monitor Labs 8810	EQOA-0881-053	053	Hi-vol/WL-disp. XRF (CA A&IHL)	EQL-0581-052	052
PCI Ozone Corp. LC-12	EQOA-0382-055	055			
Philips PW9771	EQOA-0777-023	023			
Thermo Electron 49	EQOA-0880-047	047			
<u>CO Analyzers</u>			<u>PM₁₀ Samplers</u>		
Beckman 866	RFCA-0876-012	012	Oregon DEQ Med. vol. sampler	RFPS-0389-071	071
Bendix 8501-SCA	RFCA-0276-008	008	Sierra-Andersen/GMW 1200	RFPS-1287-063	063
Dasibi 3003	RFCA-0381-051	051	Sierra-Andersen/GMW 321-B	RFPS-1287-064	064
Dasibi 3008	RFCA-0488-067	067	Sierra-Andersen/GMW 321-C	RFPS-1287-065	065
Horiba AQM-10, -11, -12	RFCA-1278-033	033	Sierra-Andersen/GMW 241 Dichot	RFPS-0789-073	073
Horiba 300E/300SE	RFCA-1180-048	048	Wedding & Assoc. high volume	RFPS-1087-062	062
Lear Siegler ML 9830	RFCA-0992-088	088			
MASS - CO 1 (Massachusetts)	RFCA-1280-050	050			
Monitor Labs 8310	RFCA-0979-041	041			
Monitor Labs 8830	RFCA-0388-066	066			
MSA 202S	RFCA-0177-018	018			
Thermo Electron 48	RFCA-0981-054	054			
			<u>PM₁₀ Analyzers</u>		
			Andersen Instr. Beta FH621-N	EQPM-0990-076	076
			R & P TEOM 1400, 1400a	EQPM-1090-079	079
			Wedding & Assoc. Beta Gauge	EQPM-0391-081	081
			<u>TSP Manual Method</u>		
			Reference method (high-volume)	-	802

APPROVED METHODS AS OF FEBRUARY 8, 1993

	MANUAL		AUTOMATED	
	REFERENCE	EQUIVALENT	REFERENCE	EQUIVALENT
CO			<ol style="list-style-type: none"> 1. CE (Beckman) 8501-SCA (50) 2. Beckman 864 (50) 3. MSA 2025 (50) 4. Bartlett AQM-10, 11, 12 (50) 5. Monitor Labs 8310 (50) 6. Bartlett APMA-3005 (20, 50, 100) 7. MAAS-CO 1 (50) 8. Dumas 3003 (50) 9. TEI 48 (50) 10. Monitor Labs 8830 (50) 11. Dumas 3008 (50) 12. Lorr Single ML 9830 (5-100) 	
NO ₂		<ol style="list-style-type: none"> 1. Radiation Arroyo 2. Radiation Arroyo/Technicon II 3. TOS-AMBA 	<ol style="list-style-type: none"> 1. Monitor Labs 8440E (.5) 2. CE (Beckman) 8101-C (.5) 3. CE 1600 (.5) 4. Moly NA30E (.1, .25, .5, 1.0) 5. Beckman 952-A (.5) 6. TEI 14 B/E (.5) 7. TEI 14 D/E (.5) 8. Beutler 8101-B (.5) 9. Philips PW7762/02 (.5) 10. Monitor Labs 8840 (.5, 1.0) 11. TEI 42 (.05, .1, .2, .5, 1.0) 12. API 200 (.5, 1.0) 13. Monitor Labs 8841 (.05, .1, .2, .5, 1.0) 14. Dumas 2108 (.5) 15. Lorr Single ML 9841 (.05-1.0) 	
O ₃			<ol style="list-style-type: none"> 1. Moly QA325-2R (.5) 2. Moly QA350-2R (.5) 3. CE (Beckman) 8002 (.5) 4. McMullan 1100-1 (.5) 5. McMullan 1100-2 (.5) 6. McMullan 1100-3 (.5) 7. Monitor Labs 8410E (.5) 8. Beckman 950A (.5) 9. CSI 2000 (.5) 	<ol style="list-style-type: none"> 1. Dumas 1000-AH, PC, RS (.5, 1.0) 2. Philips PW7771 (.5) 3. TEI 49 (.5, 1.0) 4. Monitor Labs 8410 (.5, 1.0) 5. PCI Omega Corp. LC-12 (.5) 6. Dumas 1000-AH, PC, RS (.5, 1.0) 7. Beversma 300 (.5) 8. API 400 (.1, .5, 1.0) 9. Lorr Single ML 9810 (.05-1.0)
Pb	HV with Photo AA	<ol style="list-style-type: none"> 1. HV/Photo AA (EPA) 2. HV/Fluorescence AA (EPA) 3. HV/CAP (EPA) 4. HV/WDXRF (ARL, CA) 5. HV/CAP (MT) 6. HV/EDXRF (TX) 7. HV/Fluorescence AA (Omaha-Douglas Co.) 8. HV/CAP (RI) 9. HV/CAP (NET) 10. HV/CAP (SVL) 11. HV/EDXRF (NEA) 12. HV/CAP (NH) 13. HV/CAP (KS) 14. HV/CAP (PA) 		
PM ₁₀	<ol style="list-style-type: none"> 1. W & A PM₁₀ Critical Flow HV Sampler 2. SA/OMFW 1200 3. SA/OMFW 321-B 4. SA/OMFW 321-C 5. Oregon DBQ HV Special Sampler 6. SA/OMFW 241 & 241M Dishes Sampler 			<ol style="list-style-type: none"> 1. Andersen Inc. PM421-N PM₁₀ Beta Attenuation Monitor 2. Rappaport & Patachneck TROOP Series 1400 and 1400a PM₁₀ Monitors 3. Weidung & Associates' PM-10 Beta Gauge Attenuated Portals Sampler
SO ₂	Potentiometric Method	<ol style="list-style-type: none"> 1. Technicon I 2. Technicon II 		<ol style="list-style-type: none"> 1. Lorr Single 841000 (.5) 2. Moly SA185-2A (.5, 1.0) 3. TEI 43 (.5, 1.0) 4. Philips PW7755 (.5) 5. Philips PW7700 (.5) 6. Monitor Labs 8450 (.5, 1.0) 7. ALABCO 500 (.5), 600 (1.0) 8. Beckman 953 (.5, 1.0) 9. Beutler 8303 (.5, 1.0) 10. Moly SA285E (.05, .1, .5, 1.0) 11. Monitor Labs 8850 (.5, 1.0) 12. Moly SA700 (.25, .5, 1.0) 13. Lorr Single AM0020 (.5, 1.0) 14. TEI 43A (.1, .2, .5, 1.0) 15. Dumas 4108 (.1, .2, .5, 1.0) 16. Monitor Labs 8850S (.5, 1.0) 17. API 100 (.5) 18. Beversma S.A. AP21M (.5) 19. Lorr Single ML 9850 (.05-1.0)
TSP	High Volume Method (HV)			

NOTE: The numbers in parentheses that follow the manufacturer name i.e., (.05), (.1), (.2), (.5), (1.0), or (50) indicate the full scale range(s) approved for that method. Ranges that are specified as (.05-1.0) or (5-100) indicate any full scale range between the indicated values.

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ENVIRONMENTAL PROTECTION AGENCY**
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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Appendix E

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May 1976

TECHNICAL MANUAL
FOR THE MEASUREMENT OF FUGITIVE EMISSIONS:
ROOF MONITOR SAMPLING METHOD
FOR INDUSTRIAL FUGITIVE EMISSIONS

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Office of Energy, Minerals, and Industry
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Office of Research and Development
Washington, DC 20460

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1.0 OBJECTIVE

The objective of this technical manual is to present a guide for the utilization of the Roof Monitor 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. Roof Monitor 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 an electric arc furnace steel making plant 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 stack 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 emissions using the roof monitor measurement method described in Section 2.1.3 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.

2.1.2 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.

2.1.3 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 un-

wieldy 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.

These features are embodied in the typical industrial sources and their emitted pollutants contained in Table 2-1.

The roof monitor method quantifies the emissions from such sources as the average mass flux of emissions from buildings or enclosure openings over the time period of measurement. The flux is obtained from air and pollutant material balances across the openings. Tracer tests may also be used in combination with it to define the contributions of individual sources.

2.2 Selection of Sampling Method

The initial step in the measurement and documentation of fugitive emissions at an industrial site is the selection of the 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 sampling method.

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.

TABLE 2-1

TYPICAL INDUSTRIAL FUGITIVE EMISSIONS SOURCES
MEASURED BY THE ROOF MONITOR SAMPLING METHOD

Industry	Source	Particulate Emissions	Gas and Vapor Emissions
Iron & Steel Foundries	Furnace or Cupola Charging Melting Mold Pouring	Fume, Carbon Dust, Smoke (Oil) Fume, Dust Dust	CO, HC, SO ₂ CO, SO ₂ CO, HC, PNA, Odor
Electric Furnace Steel	Charging General Operations	Metallic Fumes, Carbon Dust Metallic Fumes, Dust	CO CO
Primary Aluminum	Carbon Plant Potroom Alumina Calcining Cryolite Recovery	Tars, Carbon Dust Tars, Carbon & Aluminum Dust, Flourides Alumina Dust Carbon & Alumina Dust, Flourides	CO, HC, SO ₂ CO, HC, SO ₂ , HF - -
Primary Copper	Converter House Reverberatory Furnace Roaster Operations	Fume, Silica Fume Fume	SO ₂ SO ₂ SO ₂
Tires & Rubber	Curing Press Room Cement House	Organic Particulate Dust	HC, Odor HC, Odor
Phosphate Fertilizer	General Ventilation	Dust, Flourides	SO ₂ , HF
Lime	General Ventilation	Dust	-
Primary Steel	Blast Furnace Cast House BOF Operations Open Hearth Operations	Metallic Fumes Metallic Fumes, Carbon Dust Metallic Fumes	CO, H ₂ S, SO ₂ CO CO
Graphite, and Carbide Production	Arc Furnace Operation	Carbon Dust, Silica Fume	CO, Odor

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. Will wind conditions or 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. Will installation of measuring equipment alter the process or the emissions? Will measurements interfere with production?

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 Criteria Application

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. The process may be cyclic in nature if any one cycle is of sufficient duration to provide a representative sample. 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. Emission 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 and is least affected by the emission generation rate of the process. 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.

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 worst grouping 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 and heavy gases which may settle within the enclosure being sampled. Emissions 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 temper-

ature, 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 little consequence since the magnitude of the ambient air volume concerned is large enough to provide a smoothing effect to any circle 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 a representative pollutant cloud is included.

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 to provide gross measurements of a number of process influents and effluents; detailed systems are designed to isolate, identify accurately, and quantify individual contaminant constituents.

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 2 to 5 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 provide 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. Detailed 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.

30. TEST STRATEGIES

This section describes the approaches that may be taken to successfully complete a testing program utilizing the roof monitor 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 in-

stalled, 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 program

TABLE 3-1

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

Plant Layout	<p>Drawings:</p> <ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Access Routes to the Areas Where Test Equipment/Instrumentation Will Be Located Names, Extensions, Locations of Plant Security and Safety Supervisors Regional Meteorological Summaries

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 source operations, 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 it is to be directed to.

Quality Assurance

The test plan should address itself to 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 Roof Monitor Sampling Strategies

The roof monitor sampling method, as described in Section 2.1.3, is used to quantify emissions released into the internal atmosphere of the buildings or enclosures that contain the process equipment and which are then ventilated to the external atmosphere as fugitive emissions. The roof monitor sampling method may be utilized to measure the fugitive emissions from almost any process that ventilates through building openings such as doors, windows, or any of a wide variety of roof ventilators, where the ventilation is either gravity dependent or fan driven.

The measurements made include that of the gas flow through the opening either by direct measurement or by calculation (of the gas velocity) from physical parameters (pressure drop, thermal conductivity), the cross-sectional area of the opening, and the particulate and gaseous emission concentrations in the flowing gas. These measurements or calculations provide the data necessary to determine the total flux of the fugitive emissions from all sources operating within the enclosure or from selected sources, depending on processing sequences or cycles. Since ventilation rates, especially when gravity driven, can vary, the mass emission rates so measured are averages over the emission concentration and velocity measurement period. (Sections 3.4 and 3.5 describe the equipment used for sampling, the criteria for sampling system design, sampling techniques, and data reduction procedures for respectively, survey and detailed roof monitor sampling programs).

3.4 Survey Roof Monitor Sampling Strategy

A survey measurement system, as defined in Section 2.3, is designed to provide gross measurements of emissions to determine whether any

constituents should be considered for more detailed investigations. A survey roof monitor measurement system in its simplest form utilizes one or two hi-vol type samplers set up to sample the openings by which the fugitive emissions exit the building or enclosure and an equal number of hot wire or rotating vane anemometers for determining the gas velocity exiting the openings. The weight of particulates/volume of sample air collected and the average velocity across the openings are combined with the measured area of the opening to calculate the emission rate of the source. Grab samples of gaseous emissions may be taken at the same time as the particulate samples and the emission rate calculated in the same manner. Size distribution of the particulates may also be obtained simultaneously from a variety of methods.

3.4.1 Sampling Equipment

Pollutants that may be measured by the roof monitor technique are limited to those that can be airborne sufficiently to exit the enclosure or structure through the vent openings, i.e., particulates and gases. The gross measurement requirements for survey sampling of particulates are best satisfied by high volume filter impaction devices to provide data on the average emission rate, particle size distribution, and particle composition. Particle charge transfer or piezoelectric mass monitoring devices may be utilized for continuous or semi-continuous sampling of intermittent emission sources where peak levels must be defined.

Gaseous emissions in survey programs are usually grab-sampled for laboratory analysis using any of a wide variety of evacuated sampling vessels. Continuous or semi-continuous sampling of specific gases may

be accomplished using such devices as, for example, continuous monitor flame ionization detectors (for hydrocarbons) and automated West-Gaeke bubblers/impingers (for sulfur dioxide). Figures 3-1 and 3-2 show typical setups utilized for roof monitor/ventilator sampling for fugitive emissions.

3.4.2 Sampling Systems Design

The number and location of devices used to collect samples are extremely important to the successful completion of a survey roof monitor sampling program, especially since the program is designed for minimum cost and provides for no replication of samples. The design of the sampling system is influenced by such factors as source complexity and size, physical location and size of the vent openings, variability of the mass rate and temperature of the emissions, as well as the homogeneity of the emissions. Most situations will, in general, fit into some combination of the following parameters:

Source - Sources may be either homogeneous, emitting a single type of mixture of pollutants from each and every emission location, or heterogeneous, emitting different types or mixtures of pollutants from different locations. The resultant pollutant emission "cloud" ("cloud" being used to describe the fugitive emission plume boundaries) from a homogeneous source will be homogeneous. The pollutant as a result of mixing by suitably directed or turbulent enclosure/structure air flow, homogeneous. The physical size of a source will determine the extent of the pollutant emission "cloud" and may influence its homogeneity. The proximity of sources within the enclosure/structure will also determine the extent of the "cloud" and its homogeneity.

Emission Character - The time duration of the emissions may limit the effective sampling time. Sources which have a short time cycle (<10-15 minutes) may require different sampling methods than those of a one-hour or more time scale. The temperatures of the emissions will also effect sampling. Excessive temperatures may limit the sampling time for the emissions. If temperatures cycle excessively, instrumentation which can quickly adjust to this cycle would be required.

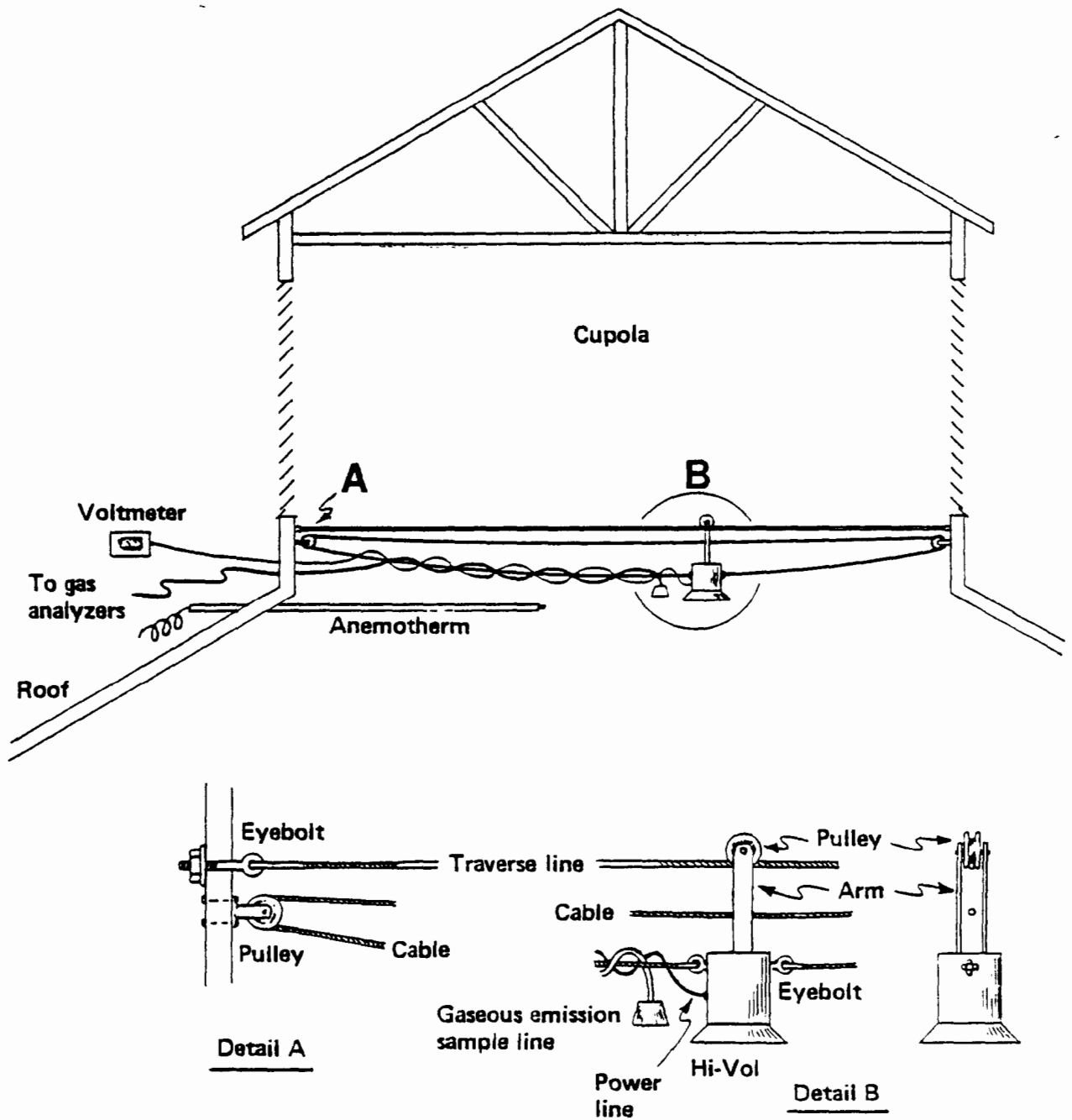


Fig.3-1. Electric arc furnace operation; roof monitor showing sampling/mounting configuration.

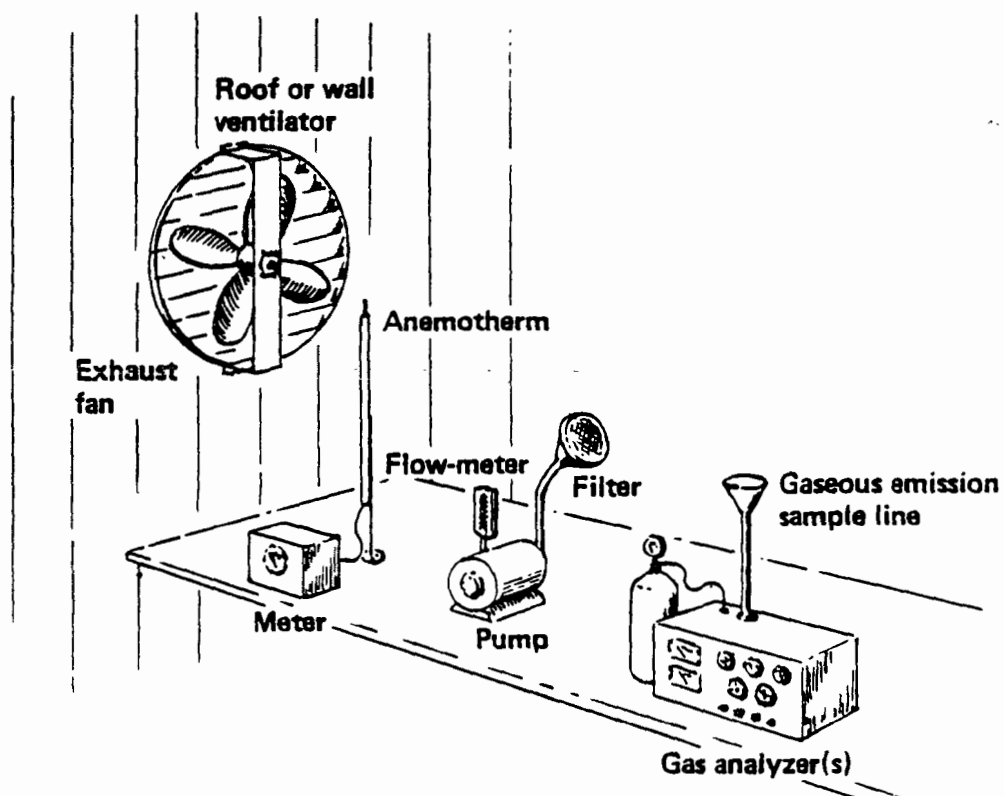


Fig. 3-2a. Roof or wall ventilator sampling configuration (with or without fan).

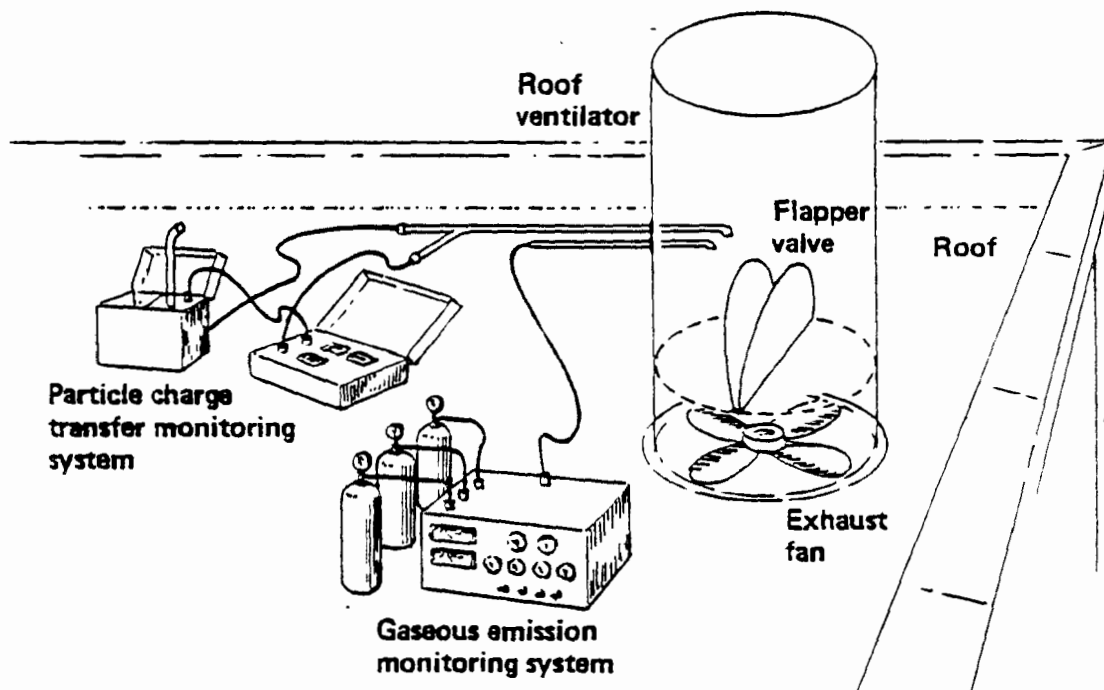


Fig. 3-2b. Roof ventilator sampling configuration.

Site Accessibility - If the site is not readily accessible, continuous monitoring equipment, which is usually higher in cost and also in complexity of arrays, might be required to measure the fugitive emissions. If standard hi-vols are used, extra samplers would need to be located in the roof monitor to conserve the number of times the sampling site has to be accessed to recover samples. Remote timing equipment and remote recording would be required also.

Emission Cycle - If the emission cycle is short, continuous monitoring equipment may be required. If not, multiple samples may need to be taken on the same filter. In this case, a remote timing and recording equipment would be required.

Table 3-3 outlines elements of conceptual systems for roof monitor sampling programs. These elements are keyed to the numbers on the Matrix of Table 3-2, and they correspond to the appropriate system elements needed to measure fugitive emissions for that matrix entry. Each matrix entry corresponds to a specific combination of factors which make up a particular roof monitor sampling program for a specific source.

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

TABLE 3-2

MATRIX OF POSSIBLE COMBINATIONS OF KEY TEST PARAMETERS

Combination Number	Source Homogeneity	Emissions Point Geometry	Site Accessibility	Emission Cycle	Suitable System Elements
1	Homogeneous	Simple	Easy	Short	(1),(4) (1) . . . etc.
2	Homogeneous	Complex	Difficult	Long	(5) Numbers refer
3	Homogeneous	Simple	Difficult	Short	(4) to conceptual
4	Homogeneous	Complex	Easy	Long	(3) system elements
5	Homogeneous	Simple	Easy	Long	(1) for a roof moni-
6	Homogeneous	Complex	Difficult	Short	(5) tor sampling
7	Homogeneous	Simple	Difficult	Long	(1),(4) program most
8	Homogeneous	Complex	Easy	Short	(5) suitable for a
9	Heterogeneous	Simple	Easy	Short	(4) given matrix
10	Heterogeneous	Complex	Difficult	Long	(6),(5) element, as de-
11	Heterogeneous	Simple	Difficult	Short	(4) scribed in Table
12	Heterogeneous	Complex	Easy	Long	(6),(5) 3-2.
13	Heterogeneous	Simple	Easy	Long	(2)
14	Heterogeneous	Complex	Difficult	Short	(5)
15	Heterogeneous	Simple	Difficult	Long	(4)
16	Heterogeneous	Complex	Easy	Short	(5)

TABLE 3-3

ELEMENTS OF CONCEPTUAL SYSTEMS FOR A
ROOF MONITOR SAMPLING PROGRAM AS APPLIED TO
SPECIFIC TYPES OF FUGITIVE EMISSION SOURCES*

1.	One Hi-Vol Sampler One Rotating Vane Anemometer One Cascade Impactor	} Fixed Station In Monitor
2.	Two Hi-Vol Samplers Two Rotating Vane Anemometers Two Cascade Impactors	} Fixed Station In Monitor
3.	One Hi-Vol Sampler One Rotating Vane Anemometer One Cascade Impactor One Portable Anemometer (Vane or Hot Wire One Respirable Dust Monitor	} Fixed Station In Monitor Manual Traverse of Doors & Windows
4.	One Continuous Particulate Monitor One Rotating Vane Anemometer One Cascade Impactor	} Movable Across and Down Roof Monitor
5.	One Continuous Particulate Monitor One Rotating Vane Anemometer One Cascade Impactor One Portable Anemometer One Respirable Dust Monitor	} Movable Across and Down Roof Monitor Manual Traverse of Doors & Windows
6.	Two Hi-Vol Samplers Two Rotating Vane Anemometers Two Cascade Impactors One Portable Anemometer One Respirable Dust Monitor	} Fixed Station In Monitor Manual Traverse of Doors & Windows

*All gaseous sampling done using grab samples for laboratory analysis.

least these minimum amounts of the pollutants to be quantified. The mass (M) of a pollutant collected is the product of the concentration of the pollutant in the air (χ) and the volume of air sampled (V), thus,

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

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 (V) is the product of its flow rate (F) and the sampling time (T), or,

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

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 sampling location 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 Equation 3-1:

$$F \text{ (cubic meters/minute)} = \frac{M \text{ (micrograms)}}{\chi \text{ (micrograms/cubic meter)}} \times T \text{ (minutes)}. \quad (3-1)$$

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.

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.

The location of samplers is also important in obtaining representative data. Where the emissions are known to exit the roof monitor or vent in a homogeneous pollutant "cloud", one sampler can be used. However, where the pollutant "cloud" is not known to be homogeneous or is definitely heterogeneous, samplers should be located at 25-100 ft intervals.

In addition, unless approximations can be made based upon relative flowrates, a sampler must be located at each separate roof monitor or vent location on the building/enclosure. This can be simplified if inspection of the site indicates that some of these vents are only minor sources of the fugitive emissions.

A critical concern in development of the mass emission rates from roof monitor fugitive emission tests is the accuracy of the flow measurements required to change air quality measurements into mass emissions. The basic equation is:

$$\text{Mass Rate (micrograms/minute)} = M (\text{micrograms})/T (\text{minutes}) = \\ \chi (\text{micrograms/cubic meter}) \times F (\text{cubic meters/minute})$$

Where χ is known quite accurately, F is the overriding error limit for fugitive emissions measurements. F can be obtained from:

$$F (\text{cubic meters/minute}) = A (\text{square meters}) \times U (\text{meters/second})$$

Preliminary estimates of the linear velocity (V) can be obtained by use of a hand hot wire anemometer with a digital or scale read-out. These will serve to determine what method of velocity measurement

TABLE 3-4

RANGE OF APPLICABILITY OF COMMON VELOCITY
MEASUREMENT DEVICES FOR ROOF MONITOR SAMPLING

Device	Flow Range	Accuracy	Usable Temp. Range
Hot Wire Anemometer*	10-8000 fpm	Fair	0-225°F
Rotating Vane Anemometer	100-6000 fpm } 50-6000 fpm }	Fair at Low fpm { Good at High fpm {	0-150°F Mechanical 0-200°F Electric
Pitot Tube Calibrated	500-6000 fpm	Good	0-2000°F***
Magnehelic Gauge**	2000-10,000 fpm	Good	0-200°F

*Cannot be used for sources with significant steam or water content.

**Although accurate has very narrow range of flow measurement and must be calibrated for opening used.

***Water cooled for high temperatures.

will be the most accurate. Temperature readings should also be taken to determine the most suitable instrument. Table 3-4 summarizes data on the four instruments which would be most suitable, which are:

1. Hot Wire Anemometers
2. Rotating Vane Anemometers
3. Pitot Tubes
4. Magnehelic Gauges (after calibration)

The method chosen must take into account:

1. Compatibility with chosen sampling site conditions.
2. Compatibility with desired error limits of tests.

3.4.4 Data Reduction

When the sampling program has been completed and the samples have been analyzed to yield average pollutant concentrations in micrograms of particulate matter or parts per million of gases in the pollutant emission "cloud", the source strength must be calculated. As previously mentioned, this requires the multiplication of these values by the cross sectional area of the opening and the average linear velocity across that opening. This must be done for every significant roof monitor or vent in the building/enclosure studied to establish the process fugitive emission rate in grams per second, or other appropriate mass emission rate units.

3.5 Detailed Roof Monitor Sampling Strategy

A detailed measurement system is designed to more precisely identify and quantify specific pollutants that a survey measurement or equivalent data indicate as a possible problem area. 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 terms of equipment time and manpower and yields data detailed and dependable enough for direct action towards achieving emission control.

Detailed systems in general employ sampling networks to measure the concentration and distribution of specific pollutants within the pollutant emission "cloud". The detailed measurements of pollutant distribution and emission rate variation replace the averaging techniques or the assumptions of representativeness of the sampling done in survey sampling systems. Detailed systems are frequently employed to compare the emissions at different process or operating conditions to determine which conditions dictate the need for emission control.

The data provided by the sampling network are processed in conjunction with detailed studies of the volumetric flow rate of the emissions from the roof monitor or vents to determine mass emission rates from the fugitive sources.

The complexity of a detailed system is largely determined by the basic accuracy desired; increasing accuracy demands more measurements either in the number of locations measured or in the number of measurements made at each location, or both. Most detailed systems will require a network of sets of instrumentation located across the plane of the opening to make simultaneous measurements since the usually lower concentrations of specific emissions preclude the use of traversing techniques with inherently short sampling durations, or assumptions regarding the distribution of emissions in the flow through the opening.

Identification and quantification of a specific fugitive emission from an enclosed source may involve measurements at more than one building opening if the flow through the separate openings is of comparable magnitude and the openings are situated to result in selectivity in the character or quantity of the emission being vented. This could occur, for example, when a roof monitor and a floor level door or window both vent emissions from a variety of sources within a building. Lighter gaseous emissions and smaller particulates would be expected to vent through the monitor, while the heavier gases and larger particulates would tend to settle and vent through the lower opening. If either of the openings is situated to vent all or most of the emissions from a specific source, resulting in a different type of emission for the two openings, the detailed measurement system might require different types of instrumentation at each location, thus adding to the system complexity.

3.5.1 Sampling Equipment

The pollutants to be characterized by a detailed roof monitor sampling system fall into the same two basic classes--airborne particulates and gases--as those measured by survey systems. Detailed 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 filter impaction, piezo-electric, 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 reviewed in Section 3.4.2 for the design of a survey sampling system are generally applicable to the design of a detailed system. The need for replacement of survey assumptions as to pollutant distribution with actual measured values, however, most frequently requires the design of a sampling network that will provide samples of a distribution at various distances along the width of the source in both the horizontal and vertical directions. Sampler locations may generally be determined in the same manner as those for a survey systems except that they must be capable of finer analysis of pollutant distribution. For detailed measurements, each location must make provision for sampling across the section of the pollutant emission "cloud" horizontally and/or vertically. Horizontal distributions over the length of the roof monitor may be measured by adding a number of samplers (usually at least two) at either side of the survey sampler location at distances estimated to yield significantly different pollutant concentrations. Vertical distributions as well as horizontal distributions across the width of the roof monitor are best determined by traversing with the samplers or their probe devices.

General rules which might be applied to system design are as follows:

1. If emissions are reasonably homogeneous, sampler locations along the horizontal length of the roof monitor should be 25-50 ft apart maximum. If heterogeneous, they should be 10-20 ft apart.
2. Vertical distances greater than 10-20 ft in roof monitor openings would require either vertically tiered samplers or traversing arrangements.
3. Traversing across the width of a roof monitor or setting up a network in that width can be employed to sample emissions before they leave the roof monitor. In cases where external accessibility is a problem, this can be used to obtain representative samples without leaving the building.
4. If any significant emissions ($> 10\%$) are presumed to exit the enclosure/structure by other than the roof monitor, that vent or exit should have its own sampler system.
5. Where a minor ($< 10\%$) amount of emissions are presumed to exit the enclosure/structure by other than the roof monitor, some estimate of this should be obtained using a portable and simplified sampler system (survey type). There can be many such openings and caution should be applied to avoid excess expenditure of time/money for tests of such minor sources.

3.5.3 Sampling Techniques

In order to obtain representative results of detailed quality, sampling techniques must:

1. Differentiate the peak emissions from the average fugitive emissions of a process. Online continuous readout devices are preferable in these cases.
2. Determine the horizontal and vertical distribution of pollutants within the emission "cloud". Multiple online continuous readout devices as well as traversing are preferable in these cases.
3. Differentiate specific components of the emissions, preferably those of highest hazard/toxicity to humans. Single component continuous online monitors or detailed laboratory analysis of collected samples of particulates, gases or liquids are preferred.

The specific techniques which might be employed vary. However, the selection criteria should include:

1. Portability
2. Power Requirements
3. Detection Limits
4. Response Time
5. Ease of Control (remote or close at hand)

3.5.4 Data Reduction/Data Analysis

After the analyses for pollutants are completed, the required calculations are made for emission concentrations, including calculations for the mean and standard deviation. Statistical differences between test methods can be obtained and confirmed by conducting various statistical significance procedures such as the "t" and "f" tests on the mean and standard deviation values for the various test methods. A tabulation of the statistical analysis results can then be made and related to the process conditions at the time of the tests. Finally, the investigator can determine whether there is a correlation between the emission results by test method and the process conditions.

3.6 Tracer Tests

Complex sources, consisting of several different sources with similar or very different emission rate patterns, can be the cause of the fugitive emissions from the roof monitor of a structure or enclosure. Emission measurements at the roof monitor of complex sources must be related back to a specific source to determine what is the most significant cause of fugitive emissions. Tracers can be released at specific rates at the location of the source to be studied for specific time periods. Knowledge of this,

as well as what sampler caught this tracer and in what concentration, can serve to differentiate each source's contribution to the fugitive emissions.

3.6.1 Tracers and Samplers

Both particulate and gaseous atmospheric tracers are in general use. The most commonly used particulate tracers are zinc sulfide and sodium fluorescein (uranine dye). The primary gaseous tracer is sulfur hexafluoride (SF_6).

Zinc sulfide is a particulate material which can be obtained in narrow size ranges to closely match the size of the pollutant of concern. The material is best introduced into the atmosphere in dry form by a blower type disseminator although it can be accomplished by spraying from an aqueous slurry solution. The zinc sulfide fluoresces a distinctive color under ultraviolet light which provides a specific and rapid means of identification and quantification of the tracer in the samples.

Sodium fluorescein is a soluble fluorescing particulate material. It is normally spray disseminated from an aqueous slurry solution to produce a particulate airborne plume, the size distribution of which can be predetermined by the spraying apparatus. Sodium fluorescein can be uniquely identified by colorimeter assessment.

Sulfur hexafluoride is a gas which can be readily obtained in ordinary gas cylinders. Sulfur hexafluoride can be disseminated by metering directly from the gas cylinder through a flow meter to the atmosphere. The amount disseminated can be determined by careful flow metering and/or weight differentiation of the gas cylinder.

Particulate tracers are usually sampled with filter impaction devices or, for particles over 10 microns in diameter, the more easily used and somewhat less accurate Rotorod sampler which collects particles on an adhesive-coated U- or H-shaped rod which is rotated in the ambient air by a battery-driven electric motor.

Sulfur hexafluoride gaseous samples are collected for laboratory gas chromatograph analysis in non-reactive bags of such materials as Mylar.

3.6.2 Tracer Sampling System Design

All of the design guidelines presented in 3.4.2 and 3.5.2 may be applied to the design of a tracer sampling system as site conditions dictate. Their application is, in general, simplified since the source strength may be controlled to provide measurable tracer concentrations at readily accessible sampling locations.

A single ambient sampler will usually be sufficient to establish that no significant amount of the tracer material is present in the ambient atmosphere approaching the source, enclosure or structure.

3.6.3 Tracer Sampling and Data Analysis

The methods introduced in Sections 3.4.3 and 3.5.3 for determining sampler design and location are fully applicable to tracer sampling. Like design guidelines, they may be more easily applied because of the control of source strength available.

The analysis of the data is also simplified since the source strength is known and no back-calculation is required.

3.7 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 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 roof monitoring fugitive emissions sampling programs using the methodology described in this document. Four programs are listed, representing minimum and more typical levels of effort for each of the survey and detailed programs defined in Sections 3.4 and 3.5, respectively. The combinations of conditions for each program are generally representative of ideal cases for each level and may not be encountered in actual practice. They do, however, illustrate the range of effort and costs that may be expected in the application of the roof monitor technique.

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 400 man-hours for minimum effort and 750 man-hours for typical effort in survey programs, and 1600 man-hours for minimum effort and 2800 man-hours for typical effort in detailed programs.

4.2 Other Direct Costs

Table 4-3 estimates for equipment purchases, rentals, calibration, and repairs; on-site construction of towers and platforms; shipping and

TABLE 4-1

CONDITIONS ASSUMED FOR ESTIMATING COSTS AND TIME
REQUIREMENTS FOR ROOF MONITOR FUGITIVE EMISSIONS
SAMPLING PROGRAMS

Parameter	Survey Programs		Detailed Programs	
	Minimum Effort	Typical Effort	Minimum Effort	Typical Effort
Building Openings	1 Roof (Small)	1 Roof (Large)	1 Roof (Large)	1 Roof, 1 Window
Emissions Schedule	Constant	Cyclic	Constant	Cyclic, Mixed
Air Flow At Opening	Steady	Cyclic	Steady	Cyclic
Sampling Locations	1 Traverse	4 Fixed	4 Fixed	12/Opening Fixed
Sampling Frequency	Once	Once	4 Times	10 Times
Estimated Basic Accuracy	$\pm 400\%$	$\pm 150\%$	$\pm 50\%$	$\pm 20\%$

Small ~ 50' long monitor
Large ~ 200' long monitor

ESTIMATED MANPOWER REQUIREMENTS FOR ROOF MONITOR
FUGITIVE EMISSIONS SAMPLING PROGRAMS

Estimates in Man-Hours

Task	Survey Programs						Detailed Programs					
	Minimum Effort			Typical Effort			Minimum Effort			Typical Effort		
	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
retest Survey	4	8	0	4	8	0	8	16	0	12	24	0
est Plan Preparation	4	12	0	4	12	0	8	24	0	12	32	24
quipment Acquisition	0	0	12	0	8	20	0	16	40	0	16	80
ield Set-Up	0	16	24	8	64	30	8	64	40	24	128	128
ield Study	20	40	40	40	80	80	120	240	240	240	480	480
ample Analysis	0	20	40	0	20	80	4	40	160	16	80	200
ata Analysis	0	20	40	8	20	80	16	40	160	32	80	200
eport Preparation	12	32	24	24	72	40	44	100	64	80	200	120
otals	40	148	180	88	284	332	204	540	704	416	1040	1232
ngineer/Scientist Total		368			704			1448			2688	
lerical		40			60			120			180	
rand Total		408			764			1568			2868	

TABLE 4-3

ESTIMATED COSTS OTHER THAN MANPOWER FOR ROOF MONITOR
FUGITIVE EMISSIONS SAMPLING PROGRAMS

Cost Item	Survey Programs		Detailed Programs	
	Minimum Effort	Typical Effort	Minimum Effort	Typical Effort
Equipment				
Instrument Purchase	\$1000	\$2000	\$3000	\$12000
Calibration	50	100	200	800
Repairs	100	150	250	600
Platforms, Etc., Construction	200	500	600	3000
Shipping	200	400	500	800
Vehicle Rentals	200	500	800	1200
Communications	50	100	200	600
Miscellaneous Field Costs	50	100	200	800
TOTAL	\$1850	\$3850	\$5750	\$19800

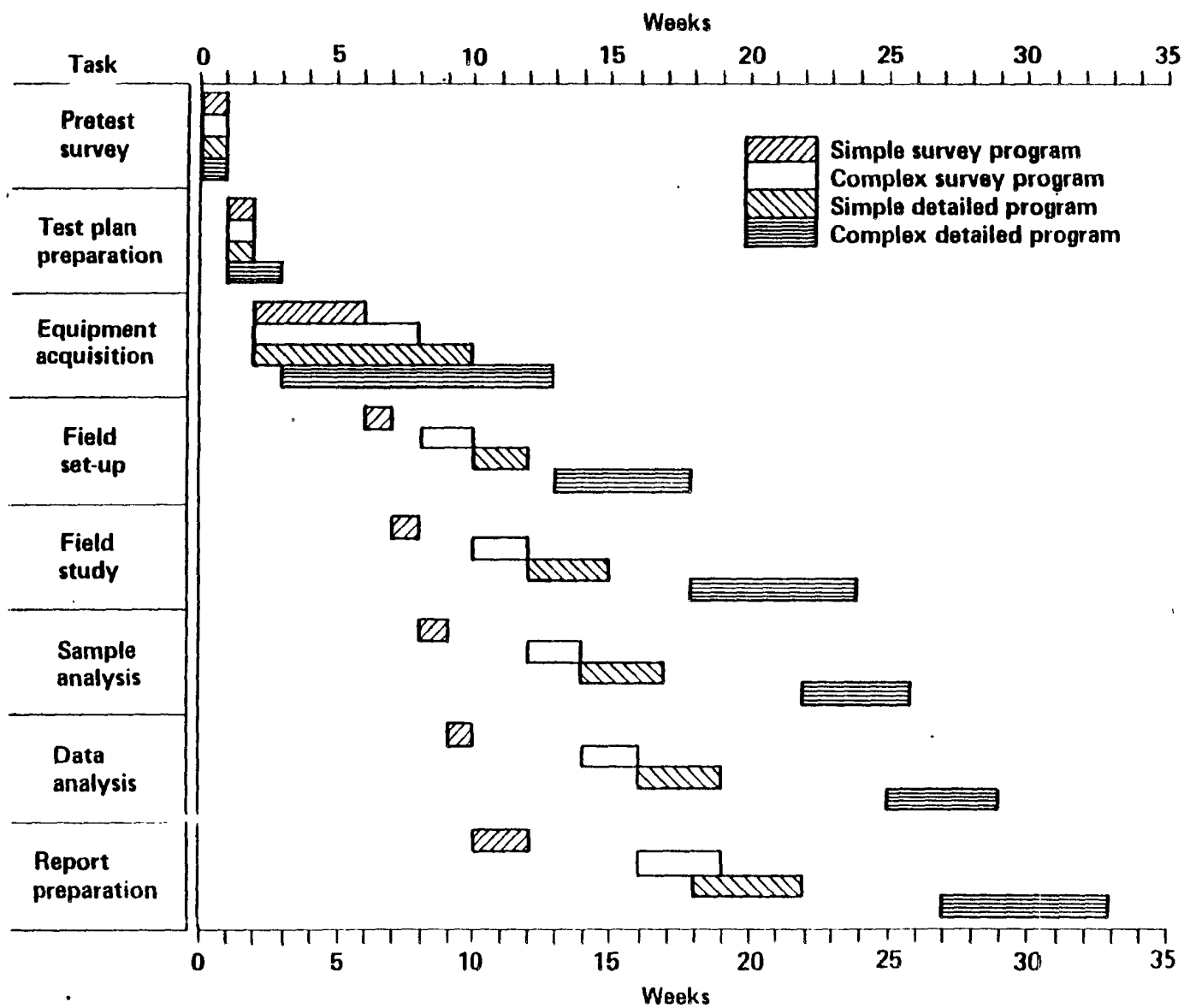
on-site ~~commu~~unications for each of the listed programs. Total costs are approximately \$1,900 for minimum effort and \$3,900 for typical effort in survey programs and \$5,800 for minimum effort and \$20,000 for typical effort in detailed programs.

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 minimum effort and 19 weeks for typical effort in survey programs and 22 weeks for minimum effort and 33 weeks for typical effort in detailed programs.

4.4 Cost Effectiveness

Figure 4-2 presents curves of the estimated cost effectiveness of the roof monitor 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.



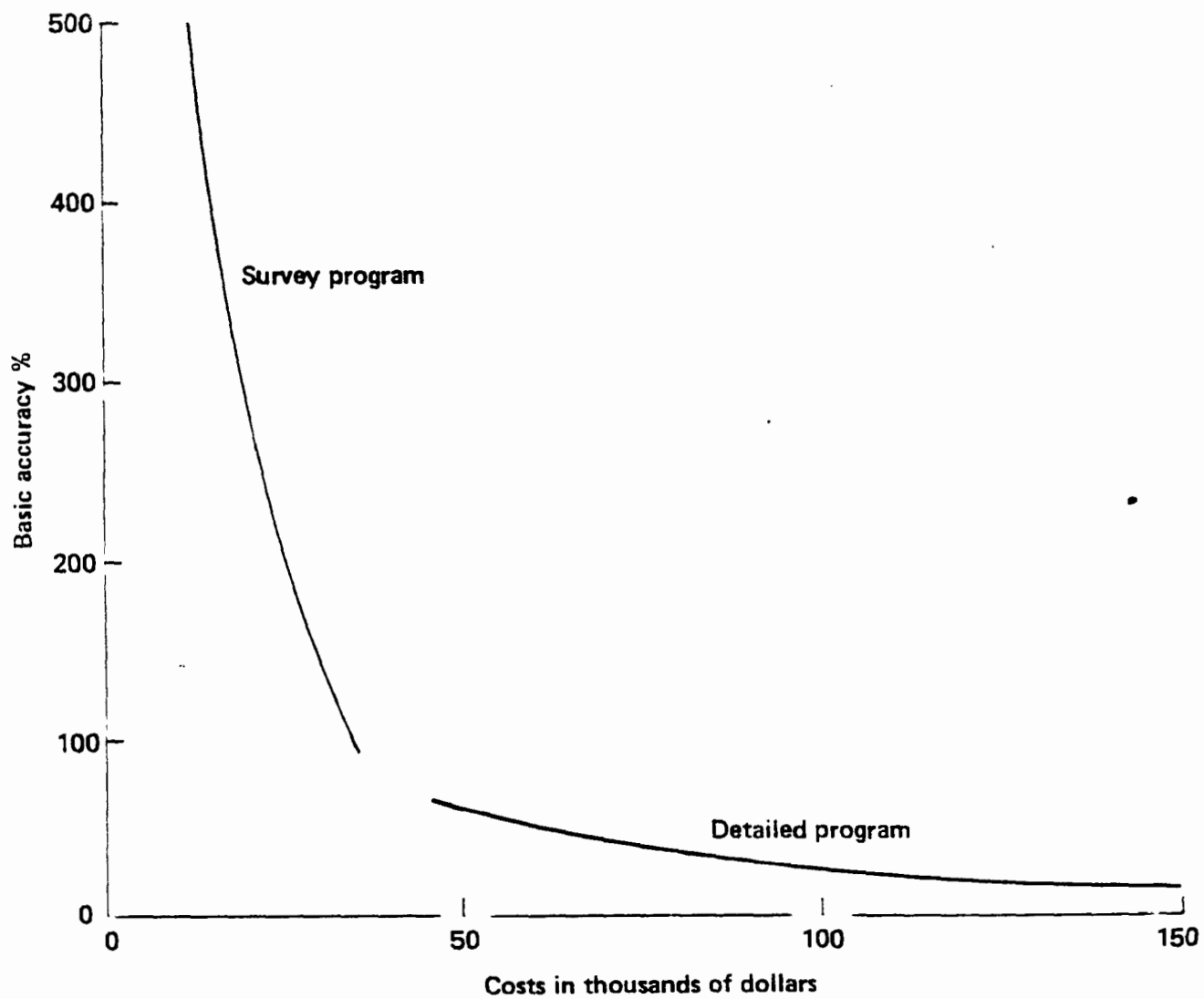


Fig. 4-2. Cost-effectiveness of roof monitor fugitive emissions sampling programs.

APPENDIX A

APPLICATION OF THE ROOF MONITORING SAMPLING METHOD
TO AN ELECTRICAL ARC FURNACE INSTALLATION

A.1.0 INTRODUCTION

This appendix presents an application of the roof monitor fugitive emissions measurement system selection and design criteria to an electric furnace steelmaking shop. 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 operation of an electric arc furnace was utilized to determine the sources and expected types of fugitive emissions that might be encountered in the measurement programs. Figure A-1 describes the use of the electric furnace in steelmaking and shows potential emission sources.

Sources of emissions at a typical electric arc furnace installation could include:

- o Charging of scrap to the hot furnace.
- o Leaks of hooding and/or electrode holes during melting.
- o Normal emissions from scrap melting.
- o Charging of limestone and flux to the melt.
- o Charging of alloying elements to the melt.
- o Tapping and pouring hot metal to the ladle.
- o Tapping and pouring slag into the slag ladle.
- o Transfer of hot metal within the electric furnace shop.

Both gaseous (CO, H₂S, SO₂, etc.) and particulate (iron, limestone, carbon, etc.) emissions are given off by these emission sources and would require quantification in any fugitive emission test program. Emissions from each of these sources can be potentially controlled by collection in a variety of hoods as illustrated in Figures A-2 and A-3, and transfer through ductwork to a remotely located baghouse. A typical state-of-the-art ventilation system for a three furnace shop is

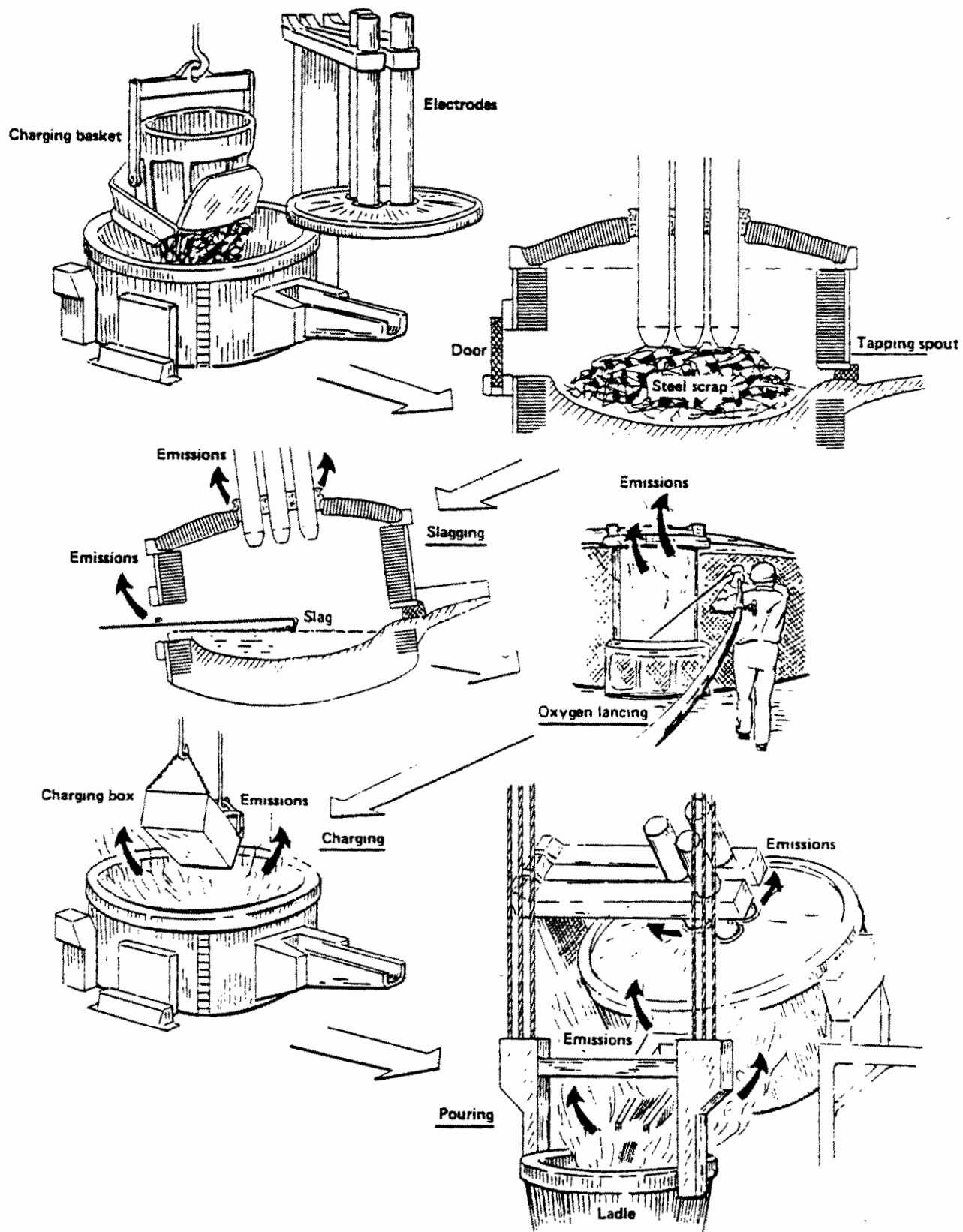


Fig. A-1 Fugitive emissions in electric furnace steel making.

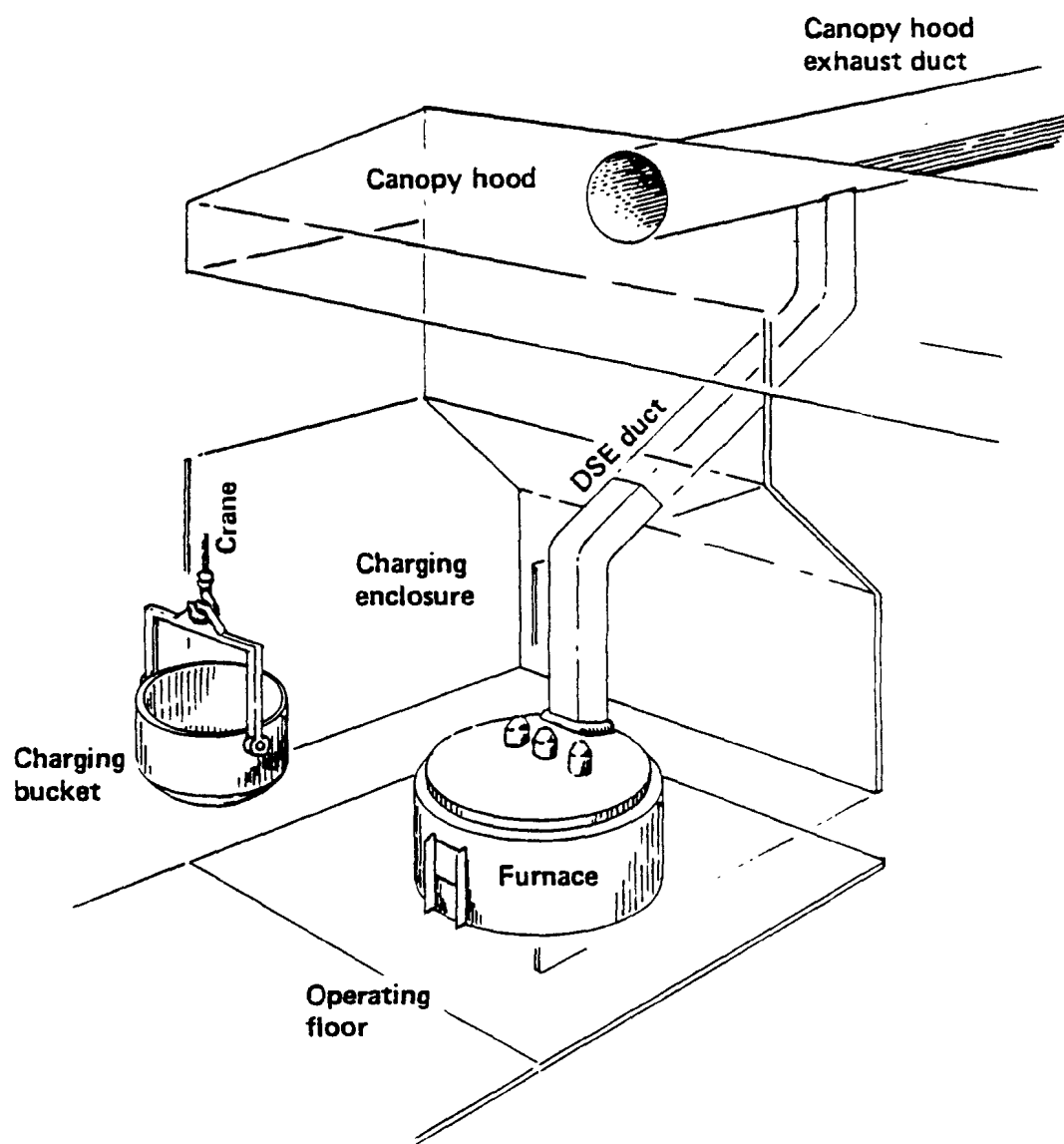


Fig. A-2 . Electric arc furnace-capture system for emissions.

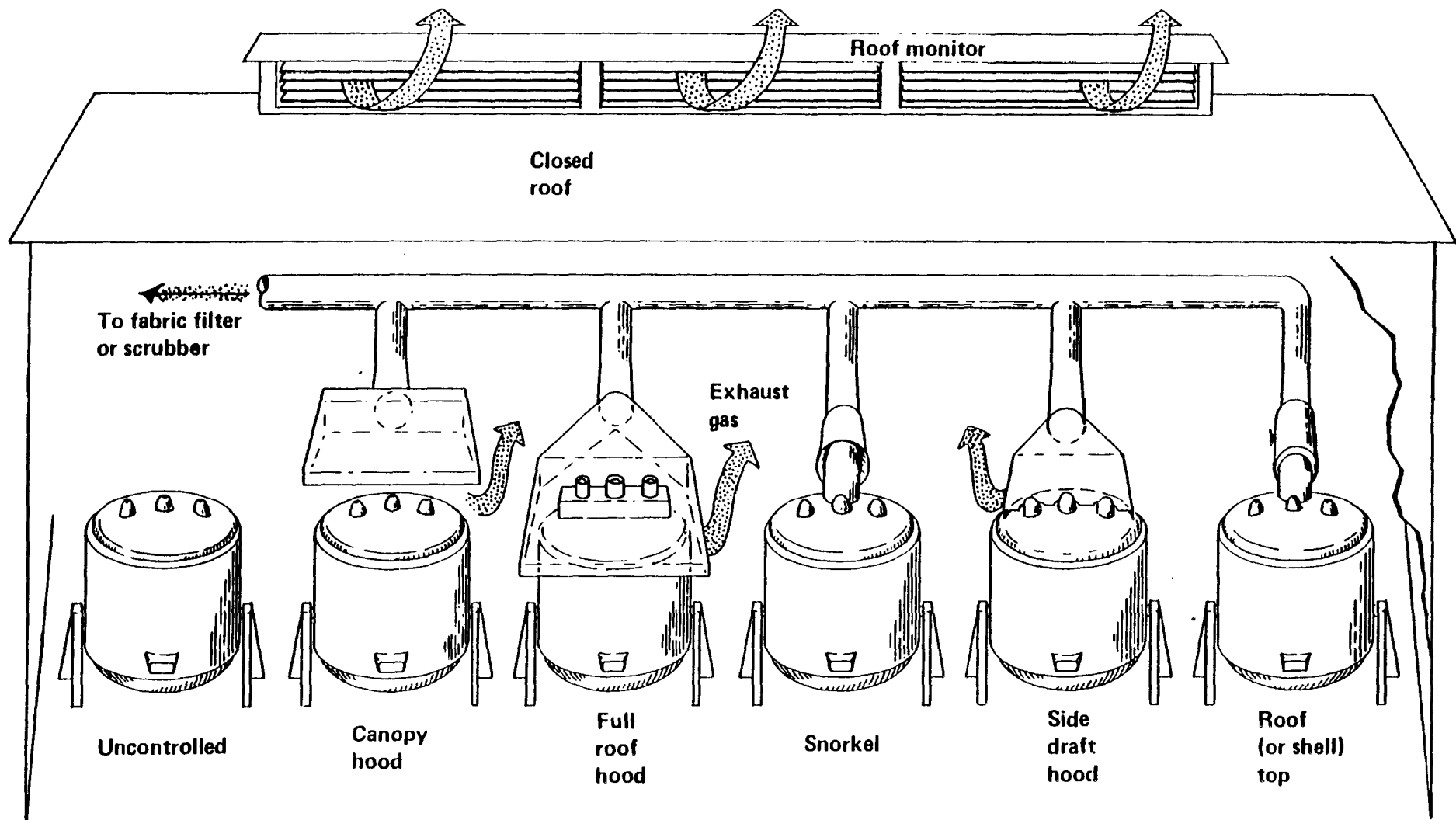


Fig. A-3 Electric arc furnace-fugitive emission control.

sketched in Figure A-4. These captured emissions can be readily identified and quantified utilizing duct-type sampling systems and methods.

Some portion of the emission from each source, however, escapes collection by the ventilation system and is carried out of the building via a roof monitor. These emissions are predominately those which occur when the furnace roof is removed and therefore the directly connected duct system must swing away either with or independent of the roof. Charging emissions are of that type, and latest designs for electric furnace shops use canopy hoods to reduce the released emissions which escape into the general shop areas. These uncaptured charging emissions are the most significant source of fugitive emissions from electric furnace steelmaking. Tapping and pouring emissions as well as hot metal transfer and transport emissions should not be ignored in the pre-test survey. Visual observation of the emission sources can aid in evaluating their significance as fugitive sources.

The EPA estimates for uncontrolled emissions, as published in the Office of Air Programs Publication AP-42, Compilation of Air Pollutant Emission Factors, are 9.2 lbs/ton metal charged without oxygen lance and 11 lbs/ton metal with oxygen lancing. Assuming 90 percent of the emissions are captured by control equipment, 0.9 to 1.1 lbs/ton metal charged could be transmitted to the atmosphere as fugitive emissions. The potential fugitive emissions from the roof monitor of a four furnace steelmaking operation with 100 ton capacity furnaces operating a three shift 24 hour cycle with 4 melts/day/furnace would therefore be 1,440 - 1,760 lbs/day of particulates, plus significant amounts of carbon monoxide, sulfur gases and other emissions.

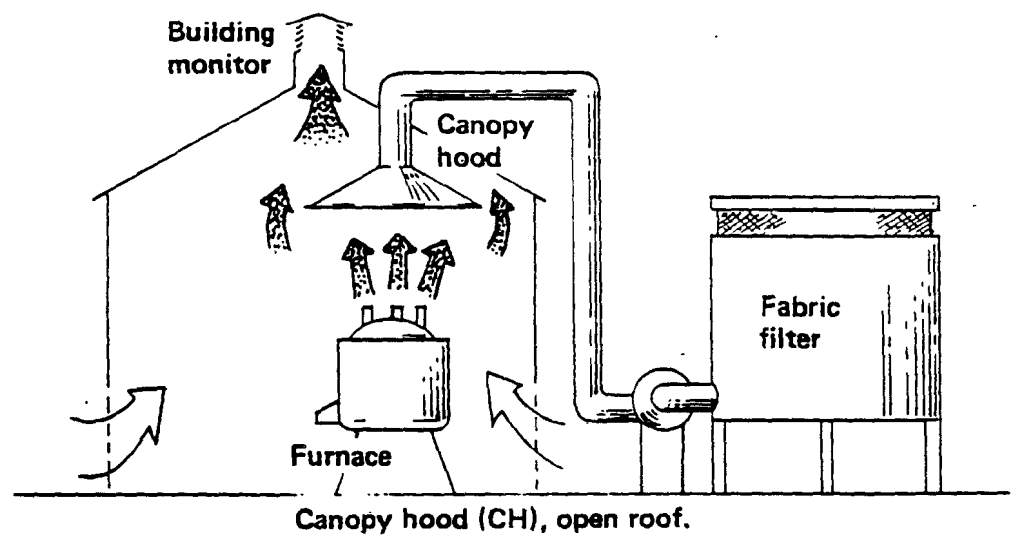
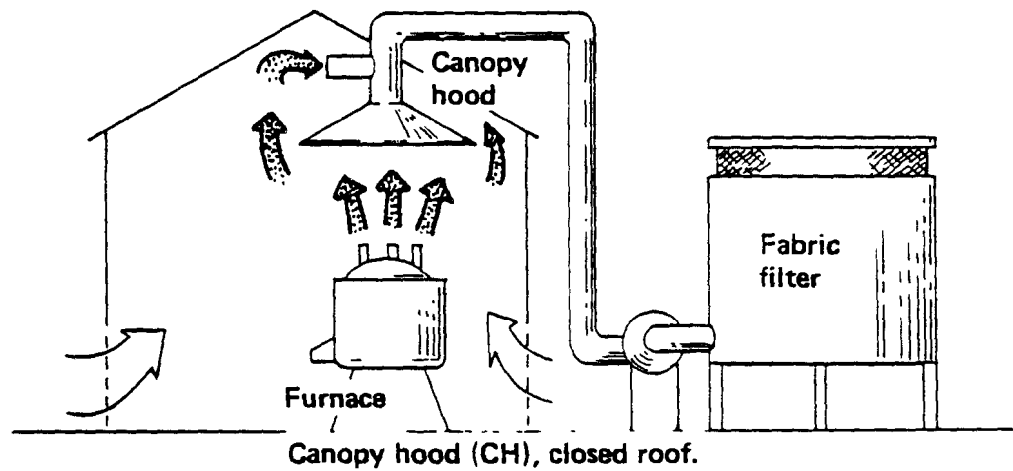
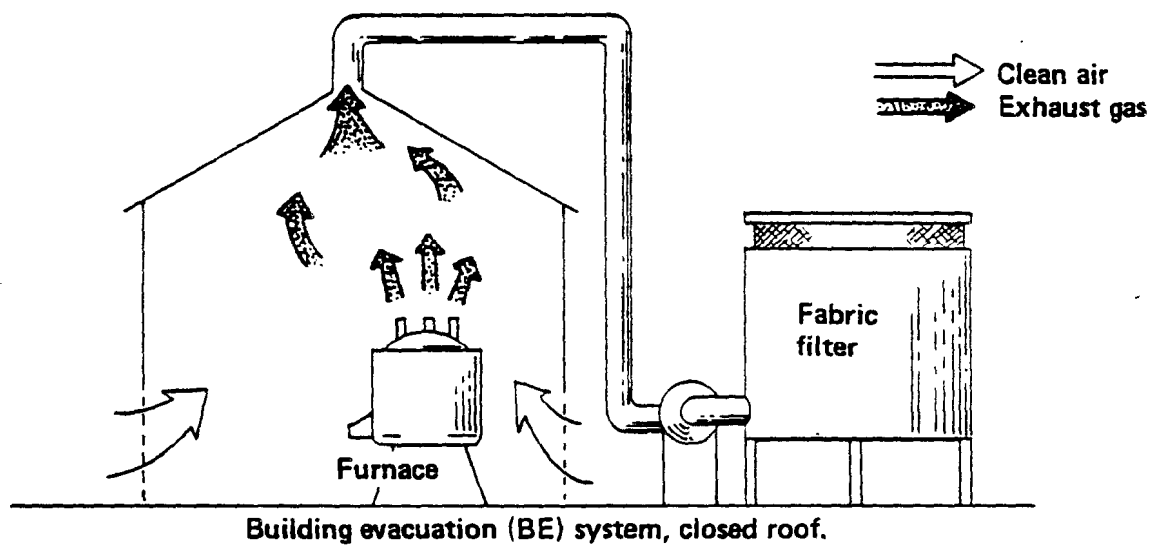


Fig. A-4 Electric arc furnace-charging/tapping fugitive emission control.

A.3.0 SURVEY MEASUREMENT SYSTEM

To determine the total plant contribution of particulates to the atmosphere, measurement must be made of the emissions from the roof monitor over a typical melt cycle from a single furnace. The results of this test can be extrapolated to estimate the total emissions over a 24 hour cycle of the entire electric furnace shop. Visual observations can aid in selection of the roof monitor location to ensure representativeness of the particulate emissions collected.

A.4.0 SAMPLER LOCATION

A typical sampler location is shown in Figure A-5. By visual observation within and outside the electric furnace shop a location which is within the "cloud" of fugitive emissions from a specific furnace can also aid in answering the questions:

- o Is the particulate emission rate (as measured by opacity) of that furnace typical of the entire group of furnaces?
- o Is the sampler location in the main flow path of the particulate "cloud"?
- o How does the variance of particulate emissions with time affect the sampler location?
- o How long a sampling period is required to obtain a representative melt cycle's particulate emissions?

A fixed location high-volume type of particulate sampler similar to that shown in Figure 3-1 would be used with a recording anemometer. The average flow rate of air through the roof monitor opening may be calculated as:

$$F = A \int_0^{\tau} \frac{dV}{\tau}$$

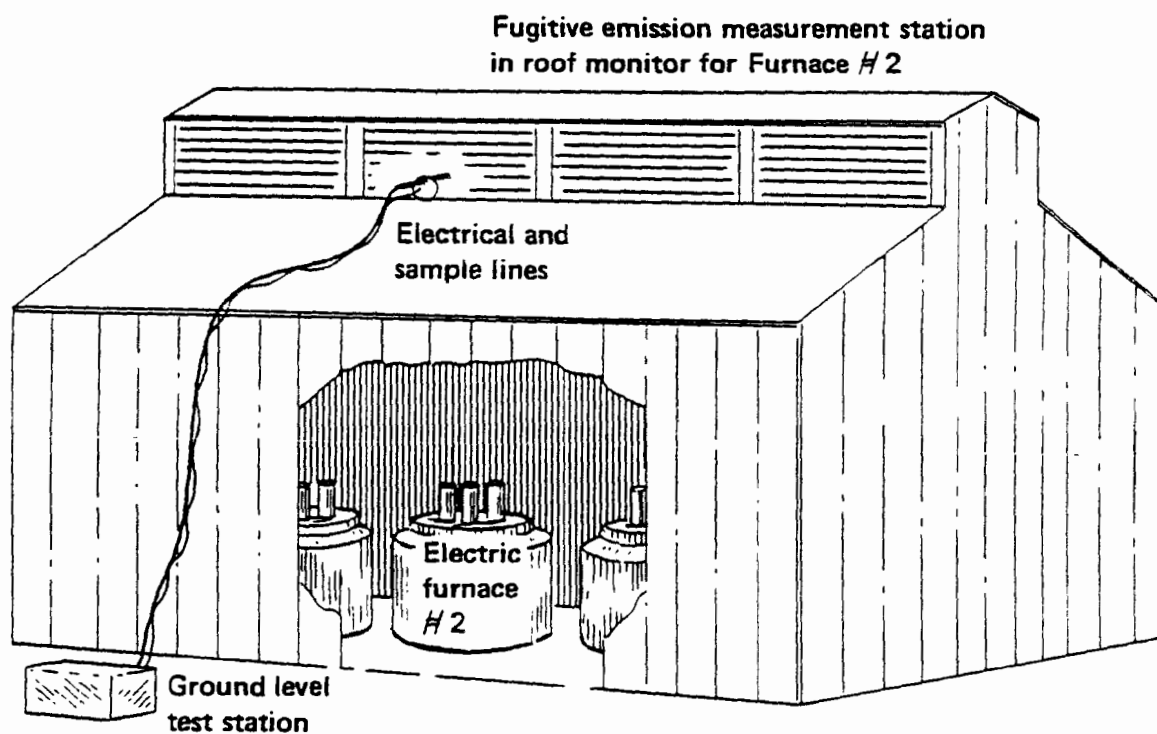


Fig. A- 5. Typical survey program site to determine the fugitive emissions from an electric furnace shop using a roof monitor technique.

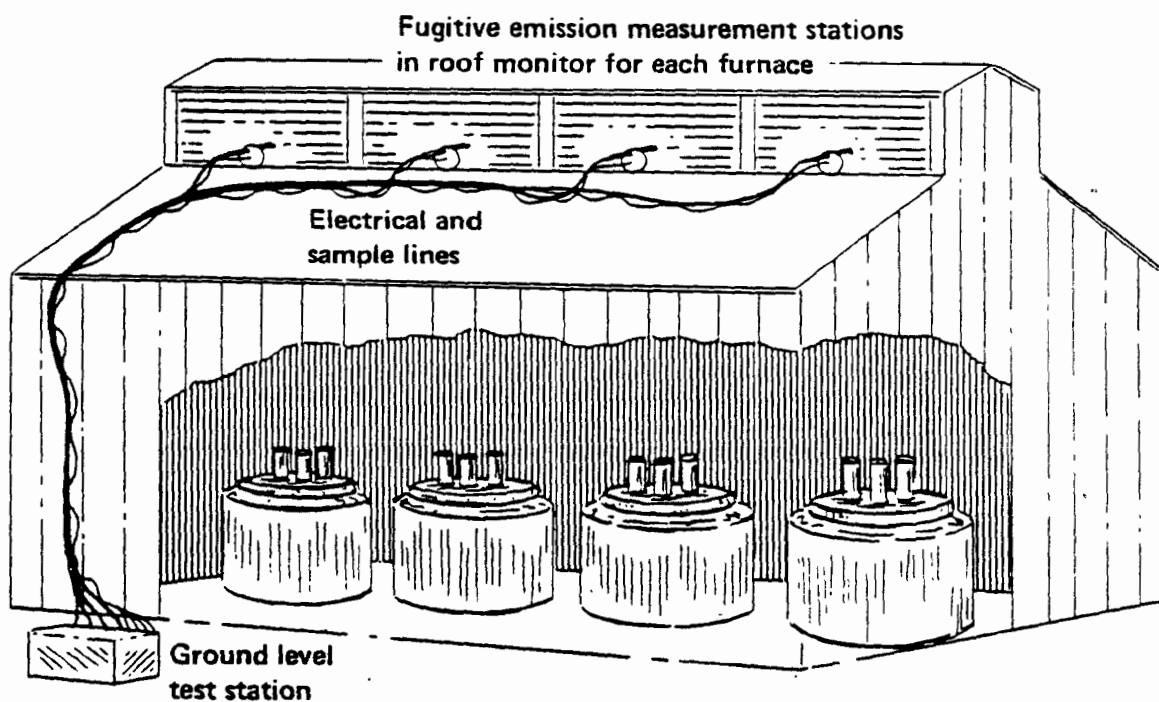


FIG. A-6 Typical detailed program site to determine the fugitive emissions from an electric furnace shop using a roof monitor technique.

where F = average air volume flow rate, cubic meters/minute

V = air velocity, meters/minute

A = roof monitor open area, square meters

τ = test duration, minutes.

V , A and τ are all directly measured values.

The particulate matter collected must be sufficient for measurement. For a high volume sampler of 18 cubic feet per minute, a desired sample weight would be 100 micrograms with a 60 minute minimum sampling time. The required concentration of particulate in the existing air would, therefore, be:

$$x = 10^{-4} \text{ (gm)}/0.5 \text{ (m}^3\text{/min)} \times 60 \text{ (minutes)}$$

$$x = 3.3 \times 10^{-6} \text{ (gm/m}^3\text{)}$$

This would be readily achieved if the particulate plume had a 10% or greater opacity.

Samples are therefore taken over a one hour or larger period and the volume of air passes through the sampler determined. Multiplication of the collected mass, by the average air flow through the roof monitor divided by the air flow through the sampler divided by the time period will give an estimate of the average emission rate in mass/time period for the total electric furnace shop in that time period. Section 3.4.3 details the calculations and how to estimate the sampling time periods.

A.5.0 DETAILED MEASUREMENT SYSTEM

To determine the total electric furnace shop emissions with some accuracy, measurements across the roof monitor of the emissions from all

of the furnaces. Figure A-6 shows such a setup for the roof monitor of a four furnace electric furnace shop. The samplers are similar to those shown in Figure 3-1. In addition, if canopy hoods are used to capture some charging and tapping emissions, they may be sampled by use of a set-up such as shown in Figure A-7.

The roof monitor sampling system must be designed to identify and quantify the electric arc furnace installation fugitive emissions by accurately measuring the air flow rate through the roof monitor while collecting samples of the emissions. The air flow rate will be determined by measuring the velocity of the air at a number of locations across the vertical plane of the monitor opening using hot-wire or rotating vane anemometers.

Sampling instruments for the measurement of the emissions will require at a minimum analyses for:

- o Carbon monoxide
- o Total suspended particulates
- o Particulate size distribution

Preferable analysis methods are:

Carbon monoxide -	non-dispersive infrared
Total particulates -	Hi-Vol or Fiberglas filters plus particulate charge count mass monitor
Particulate distribution -	Andersen Samplers or equivalent

The specific operations whose individual contributions to the total electric furnace shop fugitive emissions which can be differentiated include:

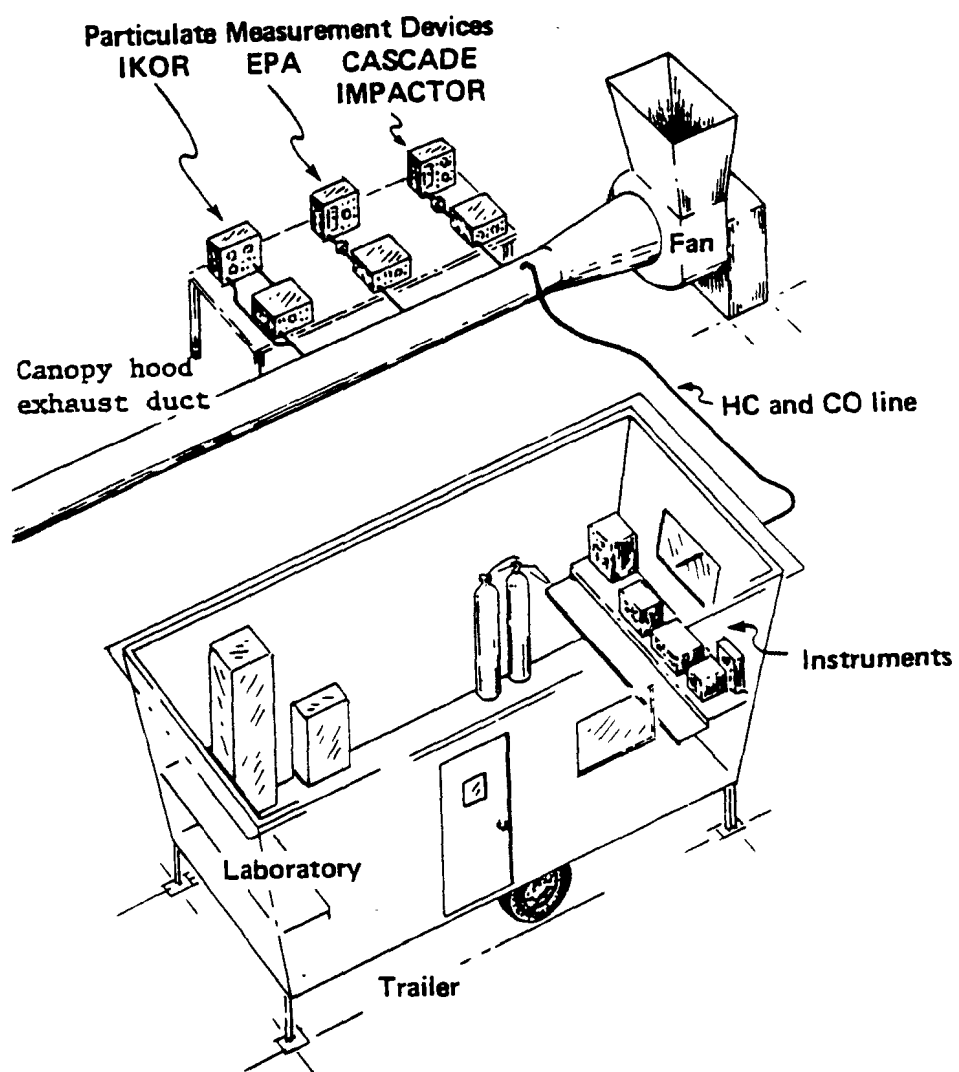


Fig. A-7. Illustration of test set-up for measuring fugitive emissions from an electric arc furnace canopy hood.

- o Charging of the hot furnace
- o Melting operations
- o Tapping and pouring

The use of continuous monitoring instrumentation permits the correlation of emission rate with the process operation to which it belongs. By monitoring the emissions for extended periods of time, meaningful average as well as instantaneous individual emission rates can thereby be obtained. Calibration of continuous traces with known concentration standards, both gaseous and particulate, is required to do this effectively.

A program designed to do this would include:

- o Continuous monitoring on a 24 hour basis of particulates and gases
- o Collection of filterable particulate matter after each total melt cycle in the furnace below each sampler
- o Continuous recording of anemometer traces on a 24 hour basis
- o Daily calibration of continuous monitors by comparison against reference standards. Calibration gases would be used for gaseous monitors and the high volume filter catch and that of the backup filter in the particle charge count mass monitor for particulate monitors.

Additional data on the emission rates of certain specific pollutants could also be obtained by use of:

- o Flame photometer continuous monitoring of sulfur gases
- o EPA Method 5 trains with condensable trains and organic emission absorber tubes to batch analyze for organics, especially carcinogens
- o Membrane type filters for collection and batch chemical/morphological analysis of specific inorganic particulate constituents such as toxic metals and free silica.

These should be at the discretion of the investigator, since they contribute more than their proportionate share to the manpower time and money investment in the fugitive emission sampling program.

A typical 4-6 week program would involve 24 hour tests on a four furnace shop, thus potentially acquiring 24 total melt cycles/day or 480 to 720 sets of data. Because of potential problems of equipment breakdown in the hot and dirty environment in which they are used, as well as the use of a 12 hour test shift (to allow use of a single well trained test crew) gives us a potential of 120 to 180 actual data sets. Each can be broken down into subsets of:

- o Furnace tested
- o Type and amount of charge used
- o Type and amount of fluxes and/or additives used
- o Portion of operating cycle involved (charge, melt, pour)
- o Data reliability and completeness

Emission factors for each part of the electric furnace melt cycle can be determined in addition to the average emission rate as determined for the survey test program. We can break down the collected mass of particulate and the flow rate as follows:

F_1 = flow rate for charge part of cycle
 M_1 = mass collected for charge part of cycle

F_2 = flow rate for melt part of cycle
 M_2 = mass collected for melt part of cycle

F_3 = flow rate for tap/pour part of cycle
 M_3 = mass collected for tap/pour part of cycle

The on-line mass monitors will be required for this. Calculations can be done as in Section 3.4.3 of each individual mass rate of emission of particulates from parts of the cycle. Similar analysis can be done for the gaseous emissions when continuous monitors are used. The result of this program would be very detailed knowledge of the fugitive emissions from a typical electric furnace melt cycle.

An additional tool to be used where better definition of exact emission sources and rates is needed is the use of in-plant tracers to simulate the sources. Gases such as SF_6 (sulfur hexafluoride) or (fluorescent dye particulates) can be released at specific points and at measured rates inside the electric furnace shop to simulate fugitive sources. These tracers are collected at the roof monitor and from the collection efficiency and concentration of collected tracer, a more accurate picture of fugitive source locations and mass rates can be determined.

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16. ABSTRACT The technical manual presents fundamental considerations that are required in using the Roof Monitor 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. Roof Monitor 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 an electric-arc furnace steelmaking plant is presented as an appendix.		
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Appendix F

Improved Emission Factors for Fugitive
Dust from Western Surface Coal Mining Sources

PEDCo-Environmental, Inc., Kansas City, MO

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Mar 84

IMPROVED EMISSION FACTORS FOR FUGITIVE DUST
FROM WESTERN SURFACE COAL MINING SOURCES

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This study was conducted in cooperation with
the U.S. Environmental Protection Agency
Region VIII Office in Denver, CO, and the
Office of Surface Mining in Washington, DC,
and Denver, CO.

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
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ABSTRACT The primary purpose of this study was to develop emission factors for significant surface coal mining operations that are applicable at Western surface coal mines and are based on state-of-the-art sampling and data analysis procedures. Primary objectives were 1) to develop emission factors for individual mining operations, in the form of equations with several correction factors to account for site-specific conditions, and 2) to develop these factors for particles less than 2.5 μm (fine particulates), particles less than 15 μm (inhalable particulates), and total suspended particulates. Secondary objectives were 1) to determine deposition rates over the 50- to 100-m distance downwind from the sources, and 2) to estimate control efficiencies for certain source categories. Emissions resulting from the following were sampled at three mines during 1979 and 1980: drilling, blasting, coal loading, bulldozing, dragline operations, haul trucks, light- and medium-duty trucks, scrapers, graders, and wind erosion of exposed areas. The primary sampling method was exposure profiling, supplemented by upwind/downwind, balloon, wind tunnel, and quasi-stack sampling. The number of tests run totaled 265.

The report concludes with a comparison of the generated emission factors with previous ones, a statement regarding their applicability to mining operations with specific caveats and collateral information which must be considered in their use and recommendations for additional research in Western and other mines.

KEY WORDS AND DOCUMENT ANALYSIS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati, (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This project involved the development of emission factors for operations at surface coal mines located in the western United States. Operations sampled included, but were not limited to, haul road traffic, scrapers, draglines, and blasts. Sampling techniques used included exposure profiling, upwind-downwind and wind tunnel testing. From this information, emission factors were developed which take into account such characteristics as soil moisture and silt content. The data presented in this study should aid both private industry and government agencies in evaluating emissions from coal mining operations. If additional information is needed, contact the Oil Shale and Energy Mining Branch of the Energy Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Since 1975 several sets of emission factors have evolved for estimating fugitive dust emission from surface coal mines. The diverse values of available emission factors, obvious sampling problems, and questions of applicability over a range of mining/meteorological conditions have undermined confidence in air quality analyses performed to date. By early 1979, these problems led to a ground swell of support, from both regulatory and mining industry personnel, for the development of new emission factors.

This study began in mid-March of 1979. The primary purpose of this study was to develop emission factors for significant surface coal mining operations that are applicable at Western surface coal mines and are based on state-of-the-art sampling and data analysis procedures. The primary objectives have been 1) to develop emission factors for individual mining operations, in the form of equations with several correction factors to account for site-specific conditions; and 2) to develop these factors in three particle size ranges--less than 2.5 μm (fine particulates), less than 15 μm (inhalable particulates), and total suspended particulates. Secondary objectives were 1) to determine deposition rates over the 50- to 100-m distance downwind from the source, and 2) to estimate control efficiencies for certain source categories.

Sampling was performed at three mines during 1979 and 1980. Emissions resulting from the following were sampled: drilling (overburden), blasting (coal and overburden), coal loading, bulldozing (coal and overburden), dragline operations, haul trucks, light- and medium-duty trucks, scrapers, graders, and wind erosion of exposed areas (overburden and coal). The primary sampling method was exposure profiling. When source configuration made it necessary, this method was supplemented by upwind/downwind, balloon, wind tunnel, and quasi-stack sampling. A total of 265 tests were run. Extensive quality assurance procedures were implemented internally for this project and were verified by audit.

Size-specific emission factors and correction parameters were developed for all sources tested. Confidence intervals and probability limits were also calculated. Additional data for determination of deposition rates were gathered, but no algorithms could be developed. Two control measures for unpaved roads were tested.

A

The report concludes with a comparison of the generated emission factors with previous ones, a statement regarding their applicability to mining operations with specific caveats and collateral information which must be considered in their use, and recommendations for additional research in Western and other mines.

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ABBREVIATIONS OF UNITS

ABBREVIATIONS

ug/m ³	micrograms per standard cubic meter
mg	milligrams
SCFM	standard cubic feet per minute
min	minutes
°C	degrees <u>c</u> elsius
in.	inches
ACFM	actual cubic feet per minute
ft	feet
ftpm	feet per minute
sftpm	standard feet per minute
cm	centimeters
m	meters
lb	pounds
VMT	vehicle miles traveled
s	seconds
° <u>k</u>	degrees <u>k</u> elvin
g	grams
yd ³	cubic yards
BTu	British Thermal Units
gal	gallons
mi	miles
CFM	cubic feet per minute
mph	miles per hour

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SECTION 1

INTRODUCTION

PRE-CONTRACT STATUS OF MINING EMISSION FACTORS

Over the past 4 or 5 years, several sets of emission factors for estimating fugitive dust emissions from surface coal mining have evolved. The first of these were primarily adaptations of published emission factors from related industries, such as construction, aggregate handling, taconite mining, and travel on unpaved roads (Monsanto Research Corporation 1975; Environmental Research and Technology 1975; PEDCo Environmental 1975; Chalekode 1975; PEDCo Environmental 1976; Wyoming Department of Environmental Quality 1976, Appendix B; U.S. Environmental Protection Agency 1977a; Colorado Department of Health 1978; Midwest Research Institute 1978).

The concept of developing emission factors by operation rather than for the entire mine has been widely accepted from the beginning. This approach recognizes the large variation in operations from mine to mine.

As demand for emission factors specifically for surface coal mining increased, some sampling studies at mines were undertaken. The first of these, sponsored by EPA Region VIII in the summer of 1977, sampled 12 operations at 5 mines in a total of 213 sampling periods (U.S. Environmental Protection Agency 1978a). Emission factors were reported by operation and mine, but no attempt was made to derive a general or "universal" emission factor equation for each operation that could be applied outside the five geographic areas where the sampling took place. Also, several problems with the upwind-downwind sampling method as employed in the study were noted in the report and by the mining industry observers. An industry-sponsored sampling study was conducted at mines in the Powder River Basin in 1978-1979. No information or proposed emission factors from that study have been released yet.

EPA Region VIII and several state agencies have evaluated the available emission factors and compiled different lists of recommended factors for use in their air quality analyses (U.S. Environmental Protection Agency 1979; Wyoming Department of Environmental Quality 1979; Colorado Department of Health 1980). Some of the alternative published emission factors vary by an order of magnitude. Part of this variance is from actual difference in average emission rates at different mines (or at different times or locations within a single mine) due to meteorological conditions, mining equipment/techniques being used, control techniques being employed, and soil characteristics.

The diverse values for available emission factors, the obvious problems encountered in sampling mining sources, and questions of applicability over a range of mining/meteorological conditions have all undermined confidence in air quality analysis done to date. These problems led to a ground swell of support from regulatory agency personnel in early 1979 for new emission factors.

The major steps in an air quality analysis for a mine are estimating the amount of emissions and modeling to predict the resulting ambient concentrations. The preamble to EPA's Prevention of Significant Deterioration (PSD) regulations notes the present inability to accurately model the impact of mines and indicates that additional research will be done. However, problems in modeling of mines have been overshadowed by concern over the emission factors. Advancement in this entire area seems to be contingent on the development of new emission factors.

PURPOSE OF STUDY

The purpose of this study is to develop emission factors for significant surface coal mining operations that are applicable at all Western mines and that are based on widely acceptable, state-of-the-art sampling and data analysis procedures. Confidence intervals are to be developed for the emission factors, based on the numbers of samples and sample variance. The present study is to be comprehensive enough so that an entire data base can be developed by consistent methods, rather than just providing some additional data to combine with an existing data base. The emission factors are to be in the form of equations with several correction factors, so values can be adjusted to more accurately may also be used as the means to combine similar emission factors (e.g., haul roads and unpaved access roads), if the data support such combinations.

The emission factors are to be generated for three size ranges of particles--less than $2.5\text{ }\mu\text{m}$ (FP), less than $15\text{ }\mu\text{m}$ (IP), and total suspended particulate (TSP). An alternative to the TSP size fraction consists of suspended particles less than $30\text{ }\mu\text{m}$ (SP); the upper size limit of $30\text{ }\mu\text{m}$ is the approximate effective cutoff diameter for capture of fugitive dust by a standard high volume particulate sampler (Wedding 1980).

Definition of particle sizes is important for at least three reasons: deposition rates in dispersion models are a function of particle size; EPA may promulgate size-specific ambient air quality standards in the near future; and visibility analyses require information on particle size distribution.

The study is also intended to determine deposition (or plume depletion) rates over the 50 to 100 m distance immediately downwind of the sources. Although it is recognized that deposition continues to be significant for distances of a few kilometers, a large percentage of the fallout occurs in the first 100 m and estimates of the additional deposition can be made more accurately from particle size sampling data than from measurements associated with the emission factor development.

A secondary purpose is to estimate the efficiencies of commonly used dust control techniques at mines, such as watering and chemical stabilization of haul roads. This aspect of the study received less emphasis as the study progressed as better information indicated that more test periods than originally anticipated would be needed to determine the basic emission factors with a reasonable margin of error.

The study was designed and carried out with special effort to encourage input and participation by most of the expected major users of mining emission factors. The intent was to obtain suggestions for changes and additions prior to developing the emission factors than criticism of the techniques and scope of the study afterward.

TECHNICAL REVIEW GROUP FOR THE STUDY

Participants

EPA's Office of Air Quality Planning and Standards (OAQPS) took the initial lead in planning for a study to develop new emission factors. Their staff became aware of the amount of concern surrounding the available mining factors when they considered including surface mining as a major source category under proposed regulations for Prevention of Significant Deterioration.

EPA Region VIII Office, which had directed the first fugitive dust sampling study at surface mines and published a compilation of recommended mining emission factors, immediately encouraged such a study and offered to provide partial funding. The newly created Office of Surface Mining (OSM) in the Department of Interior also offered support and funding. At that time, OS, had just proposed regulations pursuant to the Surface Mining Control and Reclamation Act (SMCRA) requiring air quality analyses for Western mines of greater than 1,000,000 tons/yr production (this requirement was dropped in the final regulations).

EPA's Industrial Environmental Research Laboratory (IERL) soon became involved as a result of its responsibilities for the agency's research studies on mining. This group already had planned some contract work on

fugitive dust emissions from surface coal mines in its FY/1979 budget, so its staff assumed the lead in contractual matters related to the study.

All the early participants agreed that even broader representation would be desirable in the technical planning and guidance for the study. Therefore, a technical review group was established at the outset of the study to make recommendations on study design, conduct, and analysis of results. The agencies and organizations represented on the technical review group are shown in Table 1-1. This group received draft materials for comment and met periodically throughout the study. Other groups that expressed an interest in the study were provided an opportunity to comment on the draft report.

Study Design

The study design was the most important component of the study from many perspectives. It was the primary point at which participants could present their preferred approaches. The design also had to address the problems that had plagued previous sampling studies at mines and attempt to resolve them. Most of the decision making in the study was done during this phase.

The first draft of the study design report was equivalent to a detailed initial proposal by the contractors, with the technical review group then having latitude to suggest modifications or different approaches. The rationales for most of the design specifications were documented in the report so members of the technical review group would also have access to the progression of thinking leading to recommendations.

The scope of the full study was not fixed by contract prior to the design phase. Some of the options left open throughout the design phase were number of mines, geographical areas, different mining operations, and the seasonal range to be sampled. In some cases, the final decision on recommended sampling methods was left to the results of comparative testing--alternative methods were both used initially until the results could be evaluated and the better method retained.

Several major changes were made from the first draft to the third (final) draft of the study design. These changes are summarized in Section 3. In addition, requests were made for in-depth analyses on particular aspects of the study design that were responded to in separate reports. Specifically, the separate reports and their release dates were:

Error Analysis for Exposure Profiling	October 1979
Error Analysis for Upwind-Downwind Sampling	October 1979

TABLE 1-1. TECHNICAL REVIEW GROUP FOR MINING STUDY

Organization	Representative	Alternate
Bureau of Land Management	Stan Coloff	
Bureau of Mines (U.S.)	H. William Zeller	
Consolidation Coal Company	Richard Kerch	
Department of Energy, Policy Analysis Division	Suzanne Wellborn	Bob Kane
Environmental Protection Agency Industrial Environmental Research Lab. Monitoring and Data Analysis Division Region VIII Source Receptor Analysis Branch	Jonathan Herrmann Thompson Pace E. A. Rachal James Dicke	J. Southerland David Joseph Edward Burt
Forest Service, U.S. Department of Agriculture	Douglas Fox	
National Coal Association	Charles T. Drevna	
National Park Service	Phil Wondra	J. Christian
New Mexico Citizens for Clean Air and Water	Michael D. Williams	
North American Coal Corporation	Bruce Kranz	
Office of Surface Mining Headquarters Region V	Robert Goldberg Floyd Johnson	
Peabody Coal Company	Steven Vardiman	
Wyoming Department of Environmental Quality	Randolph Wood	Chuck Collins

Quality Assurance Procedures	October 1979
Example Calculations for Exposure Profiling	November 1979
Calculations Procedures for Upwind-Downwind Sampling Method	October 1979
Statistical Plan	November 1979
Statistica Plan, Second Draft	May 1980

The above reports were being prepared while sampling proceeded at the first two mines. The contents of these reports are summarized in this report in appropriate sections.

CONTENTS AND ORGANIZATION OF THIS REPORT

This report contains 16 sections and is bound in one volume. The first five sections describe the methodologies used in the study; e.g., sampling (Section 3), the sample analysis (Section 4), and data analysis (Section 5). Sections 6 through 11 present results of the various sampling efforts.

Sections 12 through 15 describe the evaluation and interpretation of results and the development of emission factor equations. The specific topics covered by section are:

- 12 Evaluation of Results
- 13 Development of Correction Factors and Emission Factor Equations
- 14 Evaluation of Emission Factors
- 15 Summary and Conclusions

Section 16 is the list of references.

SECTION 2

SELECTION OF MINES AND OPERATIONS TO BE SAMPLED

GEOGRAPHICAL AREAS OF MOST CONCERN

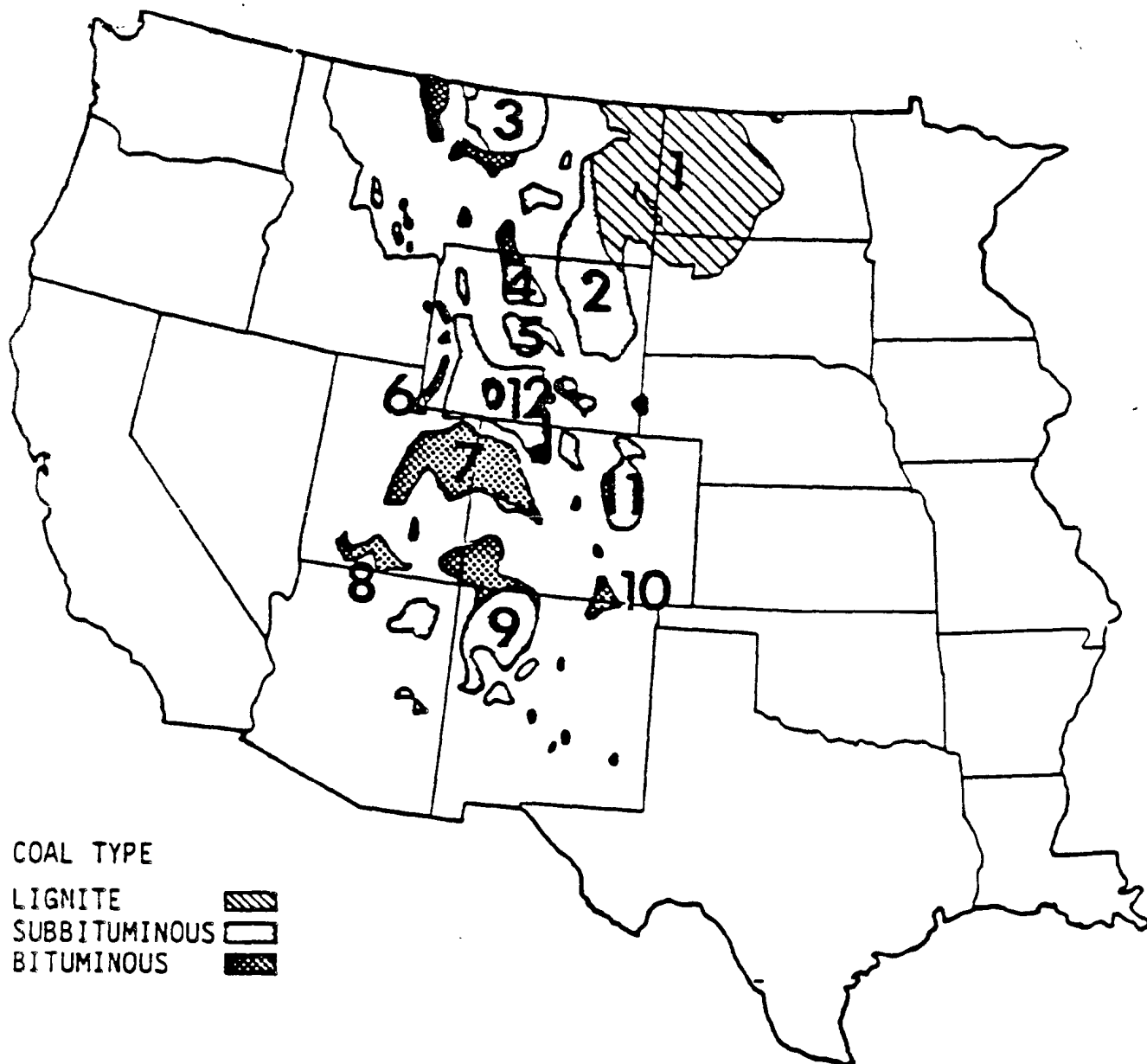
The contract for this study specified that sampling be done at Western surface coal mines. As a result of comments and recommendations made by members of the technical review group during the study design preparation, this restriction in scope was reviewed by the sponsoring agencies. The decision was made to continue focusing the study on Western mines for at least three reasons:

1. The Western areas are more arid than Eastern or Midwestern coal mining regions, leading to a greater potential for excessive fugitive dust emissions.
2. Western mines in general have larger production rates and therefore would be larger individual emission sources.
3. Most of the new mines, subject to analyses for environmental impacts, are in the West.




The need for emission factors for Eastern and Midwestern surface mines is certainly acknowledged. Consequently, an effort was made in the present study to produce emission factors that are applicable over a wide range of climatic and mining conditions.

There are 12 major coal fields in the Western states (excluding the Pacific Coast and Alaskan fields), as shown in Figure 2-1. Together, they account for more than 64 percent of the surface-mineable coal reserves in the U.S. (U.S. Bureau of Mines 1977). The 12 coal fields have different characteristics which may influence fugitive dust emission rates from mining operations, such as:

- Overburden and coal seam thickness and structure
- Mining equipment commonly used
- Operating procedures
- Terrain
- Vegetation
- Precipitation and surface moisture
- Wind speeds
- Temperatures



COAL TYPE

LIGNITE 
 SUBBITUMINOUS 
 BITUMINOUS 

<u>Coal field</u>		<u>1978 production, 10⁶ tons</u>	<u>Strippable reserves, 10⁶ tons</u>
1	Fort Union	14	23,529
2	Powder River	62	56,727
3	North Central	-	all underground
4	Bighorn Basin	-	all underground
5	Wind River	neg	3
6	Hams Fork	5	1,000
7	Uinta	2	308
8	Southwestern Utah	-	224
9	San Juan River	22	2,318
10	Raton Mesa	-	all underground
11	Denver	-	all underground
12	Green River	24	2,120

(Reference: U.S. DOE, Energy Information Administration. Bituminous Coal and Lignite Production and Mine Ops.-1978. Publication No. DOE/EIA-0118(78). Washington, D.C. June 1980.)

Figure 2-1. Coal fields of the Western U.S.

Mines in all 12 Western coal fields could not be sampled in this study. The dual objectives of the emission factor development program were to sample representative, rather than extreme, emission rates and yet sample over a wide range of meteorological and mining conditions so that the effects of these variables on emission rates could also be determined. Therefore, diversity was desired in the selection of mines (in different coal fields) for sampling.

No formal system was developed for quantifying the diversity between the Western fields. Instead, three fields with high production from surface mines and distinctly different characteristics were identified by the project participants: Fort Union (lignite), Powder River Basin, and San Juan River. Sampling at mines in each of these fields was to be the first priority. If sampling in a fourth field were possible or a suitable mine could not be located in one of the three primary areas, the Green River field was the next choice.

SIGNIFICANT DUST-PRODUCING OPERATIONS

All of the mining operations that involve movement of soil, coal, or equipment or exposure of erodible surfaces generate some amount of fugitive dust. Before a sampling program could be designed, it was first necessary to identify which of the many emission-producing operations at the mines would be sampled.

The operations at a typical Western surface mine are shown schematically in Figure 2-2. The initial mining operation is removal of topsoil and subsoil with large scrapers. The topsoil is carried by the scrapers to cover a previously mined and regraded area (as part of the reclamation process) or placed in temporary stockpiles. The exposed overburden is then leveled, drilled, and blasted. Next, the overburden material is removed down to the coal seam, usually by dragline or shovel and truck operation. It is placed in the adjacent mined cut and forms a spoils pile. The uncovered coal seam is then drilled and blasted. A shovel or front-end loader loads the broken coal into haul trucks. The coal is transported out of the pit along graded haul roads to the tippie, or truck dump. The raw coal may also be dumped on a temporary storage pile and later rehandled by a front-end loader or dozer.

At the tippie, the coal is dumped into a hopper that feeds the primary crusher. It is then moved by conveyor through additional coal preparation equipment, such as secondary crushers and screens, to the storage area. If the mine has open storage piles, the crushed coal passes through a coal stacker onto the pile. The piles are usually worked by dozers, and are subject to wind erosion. From the storage area, the coal is conveyed to the train loading facility and loaded onto rail cars. If the mine is captive, coal goes from the storage pile to the power plant.

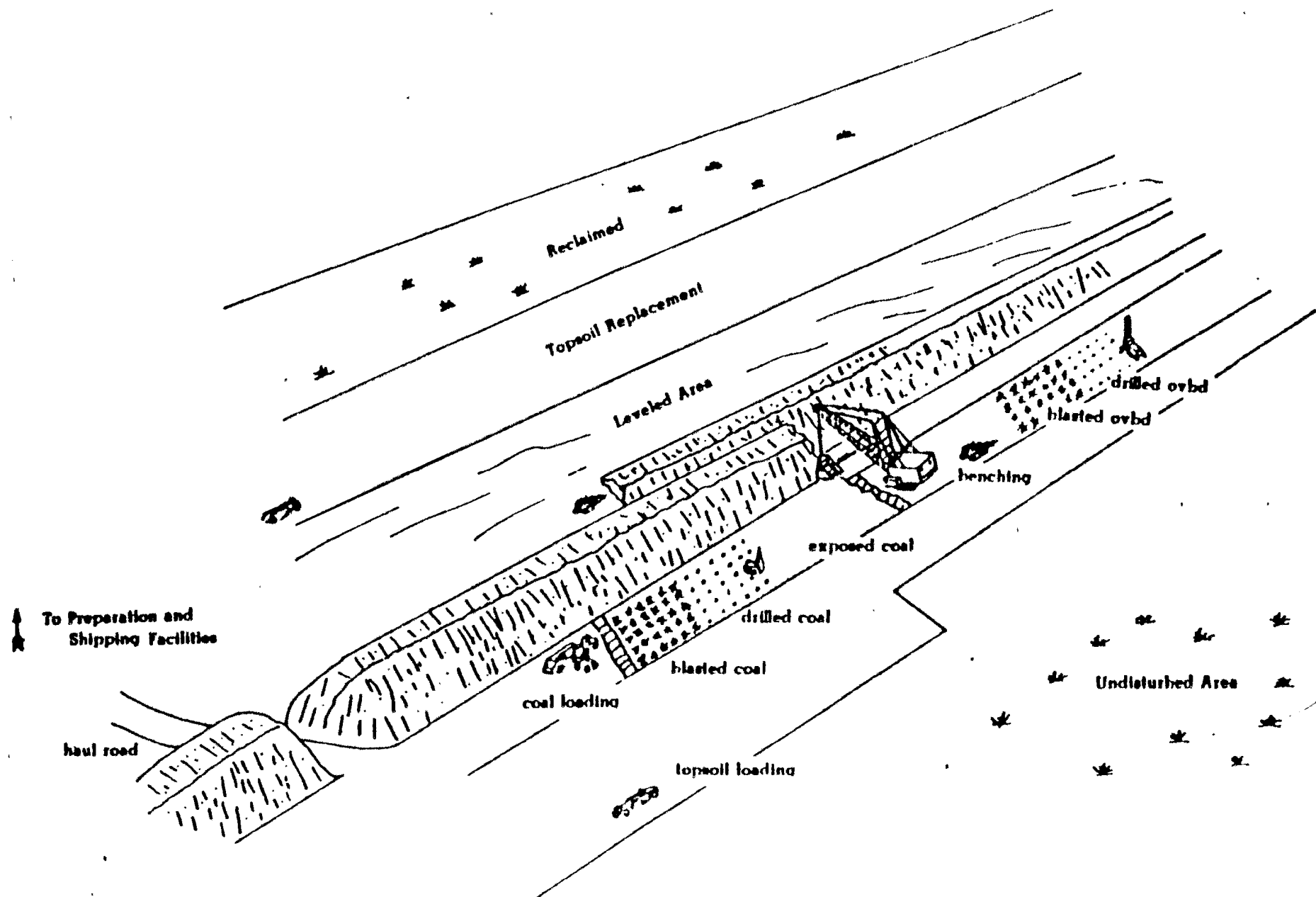


Figure 2-2. Operations at typical western surface coal mines.

During mine reclamation, which proceeds continuously throughout the life of the mine, overburden spoils piles are smoother and shaped to predetermined contours by dozers. Topsoil is placed on the graded spoils and the land is prepared for revegetation by furrowing, mulching, etc. From the time an area is disturbed until the new vegetation emerges, the exposed surfaces are subject to wind erosion.

These operations could not be ranked directly in order of their impact on particulate air quality because reliable emission factors to estimate their emissions do not exist. Also, any specific mine would probably not have the same operations as the typical mine described above, and the relative magnitudes of the operations vary greatly from mine to mine (e.g., the average haul distance from the pit to the tipple).

In the study design phase, two different analyses were done to evaluate the relative impacts of the emission sources (PEDCo Environmental and Midwest Research Institute 1979). In the first analysis, several alternative emission factors reported in the literature were used to calculate estimated emissions from a hypothetical mine having all the possible mining sources described above. The second analysis used a single set of emission factors, judged to be the best available for each source, combined with activity data from seven actual surface mines in Wyoming and Colorado. The resulting rankings from the two analyses were similar. The ranges of percentages of total mine emissions estimated by the two analyses are summarized in Table 2-1. The sources are listed in the table in order of decreasing estimated contribution.

A one percent contribution to total mine emissions was used in the study design to separate significant sources, for which sampling would be performed, from insignificant sources. There were only a few sources for which classification was questionable: draglines and wind erosion of storage piles. This conflict arose because one analysis showed them to be insignificant and the other indicated they were significant. Because these operations are integral parts of most mine operations and there was a wide disparity between alternative emission factors, they were both included as significant sources to be sampled.

The ranking was also considered in determining the number of tests for each source--more tests were allocated to sources predicted to be the major contributors.

TABLE 2-1. DETERMINATION OF SIGNIFICANT DUST-PRODUCING OPERATIONS

Operation	Primary emission composition	Range in % total mir emission
<u>Significant sources</u>		
Haul truck	soil	18-85
Light and medium duty vehicles (unpaved access roads)	soil	<1-27
Shovel/truck loading, ovb overburden	soil	4-12
Shovel/truck loading, coal	coal	<1-11
Dozer operations	either	4-11
Wind erosion of exposed areas	soil	<1-10
Scraper travel	soil	<1- 8
Blasting, ovb overburden	soil	<1- 5
Blasting, coal	coal	<1- 4
Drilling, ovb overburden	soil	<1- 4
Front-end loader	coal	1- 3
Grader	soil	1- 3
Dragline	soil	<1- 2
Wind erosion of storage piles	coal	<1- 2
<u>Insignificant sources</u>		
Truck dumping, ovb overburden	soil	<1
Truck dumping, coal	coal	<1
Scraper pickup	soil	<1
Scraper spreading	soil	<1
Coal stacker	coal	<1
Train loading	coal	<1
Enclosed storage loading	coal	<1
Transfer/conveying	coal	<1
Vehicle traffic on paved roads	soil	<1
Crushing, primary	coal	<1
Crushing, secondary	coal	<1
Screening and sizing	coal	<1
Drilling, coal	coal	<1

POTENTIAL MINES FOR SAMPLING

The number of mines to be sampled was set at three in the study design. This was based on a compromise between sampling over the widest range of mine/meteorological conditions by visiting a large number of mines and obtaining the most tests within the budget and time limits by sampling at only a few mines. The criteria for selection of appropriate mines were quite simple:

1. The three mines should have the geographical distribution described above, i.e., one each in the Fort Union, Powder River Basin, and San Juan River fields.
2. Each mine should have all or almost all of the 14 significant dust-producing operations listed in Table 2-1.
3. The mine personnel should be willing to cooperate in the study and provide access to all operations for sampling.
4. The mines should be relatively large so that there are several choices of locations for sampling each of the operations.

Using their industry contacts, the National Coal Association (NCA) members did preliminary screening to find appropriate mines and made contacts to determine whether suitable mines were interested in participating in the sampling program.

The three mines finally selected were each obtained in a different manner. The first, in the Powder River Basin, volunteered before any contacts were made with mining companies. The second mine was operated by a company with a representative on the technical review group. This mine was in the Fort Union field in North Dakota. By coincidence, these first two mines were among the five where sampling had been done in the previous EPA-sponsored emission factor development study (EPA 1978a).

Several mines in the San Juan River field were contacted by NCA and by PEDCo to participate. After failing to obtain a volunteer, provisions of the Clean Air Act were invoked to obtain access. Personnel at the third mine cooperated fully with the sampling teams and were very helpful.

The names of the three mines are not mentioned in this report. Pertinent information on the three mines is summarized in Table 2-2.

TABLE 2-2. CHARACTERISTICS OF MINES THAT WERE SAMPLED

Parameter	Units	Mine 1	Mine 2	Mine 3
Location		Powder River Basin	North Dakota	Four Corners
Production	10 ⁶ tons	9-12	1-4	5-8
Stratigraphic data				
Typical overburden depth	ft	75	35	80
Typical coal seam thickness	ft	23	2, 4, 9	8
Typical parting thickness	ft	-	2, 15, 30	35
Typical pit depth	ft	98	80	145
Av overburden density	lb/yd ³	3000	3350	5211
Operating data				
No. of active pits	-	3	2	7
Typical haul distance (one way)	mi	1.6	3.5	2.5
Av storage pile size	10 ³ tons	72	15	300
Equipment				
Draglines	No.; yd ³	3; 60	2; 33, 65	4; 38-64
Shovels	No.; yd ³	4; 17, 24	2; 15	1; 12
Front-end loaders	No.; yd ³	4; 5-12.5	1; 12	6; 23.5
Haul trucks	No.; tons	13; 100, 120	6; 170	11; 120, 150
Water trucks	No.; 10 ³ gal	5; 8, 10	3; 1, 8	2; 24
Scrapers	No.; yd ³	6; 22	12; 33, 40	3; 34
Dozers	No.	9	8	9
Av coal analysis data				
Heat value	Btu/lb	8600	10600	7750
Sulfur content	%	0.8	0.75	0.75
Moisture content	%	25	37	13

Information in this table provided by respective mining companies.

SCHEDULE

A task order was issued in mid-March, 1979, to prepare a preliminary study design for development of surface coal mining emission factors. The time period for the task order was 8 weeks (to mid-May). If the resulting sampling methods and analytical approach were acceptable to the sponsoring agencies and the technical review group being convened to guide the study and assure its wide applicability, another contract to perform the sampling and data analysis was to follow immediately so that field work could be completed during the summer and fall of 1979.

The first mine was sampled on schedule, from July 23 through August 24, 1979. However, delays in obtaining approval to sample at a second mine; requests for further documentation of calculation procedures, error analyses, and quality assurance procedures; and preparation of a detailed statistical plan caused a slip in the schedule at this point. The second mine was sampled from October 10 through November 1, 1979, precluding a sampling period at a third mine during the dusty season. The winter sampling at the first mine took place from December 4 through 13, 1979.

Sampling at the third mine, rescheduled for the spring of 1980, was postponed on several occasions for such reasons as: lapse of the primary contract with the need to find an alternative contracting mechanism; unresolved issues regarding the statistical approach; and need for several contacts to gain access to a mine for the sampling. The third mine was finally sampled from July 21 to August 14, 1980.

The actual schedule for the study is shown in chart form in Figure 2-3. The distribution of sampling periods by season should be noted. Two occurred during July-August, when emission rates would be expected to be near their maximum. One of these mines was also sampled in December, when fugitive dust rates would normally be relatively low in the Powder River Basin. The fourth sampling period was in October, a season during which potential for dust generation would be near the annual average.

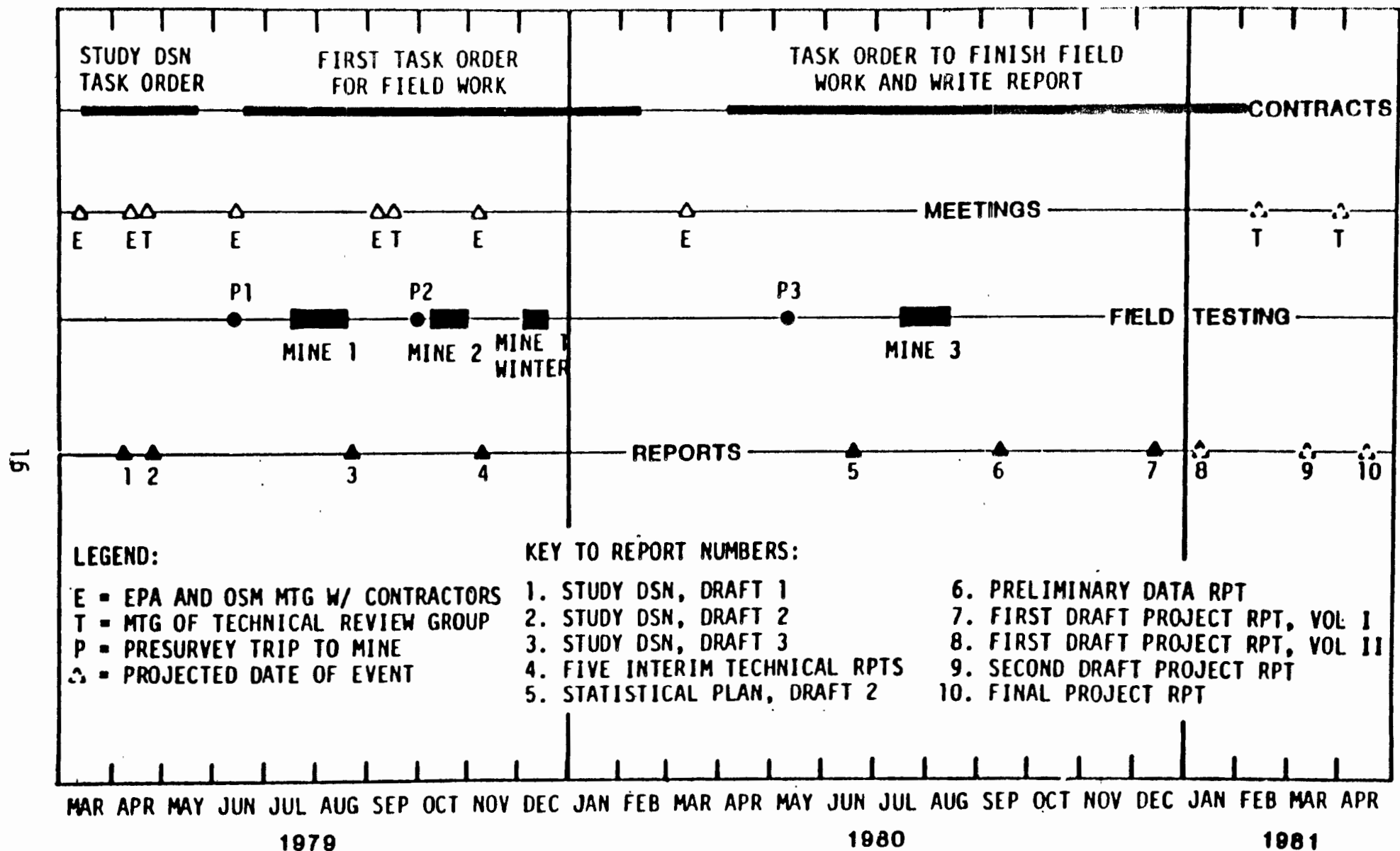


Figure 2-3. Schedule for coal mining emission factor development study.

SECTION 3

SAMPLING METHODOLOGY

TECHNIQUES AVAILABLE TO SAMPLE FUGITIVE DUST EMISSIONS

Five basic techniques have been used to measure fugitive dust emissions. These are quasi-stack, roof monitor, exposure profiling, upwind-downwind and wind tunnel. Several experimental sampling methods are in developmental stages.

In the quasi-stack method of sampling, the emissions from a well-defined process are captured in a temporary enclosure and vented to a duct or stack of regular cross-sectional area. The emission concentration and the flow rate of the air stream in the duct are measured using standard stack sampling or other conventional methods.

Roof monitor sampling is used to measure fugitive emissions entering the ambient air from buildings or other enclosure openings. This type of sampling is applicable to roof vents, doors, windows, or numerous other openings located in such fashion that they prevent the installation of temporary enclosures.

The exposure profiling technique employs a single profile tower with multiple sampling heads to perform simultaneous multi-point isokinetic sampling over the plume cross-section. The profiling tower is 4 to 6 meters in height and is located downwind and as close to the source as possible (usually 5 meters). This method uses monitors located directly upwind to determine the background contribution. A modification of this technique employs balloon-suspended samplers.

With the upwind-downwind technique, an array of samplers is set up both upwind and downwind of the source. The source contribution is determined to be the difference between the upwind and downwind concentrations. The resulting contribution is then used in standard dispersion equations to back-calculate the source strength.

The wind tunnel method utilizes a portable wind tunnel with an open-floored test section placed directly over the surface to be tested. Air is drawn through the tunnel at controlled velocities. A probe is located at the end of the test section and the air is drawn through a sampling train.

Several sampling methods using new sampling equipment or sampling arrays are in various stages of development. These include tracer studies, lidar, acoustic radar, photometers, quartz crystal impactors, etc.

SELECTION OF SAMPLING METHODS

Each of the five basic techniques used to measure fugitive dust emissions has inherent advantages, disadvantages, and limitations to its use.

The quasi-stack method is the most accurate of the airborne fugitive emission sampling techniques because it captures virtually all of the emissions from a given source and conveys them to a measurement location with minimal dilution (Kalika et al. 1976). Its use is restricted to emission sources that can be isolated and are arranged to permit the capture of the emissions. There are no reported uses of this technique for sampling open sources at mines.

The roof monitor method is not as accurate as the quasi-stack method because a significant portion of the emissions escape through other openings and a higher degree of dilution occurs before measurement. This method can be used to measure many indoor sources where emissions are released to the ambient air at low air velocities through large openings. With the exception of the preparation plant and enclosed storage, none of the sources at mines occur within buildings.

The exposure profiling technique is applicable to sources where the ground-based profiler tower can be located vertically across the plume and where the distance from the source to the profiling tower can remain fixed at about 5 meters. This limits application to point sources and line sources. An example of a line source that can be sampled with this technique is haul trucks operating on a haul road. Sources such as draglines cannot be sampled using this technique because the source works in a general area (distance between source and tower cannot be fixed), and because of sampling equipment and personnel safety.

The upwind-downwind method is the least accurate of the methods described because only a small portion of the emissions are captured in the highly diluted transport air stream (Kalika et al. 1976). It is, however, a universally applicable method. It can be used to quantify emissions from a variety of sources where the requirements of exposure profiling cannot be met.

The wind tunnel method has been used to measure wind erosion of soil surfaces and coal piles (Gillette 1978; Cowherd et al. 1979). It offers the advantages of measurement of wind erosion under controlled wind conditions. The flow field in the tunnel has been shown to adequately

simulate the properties of ambient winds which entrain particles from erodible surfaces (Gillette 1978).

Experimental sampling methods present at least three problems for coal mine applications. First, none have been used in coal mines to date. Second, they are still in experimental stages, so considerable time would be required for testing and development of standard operating procedures. Third, the per sample costs would be considerably higher than for currently available sampling techniques, thus reducing the number of samples that could be obtained. Therefore, these techniques were not considered applicable methods for this study.

After review of the inherent advantages, disadvantages and limitations of each of the five basic sampling techniques, the basic task was to determine which sampling method was most applicable to the specific sources to be sampled, and whether that method could be adapted to meet the multiple objectives of the study and the practical constraints of sampling in a surface coal mine.

Drilling was the only source which could be sampled with the quasi-stack method. No roof monitor sampling could be performed because none of the sources to be sampled occurs within a building. It was decided that the primary sampling method of the study would be exposure profiling. The decision was based primarily on the theoretically greater accuracy of the profiling technique as opposed to upwind-downwind sampling and its previous use in similar applications. Where the constraints of exposure profiling could not be met (point sources with too large a cross-sectional area), upwind-downwind would be used. The wind tunnel would be used for wind erosion sampling.

SAMPLING CONFIGURATIONS

Basic Configuration

Exposure Profiling--

Source strength--The exposure profiler consisted of a portable tower, 4 to 6 m in height, supporting an array of sampling heads. Each sampling head was operated as an isokinetic exposure sampler. The air flow stream passed through a settling chamber (trapping particles larger than about 50 μ m in diameter), and then flowed upward through a standard 8 in. x 10 in. glass fiber filter positioned horizontally. Sampling intakes were pointed into the wind, and the sampling velocity of each intake was adjusted to match the local mean wind speed as determined prior to each test. Throughout each test, wind speed was monitored by recording anemometers at two heights, and the vertical wind speed profile was determined by assuming a logarithmic distribution. This distribution

has been found to describe surface winds under neutral atmospheric stability, and is a good approximation for other stability classes over the short vertical distances separating the profiler samplers (Cowherd, Axetell, Guenther, and Jutze 1974). Sampling time was adequate to provide sufficient particulate mass (≤ 10 mg) and to average over several units of cyclic fluctuation in the emission rate (e.g., vehicle passes on an unpaved road). A diagram of the profiling tower appears in Figure 3-1.

The devices used in the exposure profiling tests to measure concentrations and/or fluxes of airborne particulate matter are listed in Table 3-1. Note that only the (isokinetic) profiling samplers directly measure particulate exposure (mass per unit intake area) as well as particulate concentration (mass per unit volume). However, in the case of the other sampling devices, exposure may be calculated as the product of concentration, mean wind speed at the height of the sampler intake, and sampling time.

Two deployments of sampling equipment were used in this study: the basic deployment described in Table 3-2 and the special deployment shown in Table 3-3 for the comparability study.

Particle size-- Two Sierra dichotomous samplers, a standard hi-vol, and a Sierra cascade impactor were used to measure particle sizes downwind. The dichotomous samplers collected fine and coarse fractions with upper cut points (50 percent efficiency) of $2.5 \mu\text{m}$ and approximately $15 \mu\text{m}$. (Adjustments for wind speed sensitivity of the $15 \mu\text{m}$ cut point are discussed in Section 5; limitations of this sampling technique are described in Section 12.

The high-volume parallel-slot cascade impactor with a 20 cfm flow controller was equipped with a Sierra cyclone preseparator to remove coarse particles that otherwise would tend to bounce off the glass fiber impaction substrates. The bounce-through of coarse particles produces an excess of catch on the backup filter. This results in a positive bias in the measurement of fine particles (see Page 6-3). The cyclone sampling intake was directed into the wind and the sampling velocity adjusted to mean wind speed by fitting the intake with a nozzle of appropriate size, resulting in isokinetic sampling for wind speeds ranging from 5 to 15 mph.

Deposition-- Particle deposition was measured by placing dustfall buckets along a line downwind of the source at distances of 5 m, 20 m, and 50 m from the source. Greater distances would have been desirable for establishing the deposition curve, but measureable weights of dustfall could not be obtained beyond about 50 m during the 1-hour test periods. Dustfall buckets were collocated at each distance. The bucket openings were located 0.75 m above ground to avoid the impact of saltating particles generated by wind erosion downwind of the source.

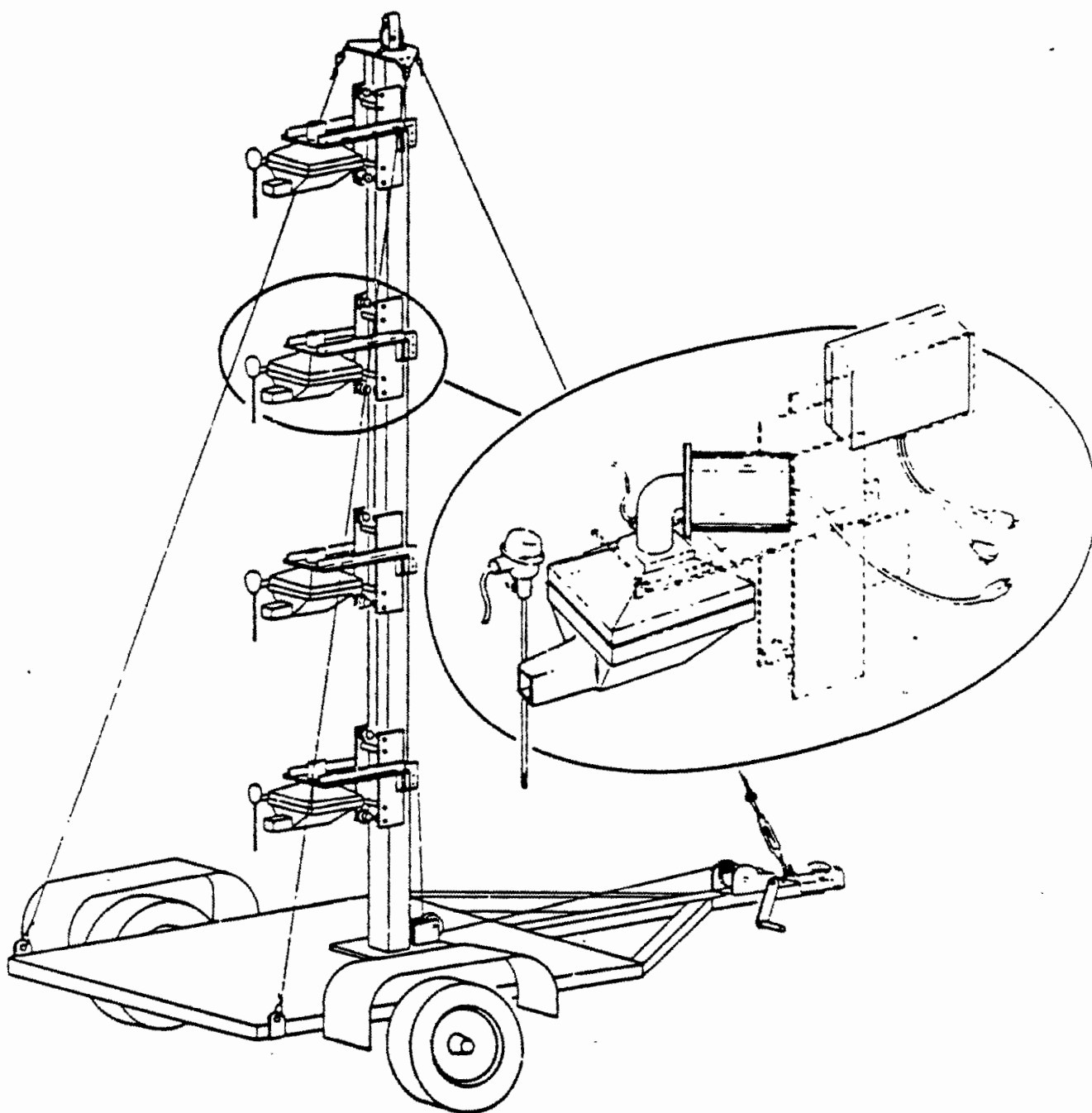


Figure 3-1. Exposure profiler.

**TABLE 3-1. SAMPLING DEVICES FOR ATMOSPHERIC
PARTICULATE MATTER--EXPOSURE PROFILING**

Particulate matter category ^a	Air sampling device			
	Type	Quantity measured	Operating flow rate	Flow Calibrator
TP	Exposure profiler head	Exposure and concentration	Variable (10-50 SCFM) to achieve iso- kinetic sampling	Anemometer calibra- tor
	Cyclone with inter- changeable probe tips and backup filter	Exposure and concentration	20 ACFM	Orifice cal- ibrator
TSP	Standard hi-vol	Concentration	40-60 ACFM	Orifice cal- ibrator
IP	Dichotomous sampler	Concentration	0.59 ACFM	Dry test meter
FP	Dichotomous sampler	Concentration	0.59 ACFM	Dry test meter

- ^a TP = Total particulate = All particulate matter in plume
TSP = Total suspended particulate = Particulate matter in size range collected
by hi-vol, estimated to be less than about
30 μ m diameter
IP = Inhalable particulate = Particulate less than 15 μ m diameter
FP = Fine particulate = Particulate less than 2.5 μ m diameter

TABLE 3-2. BASIC EQUIPMENT DEPLOYMENT FOR EXPOSURE PROFILING

Location	Distance from Source (m)	Equipment	Intake Height (m) ^a
wind	5	1 Dichotomous sampler	2.5
		1 Standard hi-vol	2.5
		2 Dustfall buckets	0.75
		1 Continuous wind monitor	4.0
wnwind	5-10	1 MRI exposure profiler with 4 sampling heads	1.5 (1.0)
			3.0 (2.0)
			4.5 (3.0)
			6.0 (4.0)
		1 Standard hi-vol	2.5 (2.0)
		1 Hi-vol with cascade impactor	2.5 (2.0)
		2 Dichotomous samplers	1.5
			4.5 (3.0)
		2 Dustfall buckets	0.75
		2 Warm wire anemometers	1.5 (1.0)
			4.5 (3.0)
wnwind	20	2 Dustfall buckets	0.75
wnwind	50	2 Dustfall buckets	0.75

Alternative heights for sources generating lower plume heights are given in parentheses.

TABLE 3-3. SPECIAL EQUIPMENT DEPLOYMENT FOR EXPOSURE
PROFILING--COMPARABILITY TESTS

Location	Distance from Source (m)	Equipment	Intake Height (m)
Upwind	5 to 10	1 Standard hi-vol 1 Standard hi-vol 2 Dustfall buckets 1 Continuous wind monitor	1.25 2.5 0.75 4.0
Downwind	5	1 MRI exposure profiler with 4 sampling heads 1 Standard hi-vol 2 Hi-vols with cascade impactors 4 Dichotomous samplers 2 Dustfall buckets 2 Warm wire anemometers	1.5 3.0 4.5 6.0 2.5 1.5 1.5 3.0 4.5 6.0 0.75 1.5 4.5
Downwind	20	1 Hi-vol with cascade impactor 2 Dustfall buckets	2.5 0.75
Downwind	50	2 Dustfall buckets	0.75

Exposure Profiling Modification for Sampling Blasts--

Source strength-- The exposure profiler concept was modified for sampling blasts. The large horizontal and vertical dimensions of the plumes necessitated a suspended array of samplers as well as ground-based samplers in order to sampler over the plume cross-section in two dimensions. Five 47 mm PVC filter heads and sampling orifices were attached to a line suspended from a tethered balloon. The samplers were located at five heights with the highest at 30.5 m (2.5, 7.6, 15.2, 22.9, and 30.5 m). Each sampler was attached to a wind vane so that the orifices would face directly into the wind. The samplers were connected to a ground based pump with flexible tubing. The pump maintained an isokinetic flow rate for a wind speed of 5 mph. In order to avoid equipment damage from the blast debris and to obtain a representative sample of the plume, the balloon-suspended samplers were located about 100 m downwind of the blast area. This distance varied depending on the size of the blast and physical constraints. The distance was measured with a tape measure. The balloon-supported samplers were supplemented with five hi-vol/dichot pairs located on an arc, at the same distance as the balloon from the edge of the blast area. These were spaced 20 m apart on the arc.

Particle size-- The five ground-based dichotomous samplers provided the basic particle size information.

Deposition--There was no measurement of deposition with this sampling method. Dustfall samples would have been biased by falling debris from the blast.

Upwind-Downwind--

Source strength-- The total upwind-downwind array used for sampling point sources included 15 samplers, of which 10 were hi-vols and 5 were dichotomous samplers. The arrangement is shown schematically in Figure 3-2. The downwind distances of the samplers from point sources were nominally 30 m, 60 m, 100 m, and 200 m. Frequently, distances in the array had to be modified because of physical obstructions (e.g., highwall) or potential interfering sources. A tape measure was used to measure source-to-sampler distances. The upwind samplers were placed 30 to 100 m upwind, depending on accessibility. The hi-vol and dichotomous samplers were mounted on tripod stands at a height of 2.5 m. This was the highest manageable height for this type of rapid-mount stand.

This array was modified slightly with sampling line sources. The array consisted of two hi-vol/dichot pairs at 5 m, 20 m, and 50 m with 2 hi-vols at 100 m. The two rows of samplers were normally separated by 20 m.

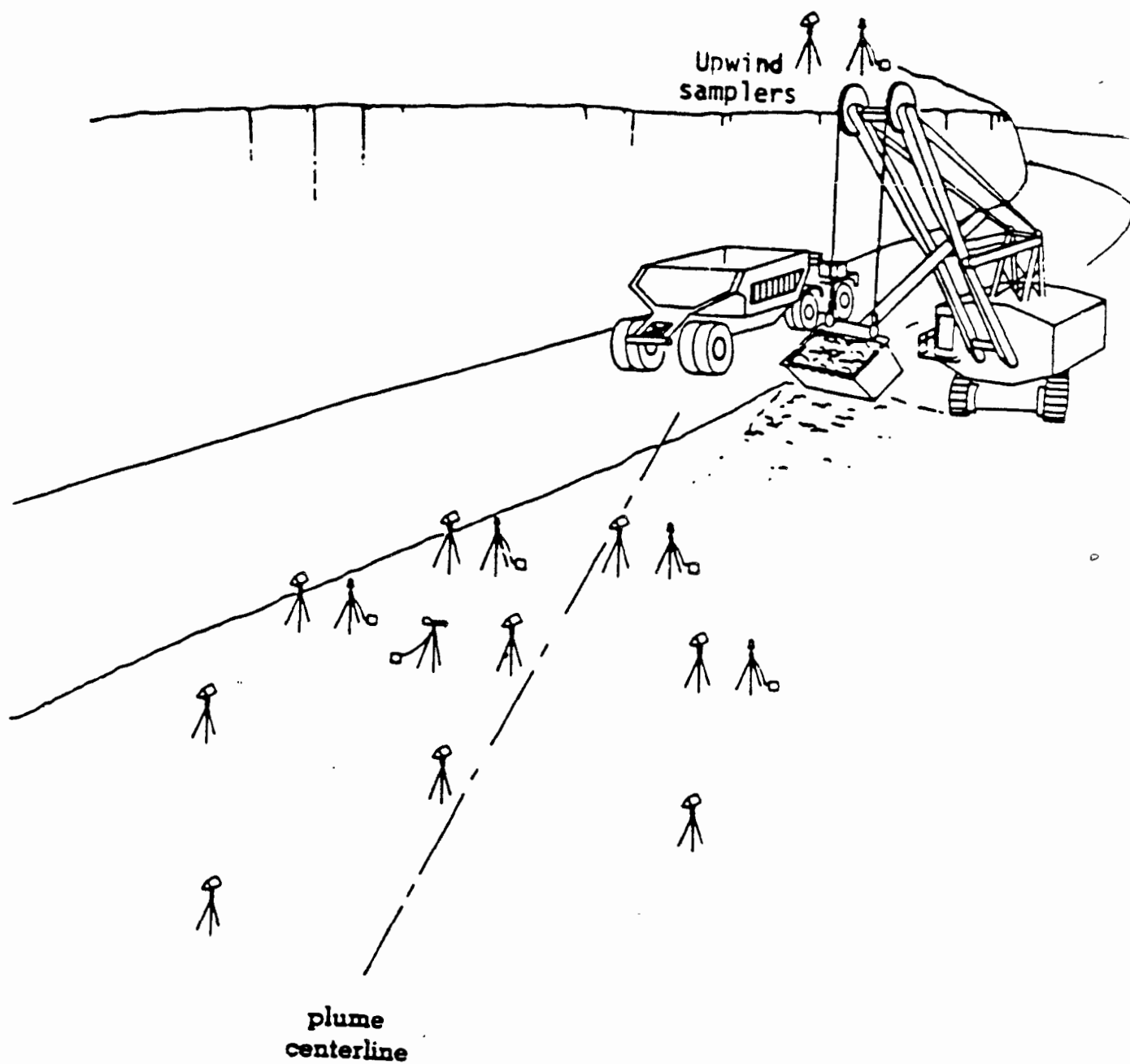


Figure 3-2. Upwind-downwind sampling array.

Particle size-- In addition to the dichotomous samplers located upwind of the source and at 30 m and 60 m distances downwind of the source, millipore filters were exposed for shorter time period during the sampling at different downwind distances. These filters were to be subjected to microscopic examination for sizing, but most of this work was suspended because of poor agreement of microscopy with aerodynamic sizing methods in the comparability study.

Deposition-- The upwind-downwind method allows indirect measurement of deposition through calculation of apparent emission rates at different downwind distances. The reduction in apparent emission rates as a function of distance is attributed to deposition. At distances beyond about 100 m, deposition rates determined by this method would probably be too small to be detected separate from plume dispersion.

Wind Tunnel--

Source strength--For the measurement of dust emissions generated by wind erosion of exposed areas and storage piles, a portable wind tunnel was used. The tunnel consisted of an inlet section, a test section, and an outlet diffuser. As a modification to previous wind tunnel designs, the working section had a 1 foot by 1 foot cross section. This enlargement was made so that the tunnel could be used with rougher surfaces. The open-floored test section of the tunnel was placed directly on the surface to be tested (1 ft x 8 ft), and the tunnel air flow was adjusted to predetermined values that corresponded to the means of the upper NOAA wind speed ranges. Tunnel wind speed was measured by a pitot tube at the downstream end of the test section. Tunnel wind speeds were related to wind speed at the standard 10 m height by means of a logarithmic profile.

An airtight seal was maintained along the sides of the tunnel by rubber flaps attached to the bottom edges of the tunnel sides. These were covered with material from areas adjacent to the test surface to eliminate air infiltration.

To reduce the dust levels in the tunnel air intake stream, testing was conducted only when ambient winds were well below the threshold velocity for erosion of the exposed material. A portable high-volume sampler with an open-faced filter (roof structure removed) was operated on top of the inlet section to measure background dust levels. The filter was vertically oriented parallel to the tunnel inlet face.

An emission sampling module was used with the pull-through wind tunnel in measuring particulate emissions generated by wind erosion. As shown in Figure 3-3, the sampling module was located between the tunnel outlet hose and the fan inlet. The sampling train, which was operated at 15-25 cfm,

consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, backup filter, and high-volume motor. Interchangeable probe tips were sized for isokinetic sampling over the desired tunnel wind speed range. The emission sampling train and the portable hi-vol were calibrated in the field prior to testing.

Particle size--The size distribution for 30 μm and smaller particles was generated from the cascade impactor used as the total particulate sampler. The procedure for correction of the size data to account for particle bounce-through is described in Section 5.

Deposition--No method of measuring the deposition rate of particles suspended by wind erosion in the test section could be incorporated into the design of the wind tunnel.

Quasi-Stack--

Source strength--An enclosure was fabricated consisting of an adjustable metal frame covered with plastic. The frame was 6 feet long with maximum openings at the ends of 5 x 6 feet. Due to problems with the plastic during high winds, the original enclosure was replaced with a wood enclosure with openings 4 x 6 feet, as shown in Figure 3-4. For each test, the enclosure was placed downwind of the drill base. The outlet area was divided into four rectangles of area, and the wind velocity was measured at the center of each rectangle with a hot wire anemometer to define the wind profile inside the frame.

Four exposure profiler samplers with flow controllers were used to sample the plume. Using the wind profile data, the sampler flow rates were adjusted to 2 to 3 minute intervals to near-isokinetic conditions.

Particle size--The only particle size measurements made with this sampling method was the split between the filter catch and settling chamber catch in the profiler heads.

Deposition--There was no direct measurement of deposition with this sampling method.

Sampling Configuration by Source

The basic sampling configurations were adapted to each source to be tested. Sampling configurations used for each source are indicated in Table 3-4 and described below.

Overburden Drilling--

This activity was sampled using the quasi-stack configuration.

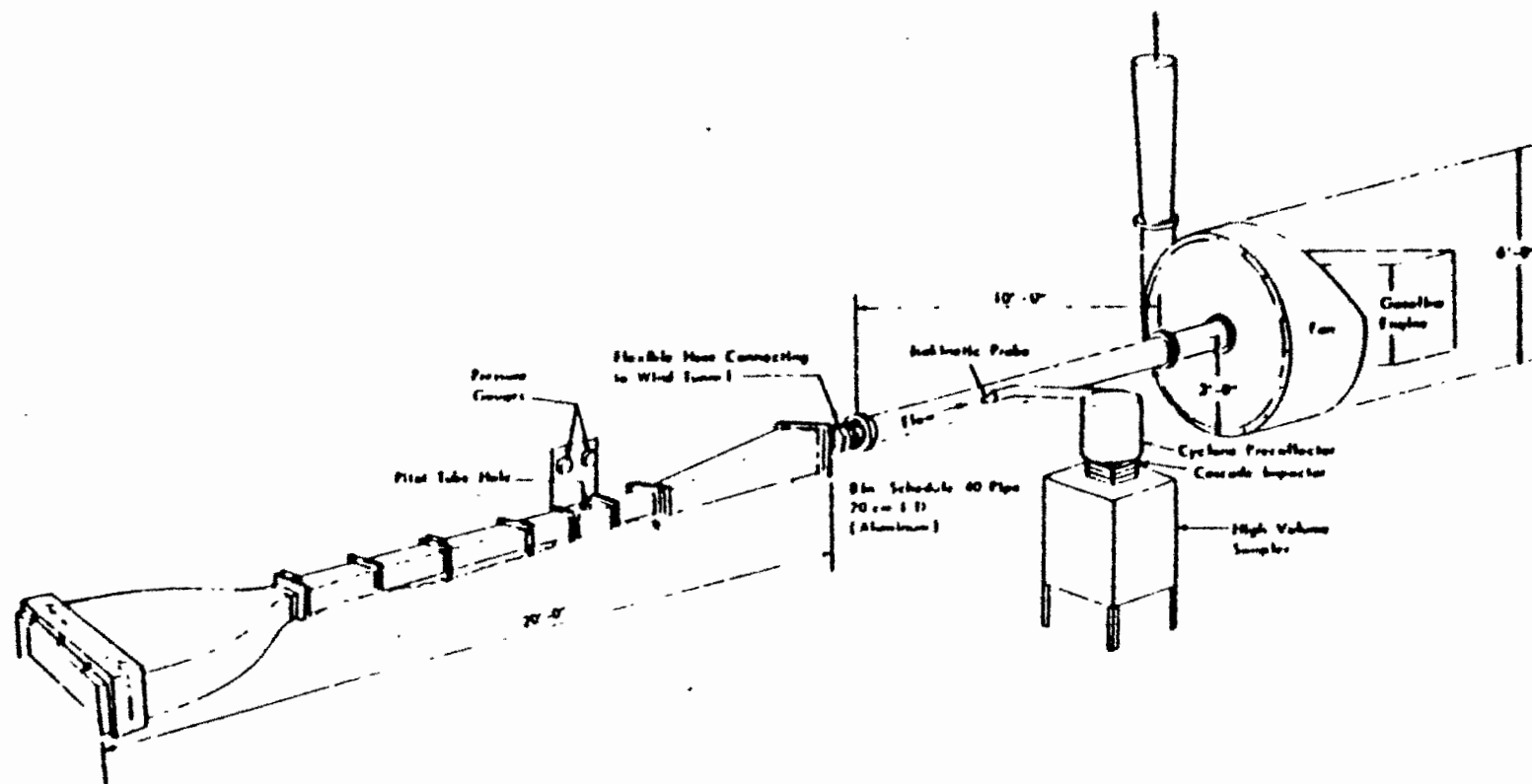


Figure 3-3. Wind tunnel.

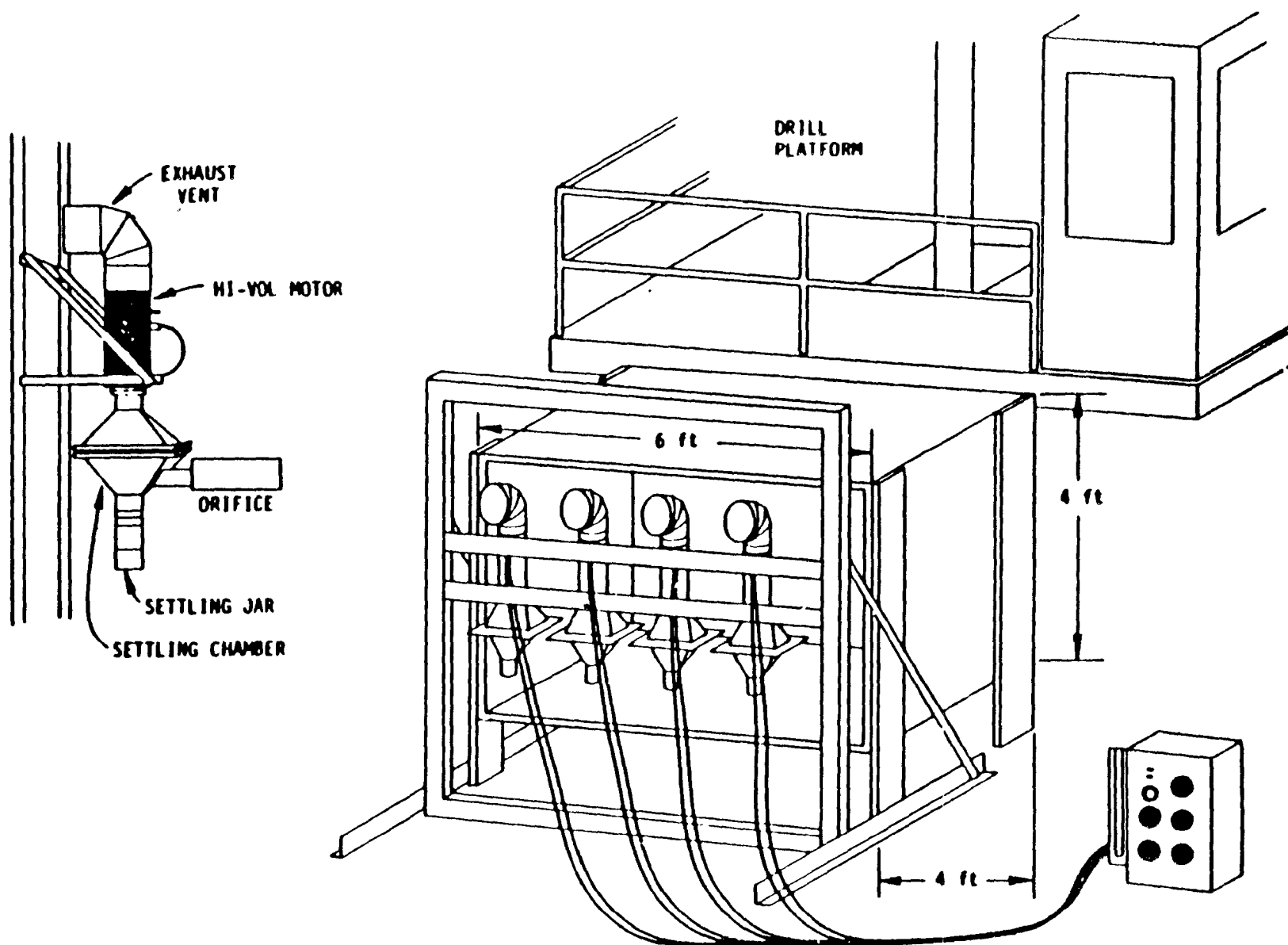


Figure 3-4. Quasi-stack sampling--temporary enclosure for drill sampling.

TABLE 3-4. SAMPLING CONFIGURATIONS FOR SIGNIFICANT SOURCES

Source	Point, line, or area ^a	Sampling configuration
Drilling (overburden)	Point	Quasi-stack
Blasting (coal and overburden)	Area	Exposure profiling (modification)
Coal loading (shovel/truck and front-end loader)	Point or area	Upwind/downwind
Dozer (coal and overburden)	Line or point	Upwind/downwind
Dragline	Point or area	Upwind/downwind
Haul truck	Line	Exposure profiling
Light- and medium-duty vehicles	Line	Exposure profiling
Scraper	Line	Exposure profiling
Grader	Line	Exposure profiling
Wind erosion of exposed areas	Area	Wind tunnel
Wind erosion of storage piles	Area	Wind tunnel

^a Several of these sources could be operated as a line, point, or area source. Where possible, the predominant method of operation was used. In other cases, sampling requirements dictated the type of operation.

Blasting--

The plume from a blast is particularly difficult to sample because of the vertical and horizontal dimensions of the plume and the inability to place sampling equipment near the blast. Further, the plume is suspected to be non-Gaussian because of the way in which the plume is initially formed. Therefore, upwind-downwind sampling is not appropriate. To sample blasts, a modification of the exposure profiling technique was developed. This modification was discussed previously. A typical sampling array is shown in Figure 3-5. The same sampling procedure was used for overburden blasts and coal blasts.

Coal Loading with Shovels or Front-End Loaders--

The exposure profiler could not be used for this source because of movement of the plume origin. Therefore, the upwind-downwind configuration for point sources was used. There are many points at which dust is emitted during truck loading--pulling the truck into position, scooping the material to be loaded, lifting and swinging the bucket, dropping the load, driving the truck away, and cleanup of the area by dozers or front-end loaders. Dropping of the load into the truck was generally the largest emission point so its emissions were used as the plume centerline for the sampling array, with the array spread wide enough to collect emissions from all the dust-producing points. Bucket size was recorded for each test, as well as the number of bucket drops.

Wind conditions and the width of the pit dictated the juxtaposition of the source and sampler array. When the winds channeled through the pit and the pit was wide enough to set up the sampling equipment out of the way of haul trucks, the samplers were set up downwind and in the pit. When winds were perpendicular to the pit, the sampling array was set up on a bench if the bench was not more than 5 to 7 meters high. With this configuration, the top of the haul truck was about even with the height of the bench; emissions from the shovel drop point could be very effectively sampled in this manner. Two coal loading sampling arrays are shown in Figure 3-6.

Dozers--

Dozers are difficult to test because they may operate either as a line source or in a general area as large as several acres over a 1-hour test period. When a dozer operated as a line source, the upwind-downwind configuration for a line source was used. The samplers were located with the assumed plume centerline perpendicular to the line of travel for the dozer. The number of times the dozer passed the samplers was recorded for each test. Since dozers could not always be found operating as a line source, captive dozers were sometimes used so that test conditions could be more accurately controlled. To sample dozers working in an area, the upwind-downwind point source configuration was used. The location and size of the area was recorded along with dozer movements.

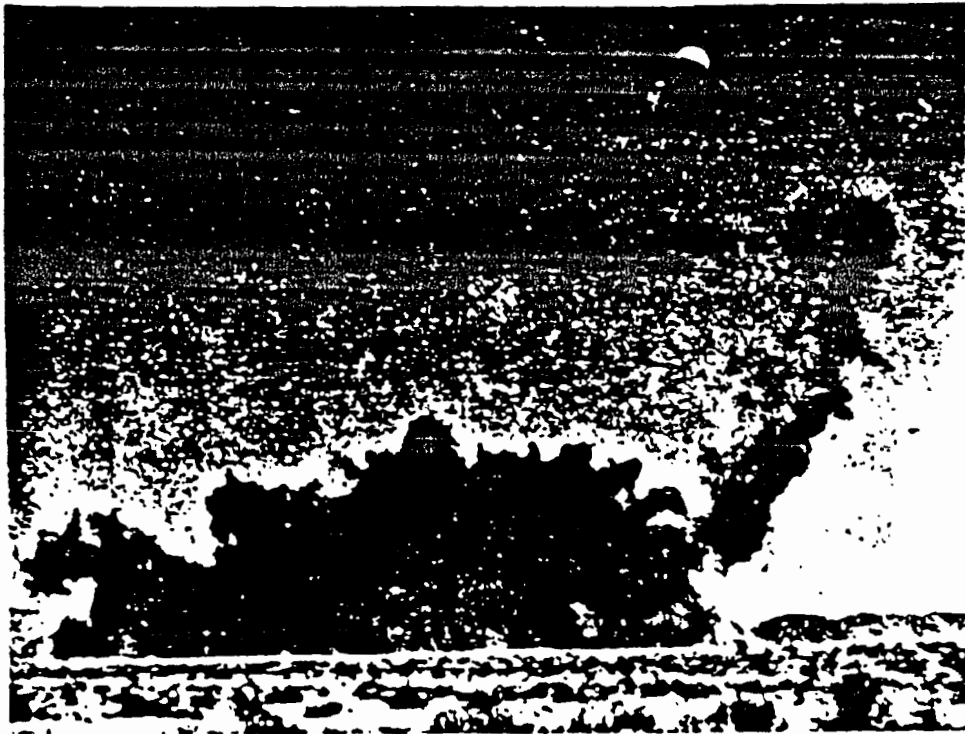


Figure 3-5. Blast sampling with modified exposure profiling configuration.



Sampling array in the pit



Sampling array on a bench

Figure 3-6. Coal loading with upwind-downwind configuration.

Dragline--

Sampling of this source was performed with the upwind-downwind configuration because of the large initial dimensions of the plume and because of the impossibility of placing samplers near the plume origin. There are three emission points--pickup of the overburden material, material lost from the bucket during the swing, and overburden drop. It was not always possible to position samplers so they were downwind of all three points. Therefore, sketches were made of each setup and field notes were recorded as to which points were included in the test. The number of drops, average drop distance, and size of the dragline bucket were also recorded.

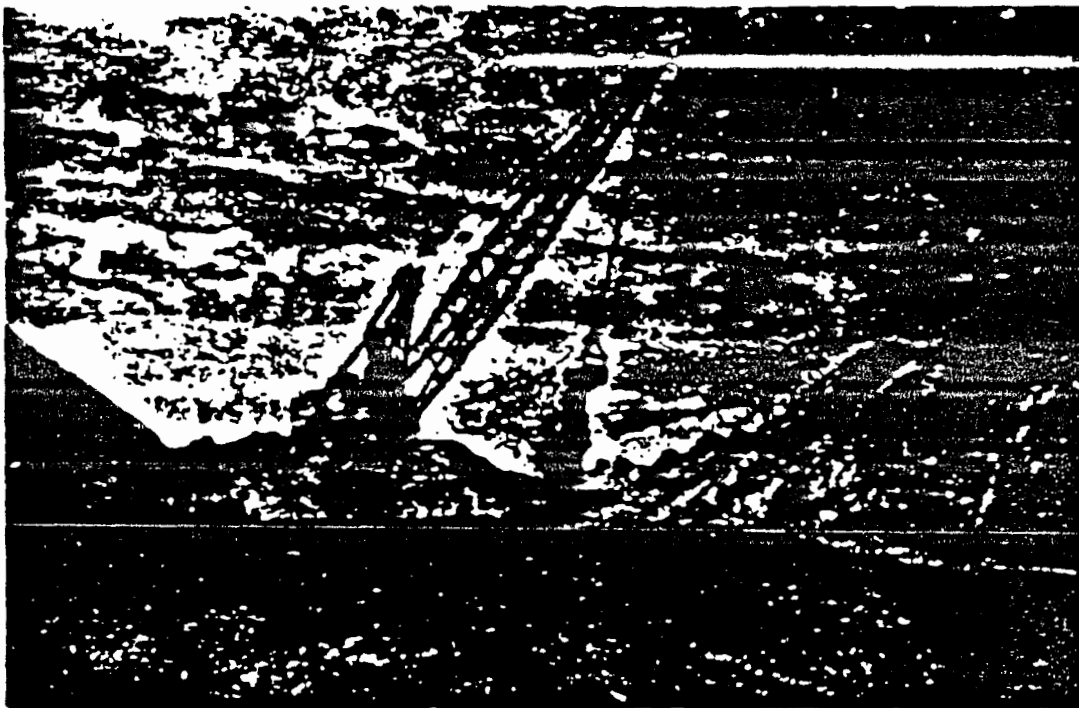
Location of the samplers relative to the dragline bucket was determined by wind orientation, size of the pit (width and length) and pit accessibility. When winds were parallel to the pit, the array was set up in the pit if there was sufficient space and the plumes from all three emission points passing over the samplers. When winds were perpendicular to the pit, draglines were only sampled if samplers could be placed on a bench downwind at approximately the same height as the spoils pile where the overburden was being dropped. Figure 3-7 shows the two typical dragline sampling configurations.

Haul Trucks--

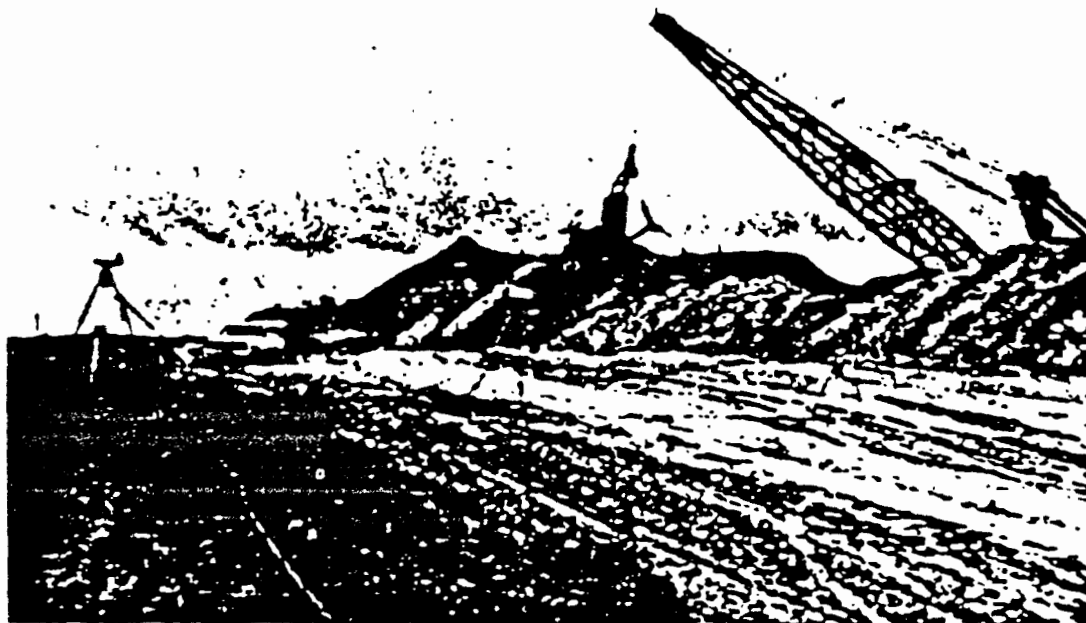
Most sampling periods for haul trucks at the first mine were performed as part of the comparability study (see Section 6), employing both exposure profiling and upwind-downwind configurations. Haul trucks were used to perform the comparative study because they are a uniformly-emitting line source and because haul road traffic is the largest particulate source in most mines. At subsequent mines, exposure profiling was used to sample this source. For each test, the wind was approximately perpendicular to the road, the air intakes of the samplers were pointed directly into the wind, and the samplers extended to a height of 6 m to capture the vertical extent of the plume. In a few cases, more than 20% of the plume mass extended above the top sampler because of a combination of light winds, unstable atmospheric conditions, and large vehicles. Consistent travel speed and diversion of watering trucks was requested during each sampling period. A haul truck sampling array is shown in Figure 3-8.

Light- and Medium-Duty Vehicles--

The sampling methodology for this category of vehicles was nearly identical to the haul truck procedures. The only exceptions were that: (1) a 4 m sampler height was adequate to sample the plume from the smaller vehicles and (2) pickup trucks belonging to the contractor were used for better control of vehicle speed and weight. In most cases, access roads



Sampling array in the pit



Sampling array at about the same height as the spoils pile

Figure 3-7. Dragline sampling with upwind-downwind configuration

specifically for lighter vehicles were used to testing. However, some sampling for light- and medium-duty vehicles was done on haul roads. Samples of the road surfaces were taken so that differences due to road properties could be evaluated (a full discussion of source characterization is included in the next subsection). A light- and medium-duty vehicle sampling array is shown in previously cited Figure 3-8.

Scraper--

This source was sampled by the exposure profiling method. Scrapers were sampled while traveling on a temporary road so that the emissions could be tested as a line source. Neither the loading nor the emptying operations were sampled, since both had been estimated to have insignificant emissions compared to scraper travel. The profiler was extended to 6 m to sample the vertical extent of the plume. In order to secure a suitable setup in a location with interference from other sources, it was often necessary to use captive equipment. A typical sampling array for scrapers is shown in Figure 3-9.

Graders--

Exposure profiling was used to sample graders. Graders operate in a fairly constant manner; only the speed and travel surface (on road/off road) vary over a time. It was assumed that the travel surface could be considered as a correction factor rather than requiring two separate emission factors. As with dozers, captive equipment was sometimes necessary to sample this source because graders did not normally drive past the same location repetitively. Even if there were regarding a short stretch of road, they would be at a different location on the road cross section with each pass, making it difficult to reposition the profiler. Therefore, captive equipment allowed better control of test variables.

Wind Erosion of Exposed Areas and Storage Piles--

The wind tunnel was used to sample these two sources. In measuring emissions with the portable wind tunnel, it was necessary to place the tunnel on a flat, nearly horizontal section of surface. Care was taken not to disturb the natural crust on the surface, with the exception of removing a few large clumps that prevented the tunnel test section from making an airtight seal with the surface.

The threshold velocity for wind erosion and emission rates at several predetermined wind speeds above the threshold were measured on each test surface. Wind erosion of exposed surfaces had been shown to decay in time for velocities well above the threshold value for the exposed surface. Therefore, some tests of a given surface were performed sequentially to trace the decay of the erosion rate over time at high test velocities. A typical wind tunnel sampling configuration is shown in Figure 3-10.



Haul truck travel



Light- and medium-duty truck

Figure 3-8. Haul road sampling with exposure profiling configuration.

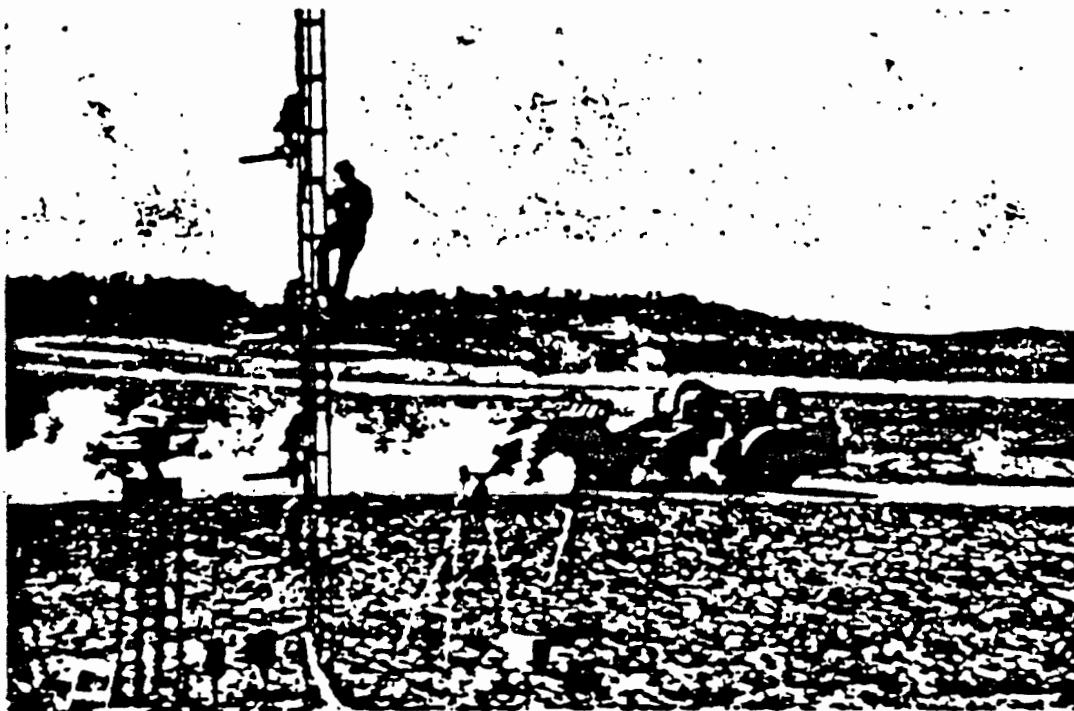


Figure 3-9. Scraper sampling with exposure profiling configuration.

Changes Made in Response to Comments

The basic sampling designs presented above represents the combined efforts of the two contractors as well as comments received from the technical review group. Specific changes made in response to technical review group comments are summarized below.

1. Dichotomous samplers were added to the exposure profiling sampling method. They were placed at four heights corresponding to the isokinetic sampling heights during the comparability study, and at two heights for the remainder of the tests. With this arrangement, dichotomous samplers replaced the cascade impactor as the primary particle size sampler in exposure profiling.
2. A fourth row of downwind sampler was added to the upwind-downwind array. Two hi-vols were placed at 200 m from the source to aid in the measurement of deposition.
3. The quasi-stack sampling method was adopted for sampling overburden drilling and an enclosure was designed and fabricated.
4. The modification of the exposure profiling method to sample blasts was devised.
5. Provisions were made to sample scrapers, and other sources as required, as captive equipment in locations not subject to other dust interferences.

SOURCE CHARACTERIZATION PROCEDURES

In order to determine the parameters that affect dust generation from an individual source, the suspected parameters must be measured at the time of the emission test. These parameters fall into three categories: properties of the materials being disturbed by wind or machinery, operating parameters of the mining equipment involved, and meteorological conditions. Table 3-5 lists the potential parameters by source that were quantified during the study.

Representative samples of materials (topsoil, overburden, coal, or road surface) were obtained at each test location. Unpaved and paved roads were sampled by removing loose material of road surface extending across the travel portion. Loose aggregate materials being transferred were sampled with a shovel to a depth exceeding the size of the largest aggregate pieces. Erodible surfaces were sampled to a depth of about 1 centimeter. The samples were analyzed to determine moisture and silt content.



Figure 3-10. Wind erosion sampling with wind tunnel.

Mining equipment travel speeds were measured by radar gun or with a stop watch over a known travel distance. Equipment specifications and traveling weights were obtained from mine personnel. For several sources, it was necessary to count vehicle passes, bucket drops, etc. These counts were usually recorded by two people during the test to ensure the accuracy of the results. Frequent photographs were taken during each test to establish the sampling layout (to supplement the ground-measured distances), source activity patterns, and plume characteristics.

Micro-meteorological conditions were recorded for each test. Most of these data were used in the calculation of concentrations or emission rates rather than as potential correction factors for the emission factor equations. During the test, a recording wind instrument measured wind direction and wind speed at the sampling site. A pyranograph was used to measure solar intensity. Humidity was determined with a sling psychrometer. A barometer was used to record atmospheric pressure. The percent of cloud cover was visually estimated.

In addition to monitoring micro-meteorological conditions, a fixed monitoring station at the mine monitored parameters affecting the entire area. Data were recorded on temperature, humidity, wind speed and direction, and precipitation.

ADJUSTMENTS MADE DURING SAMPLING

The sampling configurations detailed in this section were the result of a careful study design process completed prior to actual field sampling. Actual field conditions forced changes to elements of the study design.

A modification to the upwind-downwind sampling array was required. Whereas the study design called for two hi-vols at 200 m downwind of the source, this setup could not be adapted to field conditions. Three major reasons for the deviation from the study designs were: (a) the difficulty of locating the samplers where they were not subjected to other dust interferences; (b) the difficulty of extending power to the samplers; and (c) in many sampling locations, there was not 200 m of accessible ground downwind of the source. Therefore, only 1 hi-vol was routinely placed at the 200 m distance and in some cases no sampler was located at that distance.

Four modifications were made to the exposure profiling sampling array. First, it was impractical to mount dichotomous samplers at all four heights on the profiling tower as called for in the original study design. Dichotomous samplers were placed at two heights. Second, the study design called for an exposure profiling test to be terminated if the standard deviation of the wind direction exceeded 22.5° during test period. Because unstable atmospheric conditions were encountered at Mine 1 during the summer season,

TABLE 3-5. SOURCE CHARACTERIZATION PARAMETERS
MONITORED DURING TESTING

Source	Parameter ^a	Quantification technique
All tests ^a	Wind speed and direction Temperature Solar intensity Humidity Atmospheric pressure Percent cloud cover	Anemometer Thermometer Pyranograph Sling psychrometer Barometer Visual estimate
Overburden drilling	Silt content Moisture content Depth of hole	Dry sieving Oven drying Drill operator
Blasting	Number of holes Size of blast area Moisture content	Visual count Measurement From mining company
Coal loading	Silt content Moisture content Bucket capacity Equipment operation	Dry sieving Oven drying Equipment specifications Record variations
Dozer	Silt content Moisture content Speed Blade size	Dry sieving Oven drying Time/distance Equipment specifications
Dragline	Silt content Moisture content Bucket capacity Drop distance	Dry sieving Oven drying Equipment specifications Visual estimate
Haul truck	Surface silt content Vehicle speed Vehicle weight Surface loading Surface moisture content Number of wheels	Dry sieving Radar gun Truck scale Mass/area of collected road sample Oven drying Visual observation
Light- and medium-duty vehicles	Same parameters and quantification techniques as for haul trucks	

(continued)

it was necessary to relax this restriction. However, this change had no effect on the direction-insensitive dichotomous sampler which served as the primary sizing device. At the third mine, a second cascade impactor and hi-vol were added alongside the profiler at the height of the third profiling head. This was to provide backup data on particle size distribution in the upper portion of the plume and on the TSP concentration profile. Finally, greased substrates were used with the cascade impactors at the third mine to test whether particle bounce-through observed at the first two mines would be diminished.

A modification was required to the balloon sampling array. The study design specified that the five ground-based sampler pairs be located 10 m apart and that the balloon samplers be located on the blast plume centerline. This was found to be impractical under field conditions. The location of the plume centerline was very dependent on the exact wind direction at the time of the blast. Because the balloon sampling array required at least one hour to set up, it was impossible to anticipate the exact wind direction one hour hence. Therefore, the ground-based samplers were placed 20 to 30 m apart when the wind was variable so that some of the samplers were in the plume. The balloon sometimes could not be moved to the plume centerline quickly enough after the blast. Rapid sequence photography was used during the test to assist in determining the plume centerline; the emission factor calculation procedure was adjusted accordingly.

ERROR ANALYSES FOR SAMPLING METHODS

Separate error analyses were prepared for the exposure profiling and upwind-downwind sampling methods. These analyses were documented in interim technical reports and will be summarized here (Midwest Research Institute 1979; PEDCo Environmental 1979).

A summary of potential errors (10) in the exposure profiling method initially estimated by MRI is shown in Table 3-6. Potential errors fall in the categories of sample collection, laboratory analysis, and emission factor calculation. For particles less than 15 μm , the error in the technique was estimated by MRI to range from -14 percent to +8 percent. Subsequent field experience on this project indicated that actual error was 30 to 35 percent in that size range and higher for the less than 30 μm (suspended particulate) size range.

Potential errors initially estimated by PEDCo for the upwind-downwind sampling method are summarized in Table 3-7. A delineation was made between errors associated with line sources and point/area sources. The estimated errors were +30.5 percent and +50.1 percent, respectively.

SUMMARY OF TESTS PERFORMED

Sampling performed is shown in Table 3-8. The number of samples are shown by source and mine. A total of 265 tests were completed.

TABLE 3-6. SUMMARY OF POTENTIAL ERRORS IN THE EXPOSURE PROFILING METHOD

Source of error	Error type	Action to minimize error	Estimated error
<u>Sample collection</u>			
1. Instrument error	Random	Planned maintenance, periodic calibration and frequent flow checks	5% ^a
2. Anisokinetic sampling			
a. Wind direction fluctuation	Systematic	$\sigma_\theta < 22.5^\circ$	<10%
b. Non-zero angle of intake to wind	Systematic	$\theta < 30^\circ$	<10%
c. Sampling rate does not match wind speed	Systematic	$0.8 < IFR < 1.2$	<5%
3. Improper filter loading	Systematic	Decrease or increase sampling duration	2% for fibrous media; 10% for non-fibrous media
4. Particle bounce	Systematic	Use dichotomous sampler	Negligible
<u>Laboratory analysis</u>			
5. Instrument error	Random	Planned maintenance, periodic calibration and frequent weight checks	Negligible
6. Filter handling	Random	Use blanks for each test. Control weighing environment for humidity and temperature	2% for hi-vol filters; 5% for lo-vol filters
<u>Emission factor calculation</u>			
7. Poor definition of profile	Random	Sample at 4 or more points over plume dimension of 10 m; 90% of plume mass defined by sampling points	10%
8. Extrapolation of particle size distribution	Random	Assume log-normal particle size distribution	20% for extrapolation to 30 μm . See text.
Total (particles less than 15 μm)			-14% to + 8% ^a

^a Subsequent field experience in this project (see Section 6) indicated that the dichotomous sampler instrument error was at least 25 percent, producing a total error (for particles less than 15 μm) of 30 to 35 percent.

TABLE 3-8. SUMMARY OF TESTS PERFORMED

Sources	Mine 1	Mine 2	Mine 1W ^a	Mine 3	Total
Drill (overburden)	11	-	12	7	30
Blasting (coal)	3	6		7	16
Blasting (overburden)	2			3	5
Coal loading	2	8		15	25
Dozer (overburden)	4	7		4	15
Dozer (coal)	4	3		5	12
Dragline	6	5		8	19
Haul truck	7 ^b	9	10	9	35 ^c
Light- and medium-duty truck	5	5		3	13 ^d
Scraper	5 ^b	5	2	2	14
Grader		6		2	8
Exposed area (overburden)	11	14	3	6	34 ^e
Exposed area (coal)	10	7	6	16	39
Total	70	75	33	87	265

^a Winter sampling period.

^b Five of these tests were comparability tests.

^c Nine of these were for controlled sources.

^d Two of these were for controlled sources.

^e Three of these were for controlled sources.

SECTION 4

SAMPLE HANDLING AND ANALYSIS

SAMPLE HANDLING

Several different types of particulate samples were collected during the field work: hi-vol glass filters, filters and settling chamber catches from exposure profilers, cascade impactor stages, cyclone pre-collector catches, Teflon filters from dichotomous samples, Millipore filter cartridges from microscopic analysis, PVC filters from the balloon sampling system, and dustfall samples. These samples all required slightly different handling procedures.

At the end of each run, the collected samples were transferred carefully to protective containers. All transfer operations except removal of cartridges from the instruments were done in a van or in the field lab to minimize sample losses and contamination. Sample media were carried and transported locally in an upright position, and covered with temporary snap-on shields or covers where appropriate. Hi-vol and profiler filters were folded and placed in individual envelopes. Dust collected on interior surfaces of profiler probes and cyclone precollectors was rinsed with distilled water into containers with the settling chamber catches.

In order to reduce the amount of material dislodged from the taut dichotomous filters during handling, the preweighed filters were placed in plastic holders than were then kept in individual petri dishes throughout the handling process. The petri dishes were sealed with tape before being returned to the laboratory and stacked in small carrying cases so that they would not be inverted. Many of the dichotomous filters were hand-carried back to the laboratory by air travel rather than returning with the sampling equipment and other samples in the van.

In spite of the special handling procedures adopted for the dichotomous filters, loose particulate materials was observed in some of the petri dishes and material could be seen migrating across the filter surfaces with any bumping of the filter holder. Several corrective actions were investigated by PEDCo and MRI throughout the study, but this remained an unresolved handling problem. First, ringed Teflon filters were substituted for the mesh-backed filters initially used in an attempt to reduce movement or vibration of the exposed filters. Next, the possibility of weighing the filters in the field was reviewed. However, a

sensitive microbalance and strict filter equilibration procedures were required because of the small weights involved--filter tare weights less than 100 mg and may upwind and fine particle fraction sample weights less than 50 ug. (See Section 12 for further discussion of dichotomous samplers.)

PVC filters for the balloon samplers and Millipore filters for particle size analysis were sent to the field in plastic cartridges. These cartridges were uncapped and affixed to the air pumps during sampling, then resealed and returned to the laboratory for gravimetric or microscopic analysis. Loss of material from these filter surfaces was not observed to be a problem as it was with the Teflon filters.

All samples except the dichotomous filters were labeled with the name of the mine, date, operation, sampler, and a unique sample number (dichotomous sample holders had only the sample number). This same information was also recorded on a field data sheet at the time of sampling. Copies of the field data sheets were shown in the study design report.

To minimize the problem of particle bounce, the glass fiber cascade impactor substrates were greased for use at Mine 3. The grease solution was prepared by dissolving 100 grams of stopcock grease in 1 liter of reagent grade toluene. A low pressure spray gun was used to apply this solution to the impaction surfaces. No grease was applied to the borders and backs of the substrates. After treatment, the substrates were equilibrated and weighed using standard procedures. The substrates were handled, transported and stored in specially designed frames which protected the greased surfaces.

After samples were taken at the mines, they were kept in the field lab until returned to the main laboratory. All samples were accounted for by the field crew by checking against the field data sheet records prior to leaving the field location. Photocopies of the data sheets were made and transported separately from the samples. Upon reaching the lab, the chain of custody was maintained by immediately logging in the sample numbers of all samples received. No sample were known to have been lost through misplacement or inadequate labeling during the entire study.

Non-filter (aggregate) sample were collected during or immediately following each sampling period and labeled with identifying information. The samples were kept tightly wrapped in plastic bags until they were split and analyzed for moisture content. Dried samples were then re-packaged for shipment to the main laboratories for sieving.

ANALYSES PERFORMED

Laboratory analyses were performed on particulate samples and on aggregate samples. All monitoring of source activities and meteorological conditions was done with on-site measurements and did not result in the collection of samples for later analysis. The analyses performed are summarized in Table 4-1.

All particulate samples were analyzed in the lab of the by the contractor who took the samples. However, almost all of the aggregate sample analyses were done in the MRI lab because of their extensive past experience with aggregate analyses and to maintain consistency in methods. Aggregate samples for PEDCo's tests were taken by their field crew and moisture contents were determined in the field lab. Most of the labeled, dried aggregate samples were then turned over to MRI for all other analyses.

PEDCo performed all microscopy analyses. Initially, microscopy samples were to be used to determine full particle size distributions. After the comparability study results showed that microscopy data did not agree with that obtained from sampling devices that measured aerodynamic particle sizes, the microscopy work was limited to determination of largest particles in the plume downwind of sources.

LABORATORY ANALYSIS PROCEDURES

Filters

Particulate samples were collected on four different types of filters: glass fiber, Teflon, polyvinyl chloride (PVC) and cellulose copolymer (Millipore). The procedure for preparing and analyzing glass fiber filters for high volume air sampling is fully described in Quality Assurance Handbook for Air Pollution Measurement Systems--Volume II, Ambient Air Specific Methods (U.S. Environmental Protection Agency 1977b). Nonstandardized methods were used for the other three filter types. The procedures for each type are described below.

Glass fiber filters were numbered and examined for defects, then equilibrated for 24 hours at 70°F and less than 50 percent relative humidity in a special weighing room. The filters were weighed to the nearest 0.1 mg. The balance was checked at frequent intervals with standard weights to assure accuracy. The filters remained in the same controlled environment for another 24 hours, after which a second analyst reweighed 10 percent of them as a precision check. All the filters in each set in which check weights varied by more than 3.0 mg from initial weights were reweighed. After weighing, the filters were packed flat, alternating with onionskin paper, for shipment to the field.

TABLE 4-1. LABORATORY ANALYSES PERFORMED

Sample	Analysis performed
<u>Particulate</u>	
Hi-vol filter	Weigh, calculate concentration
Exposure profiler filter	Weigh
Settling chamber catch	Filter, dry, weigh
Cyclone precollector catch	Filter, dry, weigh
Cascade impactor stages	Weigh
Quasi-stack filter	Weigh
Settling chamber catch	Transfer, dry, weigh
Teflon filter	Weigh, calculate concentration
PVC filter	Weigh
Millipore filter	Microscopic examination for size distribution and max size
Dustfall	Filter, dry, weigh
<u>Aggregate</u>	
Raw soil sample	Moisture content
Dried sample	Mechanical sieving

When exposed filters were returned from the field, they were equilibrated under the same conditions as the initial weighing. They were weighed and check weighed in the same manner.

Teflon filters from dichotomous samplers were dessicated for 24 hours over anhydrous calcium sulfate (Drierite) before weighing, both before and after use. The filters were weighed in the same constant temperature and humidity room as the glass fiber filters. They were weighed to the nearest 0.01 mg and the check weighing had to agree within 0.10 mg or all filters in the set were reweighed. The filters themselves were not numbered, but were placed in numbered petri dishes for handling and transport. Plastic filter holders were also placed on the filters in the lab so they could be inserted directly into the dichotomous samplers in the field.

PVC filters were treated in exactly the same manner as the Teflon filters, with the exception that they were placed in plastic cartridges rather than petri dishes.

The Millipore filters used for microscopic analysis were not weighed to determine the amount of material collected. After they were exposed and returned to the lab in a plastic cartridge, a radial section of the filter was cut and mounted on a glass microscope slide. The filter section was then immersed in an organic fluid that rendered it invisible under the microscope, and a cover slip was placed over it. The slide was examined under a light microscope at 100 power using phase contract illumination. The particles were sized by comparison with a calibrated reticle in the eyepiece. Ten different fields and at least 200 particles were counted on each slide. Also, the diameters of the three largest individual particles observed were recorded.

Settling Chamber Catches and Dustfall Samples

Laboratory grade deionized distilled water was used in the field laboratory to recover samples from settling chambers and dustfall buckets. Each unit was thoroughly washed five to eight separate times. A wash consisted of spraying 15 to 25 ml water into the unit, swirling the unit around, and then quantitatively pouring the water into a sample jar (holding 150 ± 50 ml of wash water) was sealed and packed for shipping to MRI for sample recovery.

At the MRI laboratory, the entire wash solution was passed through a 47 mm Buchner type funnel holding a Type AP glass fiber filter under suction. The sample jar was then rinsed twice with 10 to 20 ml of deionized water. This water was passed through the Buchner funnel ensuring collection of all suspended material on the 47 mm filter. The tared filter was then dried in an oven at 100°C for 24 hours. After drying, the filters were conditioned at constant temperature $24 \pm 2^{\circ}\text{C}$ and constant humidity 45 ± 5 percent relative humidity for 24 hours.

All filters, both tared and exposed, were weighed to $\pm 5 \mu\text{g}$ with a 10 percent audit of tared and exposed filters. Audit limits were $\pm 10 \mu\text{g}$. Blank values were determined by washing "clean" (unexposed) settling chambers and dustfall buckets in the field and following the above procedures.

Aggregate Samples

Samples of road dust and other aggregate materials were collected in 20 to 25 kg quantities for analysis of moisture and silt content. The samples were stored briefly in airtight plastic bags, then reduced with a sample splitter (riffle) or by coning and quartering to about 1 kg (800 to 1600 g).

The final split samples were placed in a tared metal pan, weighed on a balance, and dried in an oven at 110°C overnight. Laboratory procedures called for drying of materials composed of hydrated materials or organic materials like coal and certain soils for only 2 hours. The samples were then reweighed and the moisture content calculated as the weight loss divided by the original weight of the sample alone. This moisture analysis was done in the field lab.

Dried samples were placed in plastic containers and sealed for shipment to main laboratories for determination of silt contents. This was done by mechanical dry sieving, with the portion passing a 200-mesh screen constituting the silt portion. The nest of sieves was placed on a conventional sieve shaker for 15 min. The material passing the 200-mesh screen, particles of less than $75 \mu\text{m}$ diameter, constituted the smallest particles which could be accurately determined by dry sieving according to ASTM methods.

More detailed sample collection and laboratory procedures for the moisture and silt analyses were presented in an appendix to the study design report.

QUALITY ASSURANCE PROCEDURES AND RESULTS

Quality assurance was an important concern from the beginning of this field study because of its size, complexity, and importance. Several special activities were instituted as part of the overall quality assurance effort. The primary one was delineation of specific assurance procedures to be followed throughout the study. This list of procedures was subjected to review by the technical review group; a revised version is presented in Table 4-2. It covers sampling rates, sampling media, sampling equipment and data calculations.

In addition to the quantitative checks listed in Table 4-2, many non-quantifiable procedures related to sample handling and visual inspection of equipment were adopted. Some of these were based on standard practices

but others were set more stringent than normal requirements. No quality assurance procedures for operating or maintaining dichotomous samplers had been recommended yet by EPA, so considerable project effort was expended in developing and testing these procedures.

Meteorological equipment and monitoring procedures are not covered in Table 4-2. Approved equipment was used and it was operated and maintained according to manufacturer's instructions. Meteorological instruments had been calibrated in a laboratory wind tunnel prior to the field work.

Adherence to the specified quality assurance procedures was checked periodically by the Project Officer and other members of the technical review group, by intercontractor checks, and by external independent audits. Results of the quality assurance program for flow rates and weighing are summarized in Table 4-3. Results of the audits are described in the following section.

AUDITS

In addition to the rigorous internal quality assurance program and the review procedures set up with the technical review group, several independent audits were carried out during this study to further increase confidence in results. Two different levels of audits were employed:

Intercontractor - MRI audited PEDCo and vice versa

External - Performed by an EPA instrument or laboratory expert or a third EPA contractor

The audit activities and results of audits are summarized in Table 4-4.

Although there are no formal pass/fail criteria for audits such as these, all of the audits except the collocated samplers in the comparability study and filter weighings seemed to indicate that measurements were being made correctly and accurately. The collocated sampler results are discussed further in Section 6 and 12. All the filters that exceeded allowable tolerances upon reweighing (10 percent of audited filters) lost weight. In the case of the hi-vol filters, loose material was observed in the filter folders and noted on the MRI data sheet. The amounts lost from the dichot filters would not be as readily noticeable in the petri dishes. The several extra handling steps required for auditing the filters, including their transport from Cincinnati to Kansas City, could have caused loss of material from the filters.

In addition to the external flow calibration audit at the third mine (shown in Table 4-4), another one was conducted at the second mine. However, results of this earlier audit were withdrawn by the contractor who performed

TABLE 4-2. QUALITY ASSURANCE PROCEDURES FOR MINING EMISSION
FACTOR STUDY

Activity	QA check/requirement
<u>Sampling flow rates</u>	
Calibration	
Profilers, hi-vols, and impactors	Calibrate flows in operating ranges using calibration orifice, once at each mine prior to testing.
Dichotomous samplers	Calibrate flows in operating ranges with displaced volume test meters once at each mine prior to testing.
Single-point checks	
Profilers, hi-vols, and impactors	Check 25% of units with rotameter, calibration orifice or electronic calibrator once at each site prior to testing (different units each time). If any flows deviate by more than 7%, check all other units of same type and recalibrate non-complying units. (See alternative check below).
Dichotomous samplers	Check 25% of units with calibration orifice once at each site prior to testing (different units each time). If any flows deviate by more than 5%, check all other units and recalibrate non-complying units.
Alternative	If flows cannot be checked at test site, check all units every two weeks and recalibrate units which deviate by more than 7% (5% for dichots).
Orifice calibration	Calibrate against displaced volume test meter annually.
<u>Sampling media</u>	
Preparation	Inspect and imprint glass fiber media with ID numbers.
	Inspect and place Teflon media (dichot filters) in petri dishes labeled with ID numbers.
Conditioning	Equilibrate media for 24 hours in clean controlled room with relative humidity of less than 50% (variation of less than $\pm 5\%$) and with temperature between 20°C and 25°C (variation of less than $\pm 3\%$).
Weighing	Weigh hi-vol filters and impactor substrates to nearest 0.1 mg and weigh dichot filters to nearest 0.01 mg.

(continued)

BLE-4-2 (continued).

Activity	QA check/requirement
Weighing of weights (tare and final)	Independently verify weights of 7% of filters and substrates (at least 4 from each batch). Reweigh batch if weights of any hi-vol filters or substrates deviate by more than ± 3.0 mg or if weights of any dichot filters deviate by more than ± 0.1 mg.
Correction for handling effects	Weigh and handle at least one blank for each 10 filters or substrates of each type for each test.
Prevention of handling losses	Transport dichot filters upright in filter cassettes placed in protective petri dishes.
Calibration of balance	Balance to be calibrated once per year by certified manufacturers representative. Check prior to each use with laboratory Class S weights.
<u>Sampling equipment</u> Maintenance All samplers	Check motors, gaskets, timers, and flow measuring devices at each mine prior to testing.
Dichotomous samplers	Check and clean inlets and nozzles between mines.
Equipment siting	Separate collocated samplers by 3-10 equipment widths.
Orientation Isokinetic sampling profilers only)	Adjust sampling intake orientation whenever mean (15 min average) wind direction changes by more than 30 degrees. Adjust sampling rate whenever mean (15 min average) wind speed approaching sampler changes by more than 20%.
Prevention of static code deposition	Cap sampler inlets prior to and immediately after sampling.
<u>Calculations</u> <u>and recording</u>	Use specially designed data forms to assure all necessary data are recorded. All data sheets must be initialed and dated.
Calculations	Independently verify 10% of calculations of each type. Recheck all calculations if any value audited deviates by more $\pm 3\%$.

TABLE 4-3. QUALITY ASSURANCE RESULTS

Activity	QA results
<u>Calibration</u> Profilers, hi-vols, and impactors	<p>PEDCo calibrated hi-vols a total of 6 times in the 4 visits.</p>
	<p>MRI had flow controllers on all 3 types of units. These set flows were calibrated a total of 4 times for profilers, 7 times for hi-vols and impactors.</p>
Dichotomous samplers	<p>PEDCo and MRI calibrated their 9 dichots a total of 6 times, at least once at each mine visit. Actual flow rates varied as much as 9.1% between calibrations.</p>
<u>Single point checks</u> Profilers, hi-vols, and impactors	
	<p>Out of a total of 29 single point checks, only 2 PEDCo hi-vols were found to be outside the 7% allowable deviation, thus requiring recalibration. For MRI, 20 single point checks produced no units out of compliance.</p>
Dichotomous samplers	<p>The dichotomous samplers were recalibrated with a test meter each time rather than checking flow with a calibrated orifice.</p>
<u>Weighings</u> Tare and final weights	
	<p>PEDCo reweighed a total of 250 unexposed and exposed hi-vol filters during the study. Three of the reweighings differed by more than 3.0 mg. For 238 dichot filter reweighings, only four differed by more than 0.1 mg.</p>
	<p>MRI reweighed a total of 524 unexposed and exposed glass fiber filters during the study. Four of the reweighings differed by more than 3.0 mg. For 43 dichot filter reweighings, only one differed by more than 0.1 mg.</p>
Blank filters	<p>PEDCo analyzed 88 blank hi-vol and 69 blank dichot filters. The average weight increase was 3.4 mg (0.087%) for hi-vols, 0.036 mg (0.038%) for dichots. The highest blanks were 26.3 and 0.22 mg, respectively.</p> <p>MRI analyzed 67 hi-vol and dichot filter blanks. The highest blanks were 7.05 mg and 0.52 mg, respectively.</p>

TABLE 4-4. AUDITS CONDUCTED AND RESULTS

Activity	Inter-contractor or external audit	Contractor audited	Date	No. and type of units	Results
Flow calibration	I	PEDCo	8-22-79	2 hi-vol	Each 4% from cal curve
		MRI	8-27-79	1 hi-vol	Hi-vol and impactor within 4% of curve, dichot within 2%
		PEDCo	10-12-79	2 dichot	One within 1%, other out by 12.6%
		MRI	10-12-79	2 hi-vol	Both within 7%
	E (EPA, OAQPS)	PEDCo	8-01-79	1 dichot	Within 5%
		MRI	8-01-79	7 dichot	All set 5 to 11% high
		MRI	8-06-80	2 dichot	One within 1%, other out by 10%
		PEDCo	8-05-80	10 hi-vol	7 within 5%, 2 within 7%, one 8 3% from cal curve
Filter weighing	I	PEDCo	8-06-80	5 dichot	Total flows all within 5%, 2 coarse flows differed by 6.2 and 9.2%
		PEDCo	1-02-80	39 hi-vol	Three hi-vol filters varied by more than 50 mg; all lost weight and loose material in folder was noted. Four dichots exceeded the 0.10 mg tolerance and all lost weight
		MRI	-	31 dichot	Filters not submitted yet
Laboratory procedures	E (EPA, EMSL)	PEDCo	10-30-79	Compreh. review	No problems found
		MRI	11-13-79	Compreh. review	No problems found
Collocated samplers	I	Both	7-26-79 to 8-09-79	18 hi-vol 10 dichot	Paired hi-vol values differed by an av of 34%, IP values by 35%
Systems audit	E (EPA, OAQPS)	Both	8-01-79	All	Checked siting, calibration, filter handling, and maint. procedures. Few minor problems found but concluded that operations should provide reliable data

SECTION 5

CALCULATION AND DATA ANALYSIS METHODOLOGY

NUMBER OF TESTS PER SOURCE

The study design proposed the number of samples to be collected for each operation, but these initial numbers were based primarily on available sampling time and the relative importance of each operation as a dust source. Several members of the technical review group requested a statistical analysis to determine the appropriate number of samples to be taken.

After sampling data were obtained from the first two mines/three visits, the total sample size needed to achieve a specified margin of error and confidence level could be calculated by knowing the variability of the partial data set. This method of estimating required sample size, in which about half of the preliminarily-estimated sample size is taken and its standard deviation is used to provide a final estimate of sample size, is called the two-stage or Stein method. The two-stage method, along with two preliminary data evaluations, constituted the statistical plan finally prepared for the study.

The steps in estimating total sample sizes and remaining samples in the statistical plan were:

1. Determine (by source) whether samples taken in different seasons and/or at different mines were from the same population. If they were, total sample size could be calculated directly.
2. Evaluate potential correction factors. If samples were not from a single distribution, significant correction factors could bring them into a single distribution. If they were from populations with the same mean, correction factors could reduce the residual standard deviations.
3. Calculate required sample sizes using residual standard deviations.
4. Calculate remaining samples required to achieve the desired margin of error and confidence level and recommend the number of samples for each source to be taken at the third mine.

Two-Stage Method for Estimating Sample Size

If samples are to be taken from a single normal population, the required total sample size can be calculated with the following equation based on the two-stage sampling method (Natrella 1963):

$$n = \frac{t^2 s_1^2}{d^2} \quad (\text{Eq. 1})$$

where n = number of samples required for first and second stages combined

s_1 = estimate of population standard deviation based on n_1 samples

t = tabled t -value for risk α and $n_1 - 1$ degrees of freedom

d = margin of error in estimating population mean

The margin of error, d , and the risk, α , that the estimate of the mean will deviate from the population mean by an amount d or greater are specified by the user. A relative error (d/\bar{x}) of 25 percent and a risk level of 20 percent have been specified for the calculations presented herein based on the intended use for the results, the measurement errors involved in obtaining the samples, and the accuracy of emission factors currently being used for other sources. Having specified d (or d/\bar{x}) and α , the only additional value needed to calculate n for each source is the estimate of population standard deviation, s_1 (or s_1/\bar{x}), based on the partial sample obtained to date, n_1 .

Samples from the Same Normal Population

One important restriction on the use of Equation 1, as noted above, is that samples (from different mines) must be from a single normal distribution. If average emission rates for a specific source at three different mines are 2, 10, and 50 lb/ton, and the three samples have relatively low variability, the combined data cannot be assumed to be normally distributed with a common mean. Regardless of how many samples were taken at each mine, the data would be trimodally distributed.

Therefore, before Equation 1 can be used to calculate the total sample size, a check should be performed to determine whether the available data from different mines are from populations with the same mean and variance. If not, the mines would need to be treated separately and thus require a calculation of required sample size for each mine, using the analogue of Equation 1 (n = number of samples at a single mine). The total sample size would then be the total of the three sample sizes calculated for the respective mines.

A statistical test can be performed on the data to evaluate whether two or more sets of samples taken at different mines or in different seasons are from distributions (populations) having the same means and variances (Natrella 1963; Hald 1952).^{*} This test was performed in the statistical plan and indicated that all sources at the first two mines/ three visits except coal dozers, haul roads, and overburden drills were from the same populations. Therefore, with the exceptions noted, total sample sizes could be determined directly.

Correction Factors

This approach on which this study has been based is that the final emission factors will be mean emission rates with correction factors attached to adequately account for the wide range of mining and meteorological conditions over which the emission factors must be applied. The use of correction factors may affect required sample sizes, in that correction factors which reduce the uncertainty (standard deviation) in estimating an emission factor also reduce the sample size necessary to attain a desired precision with a specified confidence. Therefore, the partial data from two mines were analyzed for significant correction factors that could reduce the sample standard deviations and thus possibly reduce required sample sizes. It should be pointed out that some additional samples are needed to adequately quantify the effect of each correction factor on the emission factor, so a small reduction in sample size due to the use of a correction factor would be offset by this need for extra data.

Independent variables thought to be candidates for correction factors were measured or monitored with each sample of emission rate. The potential correction factors are listed in Table 5-1.

The approach for evaluation of correction factors described later in this section, multiple linear regression, was used to identify significant correction factors in the partial data set. However, analysis was not as thorough (e.g., did not include transformations) because it was being done only to get a slightly better estimate of the optimum sample size.

The independent variables considered and their effects on standard deviation are summarized in Table 5-1. Using appropriate values of s (standard deviation) in Equation 1, the sample sizes consistent with the previous-discussed relative error of 25 percent and risk level of 20 percent were calculated. These numbers are shown in Table 5-2, which

^{*} Another test, the χ^2 test for goodness of fit, may be more appropriate for determining whether data are from a population with a normal distribution, but it was not used in the original statistical plan.

was taken from the statistical plan. Some \bar{x} and s values in this table may not agree exactly with values reported later in the results sections because of minor changes in calculation procedures between the time the statistical plan (e.g., method of extrapolating to 30 μm SP emission rate) was released and the final report was prepared.

These sample sizes were calculated after 2 mines/3 visits, leaving only one mine visit to obtain all the additional samples. It was not possible to complete the sampling requirements specified in Table 5-2 at the third mine within available project resources. Therefore, an attempt was made to get relative errors for all sources down to 0.31 and major sources (haul trucks, scrapers, and draglines) down to 0.25 by slightly reallocating the number of samples required for several of the sources. Table 5-3 compares four different sets of sample sizes:

1. Originally proposed in study design.
2. Calculated after 2 mines/3 visits to achieve a relative error of 25 percent at risk level of 0.20.
3. Proposed in statistical plan as feasible totals after third mine.
4. Actually collected at 3 mines/4 visits.

CALCULATION PROCEDURES

Exposure Profiling

To calculate emission rates using the exposure profiling technique, a conservation of mass approach is used. The passage of airborne particulate, i.e., the quantity of emissions per unit of source activity, is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. The exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement. The steps in the calculation procedure are presented in the paragraphs below.

Step 1 Calculate Weights of Collected Sample--

In order to calculate the total weight of particulate matter collected by a sample, the weights of air filters and of intake wash filters (profiler intakes and cyclone precollectors only) are determined before and after use. The weight change of an unexposed filter (blank) is used to adjust for the effects of filter handling. The following equation is used to calculate the weight of particulate matter collected.

TABLE 5-1. EVALUATION OF CORRECTION FACTORS WITH PARTIAL DATA SET

Source/ samples	Potential correction factor	Mult. R	Significance	Relative std deviation
Overburden drilling/23	Silt	0.58	0.004	0.838
	Depth of hole	0.63	0.161	0.699
	% moisture	0.63	0.809	0.681
Blasting (coal)/9	No. of holes	0.47	0.199	0.697
	% moisture	0.48	0.860	1.037
Coal loading/10	Bucket capacity	0.39	0.264	0.977
				1.053
Dozer (overburden)/11 overburden	Speed	0.61	0.048	1.149
	Silt	0.69	0.239	1.122
	% moisture	Did not improve regression		0.784
Dozer (coal)/7	Speed	0.84	0.019	0.657
	Silt	Did not improve regression		0.636
	% moisture	Did not improve regression		0.695
Dragline/11	Drop distance	0.88	0.000	0.416
	% moisture	0.91	0.120	1.446
	Bucket capacity	0.92	0.334	0.733
	Operation	0.96 ^a	0.048 ^a	0.662
	Silt	Did not improve regression		0.659
Haul truck/18	Silt	0.40	0.048	0.500
	No. of passes	0.46	0.074	1.470
	Control	0.47	0.148	1.377
	Moisture	0.48	0.258	1.364
Lt.- and med.- duty vehicles/6	Veh. weight (added to above)	0.54 ^b	0.280	1.387
Scraper/ 12	Silt	0.15	0.649	1.419
	% moisture	0.20	0.827	0.888
	No. of passes	0.28	0.877	0.922
Grader/5	Not enough data			0.961
				1.000

^a Interrelated with drop distance, so not used as a correction factor.

^b The four variables for haul roads all explained more variance than vehicle weight, and it did not reduce residual coefficient of variation for combined haul road/access road data set.

TABLE 5-2. CALCULATED SAMPLE SIZES USING TWO-STAGE METHOD

Source	Single pop.	First est.	n_1	$t_{0.8}^a$	s^b	\bar{x}	s/\bar{x}	n , per mine	n , total
Drilling	no	40	11	1.383	From Table 5-1		0.70	15	45
			12	1.372	From Table 5-1		0.70	15	
Blasting (coal)	yes	12	9	1.397	18.7	18.0	1.04		34
Coal loading	yes	30	10	1.383	0.031	0.027	1.15		41
Dozer (ovbd)	yes	18	11	1.383	From Table 5-1		0.56		14
Dozer (coal)	no	18	4	1.638	8.97 ^b	25.4	0.35	6 ^b	
			3	1.886	3.01 ^b	6.54	0.46	12 ^b	27
Dragline	yes	18	11	1.383	From Table 5-1		0.73		17
Haul truck (PEDCo est.)	no	30	5	1.533	4.54	9.67	0.47	9	
			6	1.476	10.37	19.20	0.54	11	30
Haul truck IP (MRI est.)	no	30	6	1.476	3.99	6.68	0.60	13	
			6	1.476	0.62	1.56	0.40	6	29
Lt.- and med.-duty vehicles	yes	15	5	1.533	3.30	2.87	1.15		50
Scraper	yes	18	12	1.363	13.99	15.75	0.89		24
Grader	?	9	5	1.533	0.90	1.7	0.53		11

^a Degrees of freedom (d.f.) for calculating t are $n_1 - 1$ unless there are correction factors, in which case d.f. are reduced by 1 for each correction factor.

^b Smaller sample sizes are required without use of correction factor for speed.

TABLE 5-3. SAMPLE SIZES PROPOSED AND OBTAINED

Source	Samples proposed in study dsn	Samples required by 2-stage method	Samples proposed in stat plan	Rel. error for samples in stat plan	Samples actually collected
Drilling	40	45	30	0.20	30
Blasting (coal)	12	34	16	0.36	16
Coal loading	30	41	24	0.32	25
Dozer (ovbd)	18	14	16	0.31	15
Dozer (coal)	18	27	10	0.31	12
Dragline	18	17	19	0.21	19
Haul truck	30	30	40	0.19	36
Lt.- and med.- duty vehicles	15	50	12 ^a	0.45 ^a	12
Scrapers	18	24	24	0.24	15
Graders	9	11	8	0.27	7

^a Expected to be combined with haul roads in a single emission factor.

$$\text{Particulate sample weight} = \text{Final filter weight} - \text{Tar filter weight} - \text{Final blank weight} - \text{Tare blank weight} \quad (\text{Eq. 2})$$

Because of the typically small fractions of finds in fugitive dust plumes and the low sampling rate of the dichotomous sampler, no weight gain may be detected on the fine filter of this instrument. This makes it necessary to estimate a minimum detectable FP concentration corresponding to the minimum weight gain which can be detected by the balance (0.005 mg). Since four individual tare and final weights produce the particulate sample weight (Equation 2), the minimum detectable weight on a filter is 0.01 mg.

To calculate the minimum FP concentration, the sampling rate ($1 \text{ m}^3/\text{h}$) and duration of sampling must be taken into account. For example, the minimum concentration which can be detected for a one-hour sampling period is $10 \mu\text{g}/\text{m}^3$. The actual sampling time should be used to calculate the minimum concentration.

Step 2 Calculate Particulate Concentrations--

The concentration of particulate matter measured by a sampler, expressed in units of micrograms per standard cubic meter ($\mu\text{g}/\text{scm}$), is given by the following equation.

$$C_s = 3.53 \times 10^4 \frac{\text{m}}{\text{Q}_s \text{ t}} \quad (\text{Eq. 3})$$

where C_s = particulate concentration, $\mu\text{g}/\text{scm}$

m = particulate sample weight, mg

Q_s = sampler flow rate, SCFM

t = duration of sampling, min

The coefficient in Equation 3 is simply a conversion factor. To be consistent with the National Ambient Air Quality Standard for TSP, all concentrations are expressed in standard conditions (25°C and 29.92 in. of Hg).

The specific particulate matter concentrations are determined from the various particulate catches as follows:

TP - Profiler: filter catch + intake catch
 or
Cyclone/cascade impactor: cyclone catch + substrate
 catches + backup filter catch

- TSP Hi-vol sampler: filter catch
- SP - Calculated: sub-30 μm fraction determined by extrapolation
 of sub-2.5 and sub-15 μm fractions assuming a
 lognormal size distribution
- IP - Size-selective inlet: filter catch
 Dichotomous sampler: coarse particulate filter catch +
 fine particulate filter catch
- FP - Dichotomous sampler: fine particle filter catch multiplied
 by 1.11

The dichotomous sampler total flow of 1 m³/h is divided into a coarse particle flow of 0.1 m³/h and a fine particle flow of 0.9 m³/h. The mass collected on the fine particle filter is adjusted for fine particles which remain in the air stream destined for the coarse particle filter.

Upwind (background) concentrations of TP or any of the respective size fractions are subtracted from corresponding downwind concentrations to produce "net" concentrations attributable to the tested source. Upwind sampling at one height (2.5 meters) did not allow determination of vertical variations of the upwind concentration. Because the upwind concentration at 2.5 meters may be greater than at the 4 to 6 meter height of the net downwind profiling tower, this may cause a downward bias of the net concentration. Upwind TP is preferably obtained with an isokinetic sampler, but should be represented well by the upwind TSP concentration measured by a standard hi-vol, if there are not nearby sources that would have a coarse particle impact on the background station.

Step 3 Calculate Isokinetic Flow Ratios--

The isokinetic flow ratio (IFR) is the ratio of the sampler intake air speed to the wind speed approaching the sampler. It is given by:

$$\text{IFR} = \frac{Q}{aU} = \frac{Q_s}{aU_s} \quad (\text{Eq. 4})$$

where Q = sampler flow rate, ACFM

Q_s = sampler flow rate, SCFM

a = intake area of sampler, ft²

U = approaching wind speed, fpm

U_s = approaching wind speed, sfpm

IFR is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias.

Step 4 Calculate Downwind Particle Size Distributions--

The downwind particle size distribution of source--contributed particulate matter at a given height may be calculated from net TP, IP, and FP concentrations at the same height (and distance from the source). Normally, the TP value from the exposure profiler head would be used, unless a cascade impactor operates much closer to isokinetic sampling conditions than the exposure profiler head.

The proper inlet cut-point of each dichotomous sampler must be determined based on the mean wind speed at the height of the sampler. The concentration from a single upwind dichotomous sampler should be adequately representative of the background contribution to the downwind dichotomous sampler concentrations. The reasons are: (a) the background concentration should not vary appreciably with height; (b) the upwind sampler, which is operated at an intermediate height, is exposed to a mean wind speed which is within about 20 percent of the wind speed extremes that correspond to the range of downwind sampler heights; and (c) errors resulting from the above conditions are small because of the typically small contribution of background in comparison to the source plume.

Independent particle size distributions may be determined from a cascade impactor using the proper 50 percent cutoff diameters for the cyclone precollector and each impaction stage. Corrections for coarse particle bounce are recommended.

If it can be shown that the FP and apparent IP fractions of the net TP concentrations do not vary significantly with height in the plume, i.e., by more than about 10 percent, then the plume can be adequately characterized by a single particle size distribution. This size distribution is developed from the dichotomous sampler net concentrations. The fine particle cutpoint of the dichotomous sampler ($2.5\ \mu\text{m}$) corresponds to the midpoint of the normally observed bimodal size distribution of atmospheric aerosol. The coarse mode represents particles produced by a single formation mechanism and can be expected to consist of particles of lognormally distributed size. The best fit lognormal line through the data points (mass fractions of TP) is determined using a standard linear regression on transformed data points as described by Reider and Cowherd (1979). This best fit line is extrapolated or interpolated to determine SP and IP fractions of TP.

Step 5 Calculate Particulate Exposures and Integrate Profiles--

For direction samplers operated isokinetically, particulate exposures may be calculated by the following equation:

$$E = \frac{M}{a} = 2.83 \times 10^{-5} \frac{C_s Q_s t}{a} \quad (\text{Eq. 5})$$

$$+ 3.05 \times 10^{-8} C_s U_s t \quad (\text{Eq. 6})$$

where E = particulate mass collected by sampler, mg

M = net particulate mass collected by sampler, mg

a = sampler intake area, cm^2

C_s = net particulate concentration, $\mu\text{g}/\text{sm}^3$

U_s = approaching wind speed, sfpm

Q_s = sampler flow rate, SCFM

t = duration of sampling, min

The coefficients of Equations 5 and 6 are conversion factors. Net mass or concentration refers to that portion which is attributable to the source being tested, after subtraction of the contribution from background.

Note that the above equations may also be written in terms of test parameters expressed in actual rather than standard conditions. As mentioned earlier, the MRI profiler heads and warm-wire anemometers give readings expressed at standard conditions.

The integrated exposure for a given particle size range is found by numerical integration of the exposure profile over the height of the plume. Mathematically, this is stated as follows:

$$A = \int_0^H E dh \quad (\text{Eq. 7})$$

where A = integrated exposure, $\text{m-mg}/\text{cm}^2$

E = particulate exposure, $\text{m-mg}/\text{cm}^2$

h = vertical distance coordinate, m

H = effective extent of plume above ground,

Physically, A represents the total passage of airborne particulate matter downwind of the source, per unit length of line source.

The net exposure must equal zero at the vertical extremes of the profile, i.e., at the ground where the wind velocity equals zero and at the effective height* of the plume where the net concentrations equals zero. The maximum TP exposure usually occurs below a height of 1 m, so that there is a sharp decay in TP exposure near the ground. The effective height of the plume is determined by extrapolation of the two uppermost net TSP concentrations.

Integration of the portion of the net TP exposure profile that extends above a height of 1 m is accomplished using Simpson's Rule on an odd number of equally spaced exposure values. The maximum error in the integrated exposure resulting from extrapolation above the top sampler is estimated to be one-half of the fraction of the plume mass which lies above the top sampler. The portion of the profile below a height of 1 m is adequately depicted as a vertical line representing uniform exposure, because of the offsetting effects of the usual occurrence of maximum exposure and the decay to zero exposure at ground level (see Figure 5-1).

Step 6 Calculate Particulate Emission Rates--

The TP emission rate for airborne particulate of a given particle size range generated by vehicles traveling along a straight-line road segment, expressed in pounds of emissions per vehicle-mile traveled (VMT), is given by:

$$e = 35.5 \frac{A}{N} \quad (\text{Eq. 8})$$

where e = particulate emission rate, lb/VMT

A = integrated exposure, m-mg/cm²

N = number of vehicle passes, dimensionless

The coefficient of Equation 8 is simply a conversion factor. The metric equivalent emission rate is expressed in kilograms (or grams) of particulate emissions per vehicle-kilometer traveled (VKT).

The SP, IP, and FP emission rates for a given test are calculated by multiplying the TP emission rate by the respective size fractions obtained in Step 4.

Dustfall flux decays with distance downwind of the source, and the flux distribution may be integrated to determine the portion of the TP emission which settles out near the source. Although this effect has been analyzed in

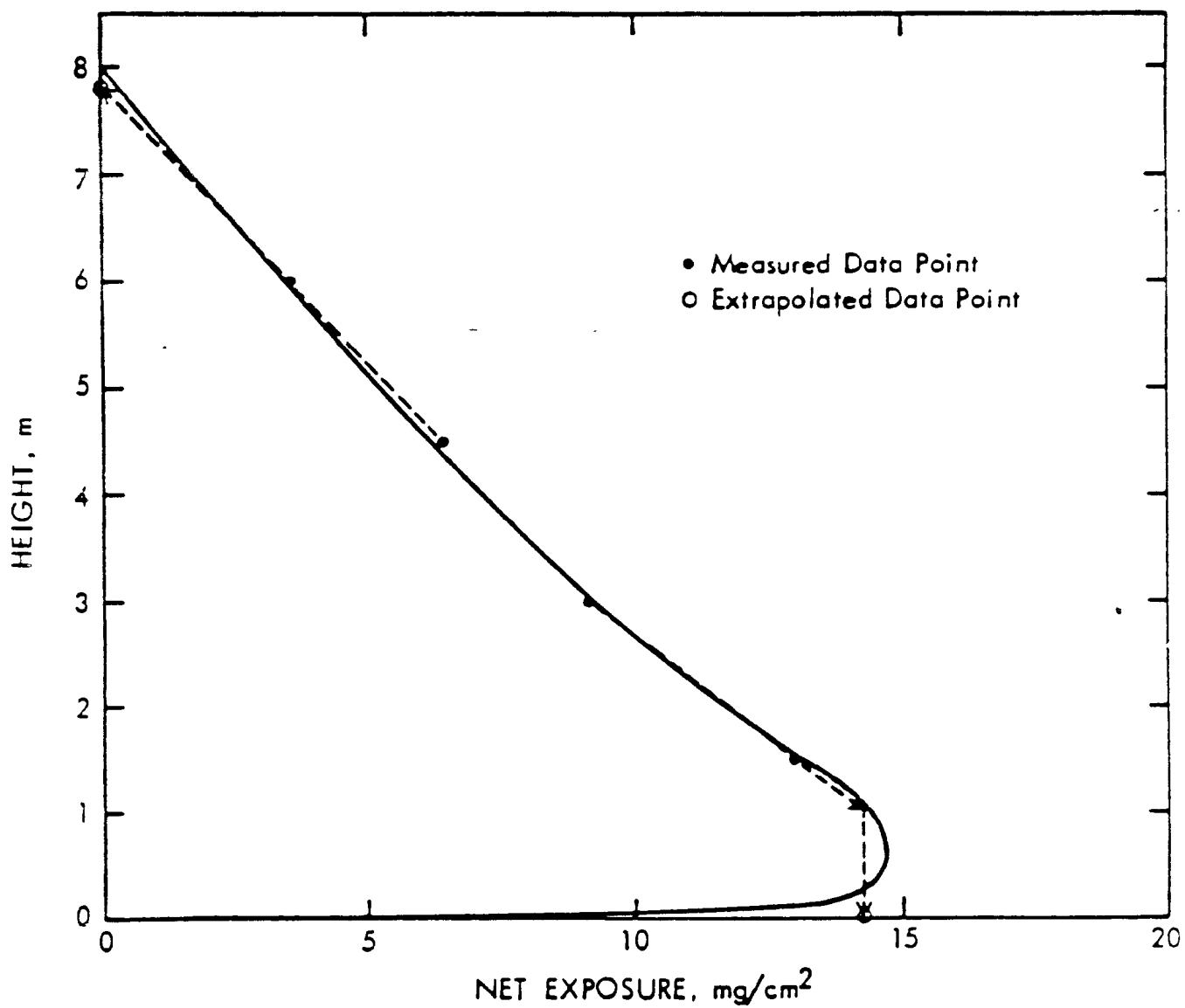


Figure 5-1. Illustration of exposure profile extrapolation procedures (haul truck run J-9).

previous studies, it is not essential to the reduction of profiling data. Consequently, no such analysis is being performed in the present study as part of the profiling calculations.

Upwind-Downwind

The basis for calculation of emission rates in the upwind-downwind sampling method is conversion of ambient concentration data into corresponding emission rates by use of a Gaussian dispersion equation. Two different forms of the Gaussian dispersion equation were used--one for line source and the other for point sources. In both cases, net downwind (downwind minus upwind) concentrations were substituted into the equation along with appropriate meteorological and distance data to calculate apparent source strengths. The eight to 10 samplers in the downwind array resulted in that number of estimates of source strength being produced for each sampling period.

In an interim technical report, the calculation procedures for the upwind-downwind method were explained in slightly greater detail than has been allocated in this report. A step-by-step calculation procedure was presented in the interim report and is summarized below:

1. Determine stability class by σ_R method.
2. Calculate initial plume dispersion, σ_{y0} and σ_{z0} .
3. Determine virtual distance x_0 .
4. Determine source-to-sampler distances.
5. Calculate plume dispersion (σ_y and σ_z) at each downwind sampling distance.
6. Correct measured concentrations for distance of sampler away from plume centerline (for point sources only).
7. Calculate source strength with Gaussian dispersion equation.
8. Convert source strength to an emission rate.

These steps are discussed briefly below.

Step 1 Determine the Stability Class--

Stability class was calculated using the σ_R method. A σ_R value was determined for each test period by the method described on the following page. Stability class was then estimated as presented in Table 5-4. An alternate method of estimating stability, based on wind speed and cloud cover, always agreed within half a stability class with the σ_R method value.

TABLE 5-4. σ_θ METHOD OF DETERMINING ATMOSPHERIC STABILITY CLASS

σ_θ	Stability class
$\sigma_\theta > 22.5^\circ$	A
$17.5 < \sigma_\theta < 22.5$	B
$12.5 < \sigma_\theta < 17.5$	C
$\sigma_\theta < 12.5$	D

($\sigma_\theta < 7.5^\circ$ would be E stability, but D would be used because all sampling occurred during daytime and E is only a nighttime stability class).

Source: Mitchell 1979.

Steps 2 through 5 Calculate Plume Dispersion Coefficients (σ_y and σ_z)--

Value of σ_y and σ_z are a function of downwind distance, x , and stability class. For distances greater than 100 m, Pasquill's dispersion curves can be used to determine values of σ_y and σ_z (Turner 1970, pp-8-9). For distances less than 100 m, the following equations were utilized:

$$\sigma_y = \frac{\sigma_{y0}}{57.3} (x) + \sigma_{y0} \quad (\text{Eq. 9})$$

$$\sigma_z = a(x + x_0)^b \quad (\text{Eq. 10})$$

The variables in Equations 9 and 10 were determined as follows:

- σ_θ - The σ_θ value is the standard deviation of horizontal wind direction and was obtained by dividing the wind direction strip chart recording for the test period into increments of 1 min each, specifying an average direction each increment, and calculating the standard deviation of the resulting set of readings. The upper limit of σ_θ for use in Equation is 32° .
- x - The source-to-sampler distance was measured in the field and later obtained from the sketch of the sampling setup for each test. It is the straight line distance from the source to the sampler rather than the perpendicular distance from the source to a row of samplers.
- σ_{y0} - Initial horizontal plume dispersion is the initial plume width divided by 4.30 (Turner 1970). The average initial plume width was observed and recorded during sampling. Photographs were also taken.
- a, b - These are empirically-derived dispersion coefficients that are only applicable within 100 m of a ground-level source (Zimmerman and Thompson 1975). The coefficients are a function of stability class:

Stability class	a	b
A	0.180	0.945
B	0.145	0.932
C	0.110	0.915
D	0.085	0.870

x_0 - The virtual distance term, x_0 , is used to simulate the effect of initial vertical plume dispersion. It is estimated from the initial vertical plume dispersion value, σ_{z0} , which in turn is the observed initial plume height divided by 2.15 (Turner 1970):

$$x_0 = b \sqrt{\sigma_{z0}/a}$$

Step 6 Correct Concentrations for Distance of Sampler Away from Plume Centerline--

The dispersion equations assume that sampling is done along the plume centerline. For line sources, this is a reasonable assumption because the emissions occur at ground level and have an initial vertical dispersion (σ_{z0}) of 3 to 5 m. Therefore, the plume centerline is about 2.5 m height, the same as the sampler heights. Field personnel attempted to position samplers so that this relationship was maintained even in rough terrain. Horizontal dispersion does not enter into the calculation for line sources.

For point sources, it is not possible to sample continuously along the plume centerline because of varying wind directions and possibly because of varying emission heights (e.g., shovels and draglines). The problem of varying wind direction was accounted for by first determining the resultant wind direction relative to the line of samplers, trigonometrically calculating the horizontal distance from the sampler to the plume centerline (y), and then determining the reduction from centerline concentration with the following equation:

$$\text{reduction factor}_y = e^{-\frac{1}{2} \left[\left(\frac{y}{\sigma_y} \right)^2 \right]} \quad (\text{Eq. 11})$$

Differences in the height of sampling and height of emission release were accounted for in the point source dispersion equation with an additional exponential expression when the average difference in height could be determined. Field personnel noted heights of emission release on data sheets for later use in dispersion calculations. The exponential expression used to determine the reduction from centerline concentration is:

$$\text{reduction factor}_z = e^{-\frac{1}{2} \left[\left(\frac{H}{\sigma_z} \right)^2 \right]} \quad (\text{Eq. 12})$$

where H = average vertical distance from plume centerline to samplers, m

Step 7 Calculate Source Strength with Gaussian Dispersion Equation--

The line source equation was used for haul road, scraper, and some dozer sources. The equation is:

$$x = \frac{2q}{\sin \phi \sqrt{2\pi} \sigma_z u} \quad (\text{Eq. 13})$$

where x = plume centerline concentration at a distance x downwind from the mining source, g/m^3

q = line source strength, g/s-m

ϕ = angle between wind direction and line source

σ_z = the vertical standard deviation of plume concentration distribution at the downwind distance x for the prevailing atmospheric stability, m

u = mean wind speed, m/s

The point source dispersion equation was used in conjunction with dragline, coal loading, and other dozer operations. This equation is:

The point source dispersion equation was used in conjunction with dragline, coal loading, and other dozer operations. This equation is:

$$x = \frac{Q}{\pi \sigma_y \sigma_z u} \quad (\text{Eq. 14})$$

where Q = point source strength, g/s

σ_y = the horizontal standard deviation of plume concentration distribution at the downwind distance x for the prevailing atmospheric stability, m

x, σ_z, u = same as Equation 14

Step 8 Convert Source Strength to an Emission Rate--

The calculated values of q were converted to an emission rate per vehicle (haul roads and scrapers) or per hour. For the per vehicle unit, the q value in g/s-m was divided by the traffic volume during the sampling period. For the per hour unit, the q value was converted to lb/h at normal operating speed. Similarly, point source Q values were converted to emission rates per ton of material handled or per hour.

In summary, upwind-downwind emission rates were calculated using either a point source or line source version of the Gaussian dispersion equation. The point source equation utilized two additional factors to account for

inability to sample on the plume centerline in the horizontal and vertical dimensions. Each sampler produced a separate estimate of emission rate for the test, so eight to 10 values associated with different downwind distances were generated for each test.

IP and FP emission rates could have been calculated by using the procedure described above. However, at any specified point within the plume, the calculated emission rate is directly proportional to measured concentration. Therefore, ratios of measured IP and FP concentrations to TSP concentrations were calculated for each pair of dichotomous and hi-vol samplers. The resulting fractions were multiplied by the calculated TSP emission rate for the corresponding point in the plume to get IP and FP emission rates.

If particle deposition is significant over the distance of the downwind sampler array, apparent emission rates should decrease with distance from the source. Therefore, upwind-downwind sampling provided an implicit measure of the rate of deposition. In addition, the possible decrease in apparent emission rate with distance meant that the eight to 10 different values for a test could not simply be averaged to obtain a single emission rate for the test. The procedure for combining the values is explained in a following subsection.

Balloon Sampling

This calculation procedure combines concepts used in quasi-stack and exposure profiling sampling. However, it is less accurate than either of these two methods because the sampling equipment does not operate at isokinetic flow rates.

The balloon samplers were preset to a flow rate that was isokinetic at a wind speed of 5 mph. Since wind speed only approached this speed in two of the 18 tests, the sampling rates were normally super-isokinetic. The other two types of equipment in the array, hi-vols and dichotomous samplers, sample at a relatively constant air flow. In spite of this limitation, it was judged that a calculation involving integration of concentrations would yield better results than could be obtained by using a dispersion equation.

Step 1 Plot Concentration Data in Horizontal and Vertical Dimensions--

Concentration data from the ground-based hi-vols and balloon-suspended samplers yield a concentration profile of the plume in both the horizontal and vertical directions. By combining these profiles with visual observations and photographs, it was possible to determine the plume boundaries. Conceptually, the next step was to approximate the volume of air that passed the sampling array by multiplying the product of wind speed and sampling duration by the cross-sectional area of the plume. The concept is similar to the procedures used in the quasi-stack calculations. Quasi-stack calculations are discussed in the next subsection.

The calculation procedure is essentially a graphical integration technique. Concentrations measured by the ground-level hi-vols (2.5 m height) were plotted against their horizontal spacing. By using visual observations, photographs taken in the field, and the curve itself, the profile was extrapolated to zero concentration at both edges of the plume. The resulting curve was assumed to represent the concentration profile at ground level and was graphically integrated. This concept is demonstrated in Figure 5-2.

Step 2 Estimate the Volume Formed by the Two Profiles--

The balloon samplers were suspended at five specific heights of 2.5, 7.6, 15.2, 22.9, and 30.5 m. Since concentrations measured by these samplers were not directly comparable to those from hi-vols, concentrations at the four heights about 2.5 m were expressed as ratios of the 2.5 m concentration. The resulting curve of relative concentration versus height was extrapolated to a height of zero concentration, as shown in Figure 5-3. The next step was to multiply each of the ratios by the area under the ground level concentration profile. This produced an approximation of the relative integrated concentration at each of the five heights. By using a trapezoidal approximation technique, an estimate of the volume formed by the two profiles was obtained.

Step 3 Calculate the TSP Emission Rate--

The final emission rate calculation was made with the following equation

$$E = 60 V(u)t \quad (\text{Eq. 15})$$

where E = total emissions from blast, mg

V = volume under the two profiles, mg/m

u = wind speed, m/s

t = sampling duration, min

The final result was then converted to lb/blast. This value was recorded as the TSP emission rate.

The next step was to calculate IP and FP emission rates. The unadjusted IP and FP concentrations for each dichot were expressed as fractions of their associated hi-vol concentrations. Then, the averages of the five unadjusted IP fractions and the five FP fractions were calculated and the 50 percent cut point for IP was adjusted to account for the inlet's dependence on wind speed. A more detailed discussion of the correction for wind speed is presented in a later subsection. The resulting fractions were multiplied by the TSP emission rate and the results reported as IP and FP emission rates.

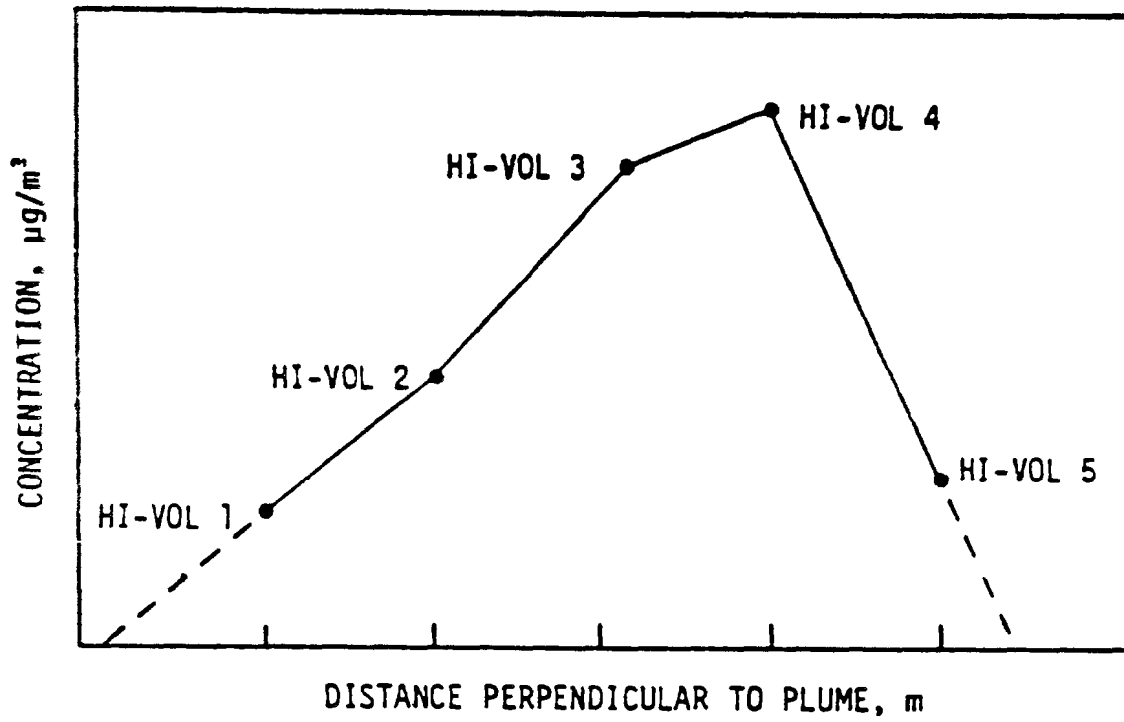


Figure 5-2. Example ground-level concentration profile.

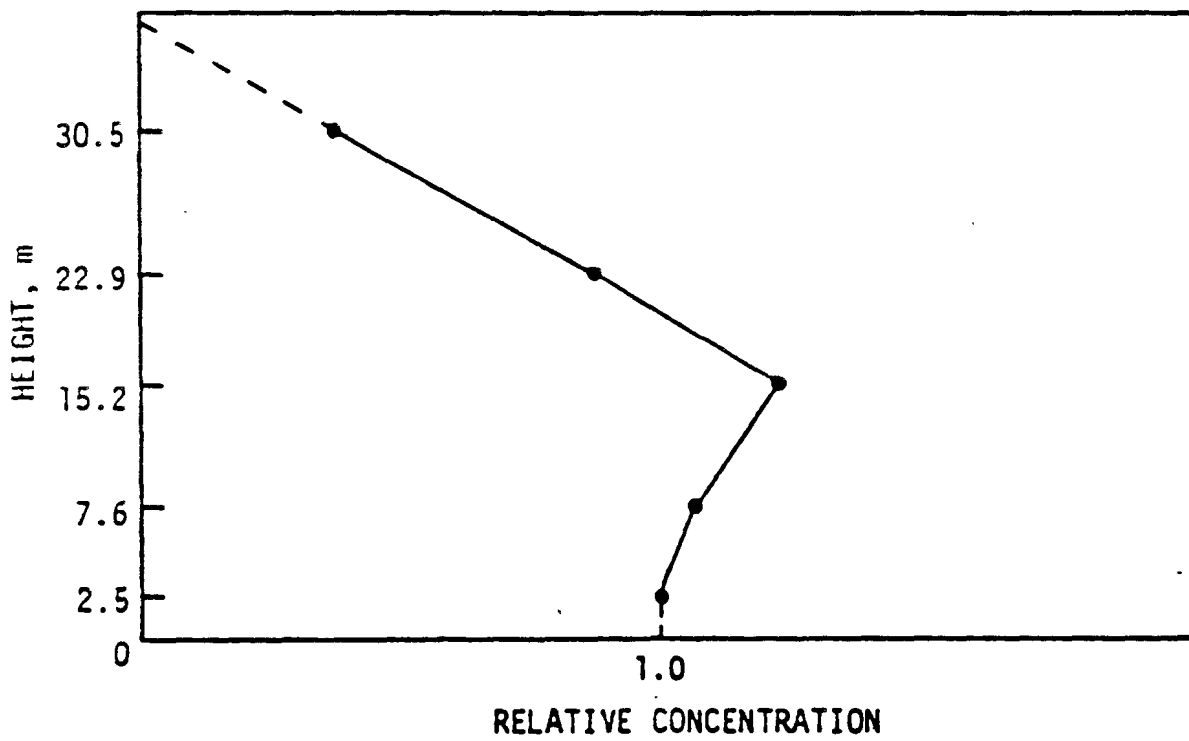


Figure 5-3. Example vertical concentration profile.

The procedure outlined above incorporates a critical assumption concerning particle size distribution. Due to a lack of particle size data at each height, the assumption has been made that the fractions of the concentration less than 15 and 2.5 μm are the same throughout the plume as they are at 2.5 m height. Since particle size distribution measured at ground level was applied to the entire plume, the reported IP and FP emission rates are probably underestimates.

Wind Tunnel

To calculate emission rates from wind tunnel data, a conservation of mass approach is used. The quantity of airborne particulate generated by wind erosion of the test surface equals the quantity leaving the tunnel minus the quantity (background) entering the tunnel. Calculation steps are described below.

Step 1 Calculate Weights of Collected Sample--

The samples are all collected on filters. Weights are determined by subtracting tare weights from final filter weights.

Step 2 Calculate Particulate Concentrations--

The concentration of particulate matter measured by a sampler, expressed in units of micrograms per cubic meter ($\mu\text{g}/\text{m}^3$), is given by the following equation:

$$C = 3.53 \times 10^4 \frac{m}{Q_s t} \quad (\text{Eq. 16})$$

where C = particulate concentration, $\mu\text{g}/\text{m}^3$

m = particulate sample weight, mg

Q_s = sampler flow rate, ACFM

t = duration of sampling, min

The coefficient in Equation 16 is simply a conversion factor.

The specific particulate matter concentrations determined from the various sampler catches are as follows:

TP - Cyclone/cascade impactor: cyclone catch + substrate
catches + backup filter
catch

TSP - Hi-Vol sampler: filter catch

To be consistent with the National Ambient Air Quality Standard for TSP, concentrations should be expressed at standard conditions (25° and 29.92 in. of Hg.).

Tunnel inlet (background) concentrations of TP or any of the respective particulate size fractions are subtracted from corresponding tunnel exit concentrations to produce "net" concentrations attributable to the tested source. The tunnel inlet TP concentration is preferably obtained with an isokinetic sampler, but should be represented well by the TSP concentration measured by the modified hi-vol, if there are no nearby sources that would have a coarse particle impact on the tunnel inlet air.

Step 3 Calculate Tunnel Volume Flow Rate--

During testing, the wind speed profile along the vertical bisector of the tunnel working section is measured with a standard pitot tube and included manometer, using the following equation:

$$u(z) = 6.51 \frac{H(z) T}{P} \quad (\text{Eq. 17})$$

where $u(z)$ = wind speed, m/s

$H(z)$ = manometer reading, in. H_2O

z = height above test surface, cm

T = tunnel air temperature, °K

P = tunnel air pressure, in. Hg

The values for T and P are equivalent to ambient conditions.

A pitot tube and inclined manometer are also used to measure the centerline wind speed in the sampling duct, at the point where the sampling probe is installed. Because the ratio of the centerline wind speed in the sampling duct to the centerline wind speed in the test section is independent of flow rate, it can be used to determine isokinetic sampling conditions for any flow rate in the tunnel.

The velocity profile near the test surface (tunnel floor) and the wall of the tunnel is found to follow a logarithmic distribution (Gillette 1978)

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (\text{Eq. 18})$$

where u^* = friction velocity, cm/s

z_0 = roughness height, cm

The roughness height of the test surface is determined by extrapolation of the velocity profile near the surface to $z=0$. The roughness height for the plexiglas walls and ceiling of the tunnel is 6×10^{-4} cm. These velocity profiles are integrated over the cross-sectional area of the tunnel (30.5 cm x 30.5 cm) to yield the volumetric flow rate through the tunnel for a particular set of test conditions.

Step 4 Calculate Isokinetic Flow Ratio--

The isokinetic flow ratio (IFR) is the ratio of the sampler intake air speed to the wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q_s}{aU_s} \quad (\text{Eq. 19})$$

where Q_s = sampler flow rate, ACFM

a = intake area of sampler, ft^2

U_s = wind speed approaching the sampler, fpm

IFR is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias.

Step 5 Calculate Downstream Particle Size Distribution--

The downstream particle size distribution of source-contributed particulate matter may be calculated from the net TP concentration and the net concentrations measured by the cyclone and by each cascade impactor stage. The 50 percent cutoff diameters for the cyclone precollector and each impaction stage must be adjusted to the sampler flow rate. Corrections for coarse particle bounce are recommended.

Because the particle size cut point of the cyclone is about 11 μm , the determination of suspended particulate (SP, less than 30 μm) concentration and IP concentration requires extrapolation of the particle size distribution to obtain the percentage of TP that consists of SP (or IP). A lognormal size distribution is used for this extrapolation.

Step 6 Calculate Particulate Emission Rates--

The emission rate for airborne particulate of a given particle size range generated by wind erosion of the test surface is given by:

$$e = \frac{C_n Q_t}{A} \quad (\text{Eq. 20})$$

where e = particulate emission rate, $\text{g/m}^2\text{-s}$

C_n = net particulate concentration, g/m^3

Q_t = tunnel flow rate, m^3/s

A = exposed test area = 0.918m^2

Step 7 Calculate Erosion Potential--

If the emission rate is found to decay significantly (by more than about 20 percent) during back-to-back tests of a given surface at the same wind speed, due to the presence of non-erodible elements on the surface, then an additional calculation step must be performed to determine the erosion potential of the test surface. The erosion potential is the total quantity of erodible particles, in any specified particle size range, present on the surface (per unit area) prior to the onset of erosion. Because wind erosion is an avalanching process, it is reasonable to assume that the loss rate from the surface is proportional to the amount of erodible material remaining;

$$M_t = M_o e^{-kt} \quad (\text{Eq. 21})$$

where M_t = quantity of erodible material present on the surface at any time, g/m^2

M_o = erosion potential, i.e., quantity of erodible material present on the surface before the onset of erosion, g/m^2

k = constant, s^{-1}

t = cumulative erosion time, s

Consistent with Equation 21, the erosion potential may be calculated from the measured losses from the test surface to two erosion times:

$$\frac{\ln\left(\frac{M_o - L_1}{M_o}\right)}{\ln\left(\frac{M_o - L_2}{M_o}\right)} = \frac{t_1}{t_2} \quad (\text{Eq. 22})$$

where L_1 = measured loss during time period 0 to t_1 , g/m²

L_2 = measured loss during time period 0 to t_2 , g/m²

The loss may be back-calculated as the product of the emission rate from Equation 20 and the cumulative erosion time.

Quasi-Stack

The source strengths of the drill tests are determined by multiplying the average particulate concentration in the sampled volume of air by the total volume of air that passed through the enclosure during the test. For this calculation procedure, the air passing through the enclosure is assumed to contain all of the particulate emitted by the source. This calculation can be expressed as:

$$E = \chi V \quad (\text{Eq. 23})$$

where E = source strength, g

χ = concentration, g/m³

V = total volume, m³

Step 1 Determine Particle Size Fractions--

As described in Section 3, isokinetic samplers were used to obtain total concentration data for the particulate emissions passing through the enclosure. Originally, these data were to be related to particle size, based on the results of microscopic analyses. However, the inconsistent results obtained from the comparability tests precluded the use of this technique for particle sizing. Consequently, the total concentration data were divided into suspended and settleable fractions. The filter fraction of the concentration was assumed to be suspended particulate and the remainder was assumed to be settleable particulate.

Step 2 Determine Concentration for Each Sampler--

Rather than traverse the enclosure, as is done in conventional source testing, four separate profiler samplers were used during each test. The samplers were spaced at regular intervals along the horizontal centerline of the enclosure. Each sampler was set to approximate isokinetic sampling rate. This rate was determined from the wind velocity measured at each sampler with a hot-wire anemometer. The wind velocity was checked at each sampler every 2 to 3 minutes and the sampling rates were adjusted as necessary.

Step 3 Calculate volume of Air Sampled by Each Profiler--

In order to simplify the calculation of source strength, it was assumed that the concentration and wind velocity measured at each sampler were representative of one-fourth the cross-sectional area of the enclosure. Thus, the total volume of air associated with each profiler concentration was calculated as follows:

$$V_i = (u_i) (a/4)(t) \quad (\text{Eq. 24})$$

where V_i = total volume of air associated with sampler i , m^3

u_i = mean velocity measured at sampler i , m/min

a = cross-sectional area of enclosure, m^2

t = sampling duration, min

Step 4 Calculate the Total Emissions as Sum of Four Partial Emission Rate

Separate source strengths, E , are calculated for the total concentration and the fraction captured on the filter. The equation is:

$$E = \sum_{i=1}^4 V_i x_i \quad (\text{Eq. 25})$$

These source strengths, in grams, were converted to pounds per hole drilled and are reported in Section 11.

PARTICLE SIZE CORRECTIONS

Several different size fraction measurements require a mathematical calculation to correct for some deficiency in the sampling equipment from ideal size separation. Three of the calculation procedures are described here:

Correction of dichotomous samples to 15 μm values

Conversion of physical diameters measured microscopically to equivalent aerodynamic diameters

Correction of cascade impactor data to account for particle bounce-through.

Correction of Dichotomous Data

Recent research indicates that the collection efficiency of the dichotomous sampler inlet is dependent on wind speed (Wedding 1980). As shown in Figure 5-4, the 50 percent cut point that is nominally 15 μm actually varies from 10 to 22 μm over the range of wind speeds tested.

The procedure developed in the present study to correct dichot concentrations to a 15 μm cut point was to:

1. Determine the average wind speed for each test period.
2. Estimate the actual cut point for the sample from Figure 5-4.
3. Calculate net concentrations for each stage by subtracting upwind dichot concentrations.
4. Calculate the total concentration less than the estimated cut point diameter by summing the net concentrations on the two stages.
5. Adjust the fine fraction ($<2.5 \mu\text{m}$) concentration by multiplying by 1.11 to account for fine particles that remain in the portion of the air stream that carries the coarse fraction particles.
6. Calculate the ratio of fine fraction to net TSP concentration and the ratio of total net dichot concentration to net TSP concentration.
7. Plot (on log-probability paper) two data points on a graph of particle size versus fraction of TSP concentration. The two points are the fraction less than 2.5 μm and the fraction less than the cut point determined in step 2.
8. Draw a straight line through the two points and interpolate or extrapolate the fraction less than 15 μm . (Steps 7 and 8 are a graphical solution that may be replaced by a calculator program that can perform the linear interpolation or extrapolation with greater precision.)

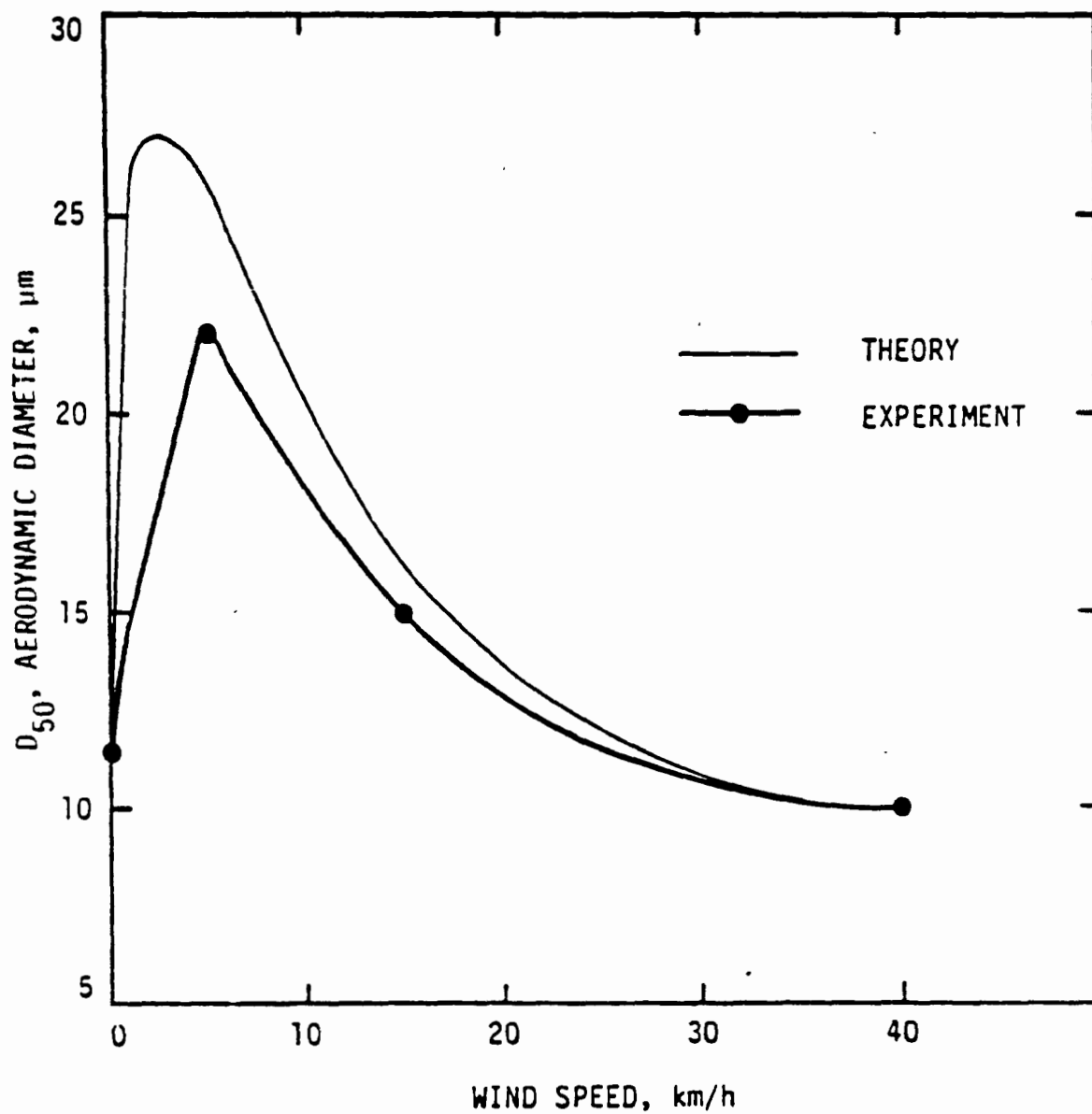


Figure 5-4. Plot of the 50 percent cut point of the inlet versus wind speed.

9. Calculate the net concentration less than 15 μm from this fraction and the known net TSP concentration.

A relatively small error is involved in the assumption of a log linear curve between the two points because the 15 μm point is so near the point for the actual upper limit particle size. The largest uncertainty in applying this correction is probably the accuracy of the research data in Figure 5-4.

* Conversion of Microscopy Data to Aerodynamic Diameters

Three calculation procedures for converting physical particle diameters into equivalent aerodynamic diameters were found in the literature (Hesketh 1977; Stockham 1977; and Mercer 1973). One of these was utilized in calculations in a recent EPA publication, so this procedure was adopted for the present project (U.S. Environmental Protection Agency 1978b). The equation relating the two measurements of particle size is:

$$d_a = d \sqrt{\frac{\rho C}{C_a}} \quad (\text{Eq. 26})$$

where d_a = particle aerodynamic diameter, μm

d = particle physical diameter, μm

ρ = particle density

C = Cunningham factor

$$= 1 + 0.000621 T/d$$

T = temperature, $^{\circ}\text{K}$

C_a = Cunningham correction for d_a

This equation requires a trial-and-error solution because C_a is a function of d . The multiple iterations can be performed by a computer or calculator program (U.S. Environmental Protection Agency 1978b).

In practice, C_a is approximately equal to C so the aerodynamic diameter (d_a) is approximately the physical diameter (d) times ρ . An average particle density of 2.5 was assumed with the microscopy data from this study, thus yielding conversion factors of about 1.58. It is questionable whether the trial-and-error calculation of C_a in Equation 26 is warranted when density values are assumed.

Correction of Cascade Impactor Data

To correct for particle bounce-through, MRI has developed a procedure for adjusting the size distribution data obtained from its cascade impactors, which are equipped with cyclone precollectors. The true size distribution (after correction) is assumed to be lognormal as defined by two data points: the corrected fraction of particulate penetrating the final impactation stage (less than $0.7\text{ }\mu\text{m}$) and the fraction of particulate caught by the cyclone (greater than about $10\text{ }\mu\text{m}$). The weight of material on the backup stage was replaced (corrected) by the average of weights caught on the two preceding impactation stages if the backup stage weight was higher than this average.

Because the particulate matter collected downwind of a fugitive dust source is produced primarily by a uniform physical generation mechanism, it was judged reasonable to assume that the size distribution of airborne particulate smaller than $30\text{ }\mu\text{m}$ is lognormal. This in fact is suggested by the uncorrected particle size distributions previously measured by MRI.

The isokinetic sampling system for the portable wind tunnel utilizes the same type of cyclone precollector and cascade impactor. An identical particle bounce-through correction procedure was used with this system.

COMBINING RESULTS OF INDIVIDUAL SAMPLES AND TESTS

Combining Samples

In the quasi-stack and exposure profiling sampling methods, multiple samples were taken across the plume and the measurements were combined in the calculations to produce a single estimate of emission rate for each test. However, in the upwind-downwind method, several (eight to 10) independent estimates of emission rate were generated for a single sampling period. These independent estimates were made at different downwind distances and therefore had differing amounts of deposition associated with them.

The procedure for combining upwind-downwind samples was based on comparison of emission rates as a function of distance. If apparent emission rates consistently decreased with distance (not more than two values out of progression for a test), the average from the front row samplers was taken as the initial emission rate and deposition at succeeding distances was reported as a percent of the initial emission rate. If apparent emission rates did not have a consistent trend or increased with distance, then all values were averaged to get an emission rate for the test and deposition was reported as negligible. Since deposition cannot be a negative value, increases in apparent emission rates with distance were attributed to data scatter, non-Gaussian plume dispersion, or inability to accurately locate the plume centerline (for point sources).

The amount of deposition from the front row to the back row of samplers is related to the distance of these samplers from the source, i.e., if the front samplers are at the edge of the source and back row is 100 m downwind (this was the standard set-up for line sources), a detectable reduction in apparent emission rates should result. However, if the front row is 60 m from the source and back row is 100 m further downwind (typical set-up for point sources due to safety considerations), the reduction in apparent emission rates with distance is likely to be less than the average difference due to data scatter.

These dual methods of obtaining a single estimate of emission rate for each test introduce an upward bias into the data; high levels on the front row in general lead to their retention as the final values, while low levels in general lead to averaging with higher emission rates from subsequent rows. This bias is thought to be less than the errors that would result in applying either of these methods universally for the different deposition situations described above. It should also be noted that other types of deposition measurements are possible.

Any single estimate more than two standard deviations away from the average of the remaining samples was considered an outlier and not included in calculating the average emission rate.

Combining Tests

Emission rates for three particle size ranges were reported for all tests, along with data on the conditions under which the tests were taken. These data were first subjected to multiple linear regression (MLR) analysis, as described below. Of the three size ranges, only the TSP and IP data were used in the MLR analysis. This analysis identified significant correction parameters for each source.

Next, adjusted emission rates were calculated for each test with the significant correction parameters. From this data set, average emission rates (base emission factors) and confidence intervals were calculated. The emission factor equation is this average emission rate times the correction factors determined from the MLR analysis.

PROCEDURE FOR DEVELOPMENT OF CORRECTION FACTORS

The method used to evaluate independent variables for possible use as correction factors was stepwise MLR. It was available as a compute program as part of the Statistical Package for the Social Sciences (SPSS). The MLR program outputs of interest in evaluating the data sets for each source were the multiple regression coefficient, significance of the variable, and reduction in relative standard deviation due to each variable. The stepwise MLR technique is described in moderate detail in Appendix A. Further information on it can be found in the following references:

Statistical Methods, Fourth Edition (Snedecor 1946); Applied Regression Analysis (Draper 1965); and SPSS, Second Edition (Nie 1975).

Because of the high relative standard deviations (s/\bar{x}) for the data sets and the desire to have correction factors in the emission factor equations multiplicative rather than additive, all independent and dependent variable data were transformed to natural logarithms before being entered in the MLR program.

The stepwise regression program first selected the potential correct factor that was the best predictor of TSP emission rate, changed the dependent variable values to reflect the impact of this independent variable, then repeated this process with remaining potential correction factors until all had been used in the MLR equation or until no improvements in the predictive equation was obtained by adding another variable. Not all variables included in the MLR equation were necessarily selected as correction factors.

A detailed description of correction factor development procedures is given in Section 13 of Volume II.

SECTION 6

RESULTS OF SIMULTANEOUS EXPOSURE PROFILING AND UPWIND-DOWNWIND SAMPLING

The exposure profiling and upwind-downwind samplers were run on a common source for several tests so that simultaneous measurements by these methods could be compared. This complex undertaking was essential to establish that the methods were yielding similar results. The simultaneous sampling, called the comparability study, was performed before any of the other testing so that any major discrepancies could be resolved or the study design reevaluated prior to sampling at the second and third mines.

The original intent was to prepare a technical report on the results of the comparability study and any recommended sampling modifications for distribution between the first and second mine visits. However, a series of changes in the method of calculating the suspended particulate fraction of the total profile catch and the temporary nonavailability of an EPA-recommended computer program for particle size interpolation prevented the exposure profiling values from being determined. Preliminary calculations for six of the 10 tests, presented at a September 13, 1979 meeting of the technical review group after completing the last comparability test on August 9, indicated good agreement between the two methods:

The average ratio for 14 pairs of simultaneous measurements was reported to be 0.92, with only two of the paired values differing by more than a factor of 2.0.

Therefore, sampling was conducted as specified in the study design report at the other two mines. By the time the calculations for suspended particulate from profiler tests were finalized, the need for a separate comparability study report had passed.

DESCRIPTION OF COMPARABILITY STUDY

The two sources selected for testing in the comparability study were haul roads and scrapers. They are ground-level moving point sources (line sources) that emit from relatively fixed boundaries, so the alternative sampling methods are both appropriate and the extensive sampling array could be located without fear of the source changing locations. Also, haul roads and scrapers were suspected to be two of the largest fugitive dust emission sources at most surface coal mines.

Five tests of each source were conducted over a 15-day period. One additional haul road test was attempted but aborted because of wind direction reversal shortly after the beginning of the test. The individual tests were of about one hour duration. All five tests of each source were performed at a single site; only two sites and one mine were involved in the comparability study.

Profiling towers were placed at three distances from the source--5, 20, and 50 m--in order to measure the decrease in particulate flux with distance, and indirectly the deposition rate. The relatively large distances of the back profiler from the source created one problem: these two profilers had to be significantly taller than the first tower because the vertical extent of the plume expands with distance from the source. The towers were fabricated to be 9 and 12 m high, respectively, for the 20 and 50 m setbacks.

Hi-vols and dichotomous samplers for the upwind-downwind configuration were located at the same three downwind distances as the profiling towers. Two samplers of each type were placed at these distances. In addition, two hi-vols were located at 100 m downwind of the source.

Duplicate dustfall buckets were placed at the 5, 20, and 50 m distances to measure deposition rates directly, for comparison with the calculated plume mass depletion rates from the profiler and upwind-downwind samplers. Some sampling equipment was also set out to obtain independent particle size distribution measurements. Cascade impactors were placed at two heights at 5 m setback and at one height at 20 m. Millipore filters for microscopic examination were exposed briefly during each sampling period at five different heights (corresponding to profiler sampling head heights) at the 20 m distance.

Upwind samplers consisted of three hi-vols and a dichotomous sampler, all located 20 m from the upwind edge of the source. Two of these were operated by PEDCo as part of the upwind downwind array, and the other two (hi-vols at 1.5 and 2.5 m height) were operated by MRI as the background samplers at the 5 m downwind distance as parts of their separate arrays, but which also served as quality assurance checks for the sampling and equipment.

Finally, wind speed and direction were continuously recorded during the tests by separate instruments operated by PEDCo and MRI. Profile samplers on each tower were kept at isokinetic flow rates by frequency monitoring hot-wire anemometers at the heights of each of the samplers and adjusting flows to match measured wind speeds. Therefore, wind speeds from five different locations in the sampling array and two wind direction charts were available for comparison.

The sampling configuration used in the comparability study is shown schematically in Figure 6-1. These sampling periods involved much extra equipment, so it was not feasible to use this configuration throughout the project.

RESULTS OF COMPARABILITY STUDY

Particle Size Data

Particle size data were generated by three different methods in the comparability study: dichotomous sampler, cascade impactor and microscopy. These three methods all have some shortcomings; corrections to the data were required in all three cases. The cut point for the coarse stage of the dichotomous sampler was adjusted to eliminate the wind speed error of the inlet design. The backup filter weight of the cascade impactor was reduced to correct for particle bounce-through; this weight reduction averaged 4.2 percent of the total particulate sample for the ten comparability tests shown in Table 6-1. Physical particle sizes measured under the microscope were converted to equivalent aerodynamic diameters for comparison with the other size data. The procedures for these corrections were described in Section 5.

The particle size data for collocated samplers are presented in Table 6-1. For better visual comparison, the size distributions are also shown graphically in Figures 6-2 and 6-3. In order to reduce the curves on each graph to a manageable number, the duplicate samples taken by the same method at each distance (see Table 6-1) have been averaged to create a single curve. All of the dichot and impactor curves are straight lines because they are based on two data points and an assumption of lognormal distribution of particles by weight.

Microscopy produced the widest variations between samples--some showed that less than 10 percent of the particles were sub-30 μm and others showed all particles in the sample to be less than 15 μm . It was concluded that the relatively small number of particles counted manually on each filter (300 to 500) precluded the samples from being representative of the actual size distribution. This is particularly evident when the number of large particles counted is considered. Each particle of 40 μm diameter observed has 64,000 times the mass of a 1 μm particle and 64 times the mass of a 10 μm particle. Therefore, if two particles larger than 40 μm are found in the fields selected, this could result in 30 percent by weight being in that size range; whereas, a sample with one particle larger than 40 μm would have only about 17 percent of its weight in that size range. Thus, one extra large particle shifts the entire distribution by 13 percent in this example.

This evaluation is not an indictment of optical microscopy as a particulate assessment technique. In cases where there are different

HI-VOL
 DICHOTOMOUS SAMPLER
 PROFILER HEAD
 CASCADE IMPACTOR
 DUSTFALL

<u>MRI</u>	<u>PEDCo</u>
▲	▲
△	▲
□	■
○	
┐	

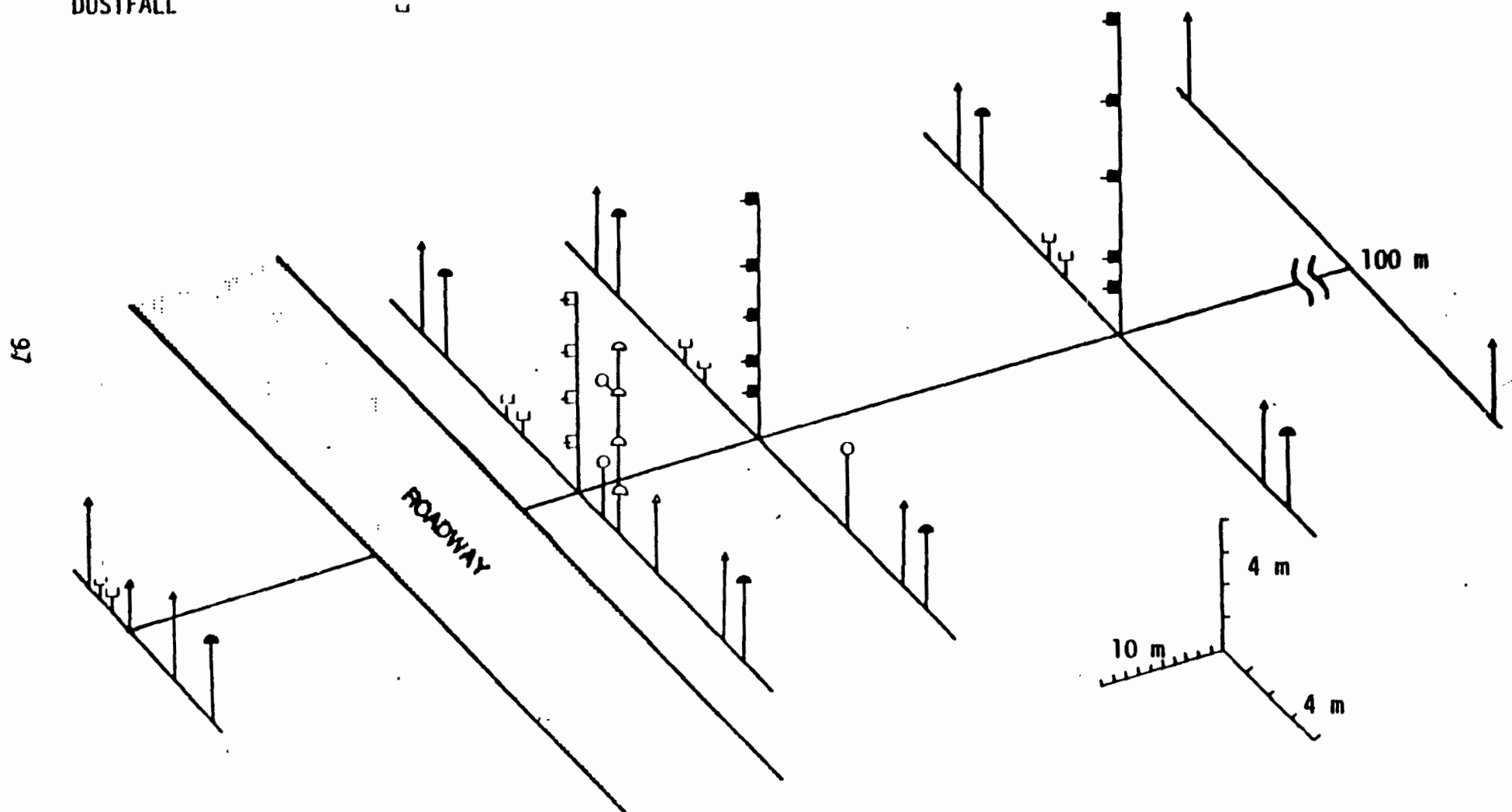


Figure 6-1. Sampling configuration for comparability studies.

TABLE 6-1. COMPARISON OF PARTICLE SIZE DATA OBTAINED BY DIFFERENT TECHNIQUES

Test	Aero- dynamic size μm	Cumulative percent smaller than stated size									
		At 5 m dist				At 20 m dichot, 2.5 m ht				At 50 m, 2.5 m ht	
		Dichot		Impactor		Dichot		Impactor	Micro- scopy	Dichot	
		3.0 m	6.0 m	1.5 m	4.5 m	Left	Right			Left	Right
J1	2.5	0.5	1.3	2.2	2.7	0.6	0.6	7.2	a	a	a
	5.0	2.1	3.2	4.2	5.4	3.2	4.0	12.3	a	a	a
	10.0	6.3	7.3	7.4	9.8 ^b	11.9	16.0	19.7	a	a	a
	15.0	11.0	11.0	10.0 ^b	13.5 ^b	21.4	29.1	25.1 ^b	a	a	a
	20.0	15.5	14.4			30.2	40.7		a	a	a
	30.0	23.7	20.3			44.9	67.8		a	a	a
J2	2.5	1.0	1.2	2.1	19.9	0.8	0.6	1.3	a	4.4	2.8
	5.0	1.6	3.3	4.3	35.7	2.1	2.8	2.6	a	8.2	5.5
	10.0	2.5	7.8	8.2	54.3 ^b	5.0	9.6	4.9 ^b	a	14.1	10.0
	15.0	3.3	12.1	11.5 ^b	65.1 ^b	7.7	17.1	6.8 ^b	a	18.7	13.6
	20.0	3.9	16.0			10.2	24.2		a	22.4	16.6
	30.0	5.0	22.7			14.8	36.4		a	28.3	21.5
J3	2.5	0.7	5.6	5.7	4.6	0.9	0.7	4.7	9.6 ^c	2.0	1.6
	5.0	2.3	11.2	11.2	9.1	3.4	4.0	8.6	21.3	5.7	4.9
	10.0	6.4	20.1	19.6 ^b	16.3 ^b	10.1	15.0	14.6 ^b	33.4	13.2	12.3
	15.0	10.6	26.8	26.1 ^b	21.8 ^b	17.0	26.8	19.2 ^b	44.9	19.9	19.1
	20.0	14.6	32.1			23.3	37.3		68.8	25.8	25.2
	30.0	21.8	40.3			34.2	53.2		100.0	35.4	35.1
J4	2.5	0.4	1.5	2.7	4.4	2.2	2.2	6.2	<0.1 ^c	3.7	3.7
	5.0	1.3	3.2	4.9	8.2	4.6	5.3	11.5	0.2	7.8	7.4
	10.0	3.7	6.3	8.4 ^b	14.1 ^b	8.6	11.1	19.2 ^b	0.7	14.6	13.2
	15.0	6.1	7.0	11.2 ^b	18.7 ^b	12.0	16.1	24.9 ^b	2.0	20.1	17.9
	20.0	8.5	11.4			14.8	20.5		4.4	24.7	21.7
	30.0	13.0	15.4			19.7	27.6		8.8	31.9	27.9
J5	2.5	1.8	2.5	6.5	5.5	2.7	3.1	6.6	2.3 ^c	7.8	7.6
	5.0	4.3	4.6	11.6	10.0	4.8	7.4	11.9	11.6	13.8	13.3
	10.0	9.1	7.8	19.1 ^b	16.7 ^b	8.0	15.2	19.7	44.9	22.3	21.4
	15.0	13.2	10.4	24.6 ^b	21.8 ^b	10.5	21.7	25.4 ^b	100.0	28.3	27.2
	20.0	16.9	12.6			12.5	27.1			33.1	31.7
	30.0	23.0	16.1			15.9	35.8			40.3	38.6
J9	2.5	0.9	2.7	2.3	2.7	1.4	1.6	3.2	2.5 ^c	1.8	1.8
	5.0	3.0	7.1	4.9	5.3	5.3	8.7	6.7	12.9	6.3	7.0
	10.0	8.5	15.6	9.5 ^b	9.5 ^b	14.8	28.4	12.4	54.4	16.8	19.7
	15.0	13.9	22.9	13.4 ^b	12.8 ^b	23.9	45.5	16.9 ^b	69.7	26.5	31.2

(continued)

TABLE 6-1 (continued).

Test		Aero- dynamic size μm	Cumulative percent smaller than stated size									
			At 5 m dist				At 20 m dichot, 2.5 m ht				At 50 m, 2.5 m ht	
			Dichot		Impactor		Dichot		Impactor	Micro- scopy	Dichot	
			3.0 m	6.0 m	1.5 m	4.5 m	Left	Right			Left	Right
J10	20.0	19.1	29.0			31.9	58.0		87.6	34.7	40.8	
	30.0	28.0	38.8			44.7	74.6		100.0	47.5	54.7	
	2.5	1.2	3.5	7.3	4.7	3.4	1.7	9.8	<0.1 ^c	4.0	2.0	
	5.0	4.1	11.2	13.0	9.3	14.1	9.9	17.0	0.3	10.0	5.9	
	10.0	11.2	27.0	21.3 _b	16.7 _b	37.1	32.3	27.0 _b	1.2	20.9	14.0	
	15.0	18.0	39.8	27.3 _b	22.4 _b	53.9	50.6	33.9 _b	4.2	29.6	21.4	
	20.0	24.3	49.6			65.8	64.1		6.3	36.7	27.7	
J12	30.0	34.7	63.4			80.1	80.1		9.4	47.4	37.9	
	2.5	1.5	6.8	5.4	13.5	3.5	2.8	11.5	0.8 ^c	3.6	4.5	
	5.0	4.5	14.1	10.2	22.7	10.0	7.7	19.6	19.5	8.9	11.8	
	10.0	11.1	25.4	17.7 _b	34.7 _b	22.6	17.4	30.5 _b	88.7	18.4	24.8	
	15.0	17.3	33.6	23.3 _b	42.6 _b	32.9	25.6	37.8 _b	100.0	26.2	35.0	
	20.0	22.8	40.1			41.2	32.5			32.6	43.0	
	30.0	31.9	49.6			53.0	43.3			42.5	54.3	
J20	2.5	0.5	0.4	3.7	3.9	7.7	5.0	5.8	a	2.5	2.9	
	5.0	2.7	2.2	6.7	7.2	15.5	12.5	9.9	a	7.0	9.3	
	10.0	10.6	8.9	11.3 _b	12.4 _b	27.2	25.5	16.0 _b	a	15.9	22.6	
	15.0	19.6	16.8	14.9 _b	16.4 _b	35.7	35.6	20.5 _b	a	23.6	33.8	
	20.0	28.2	24.6			42.2	43.5			30.2	42.8	
	30.0	42.7	38.2			51.2	54.4			40.6	55.6	
	2.5	0.6	0.4	7.7	9.0	2.8	4.5	10.0	a	8.7	5.4	
J21	5.0	2.6	1.4	14.3	16.2	8.3	11.0	18.5	a	17.1	15.2	
	10.0	8.3	3.8	23.8 _b	26.4 _b	19.4	22.4	30.5 _b	a	29.4	32.6	
	15.0	14.5	6.2	30.6 _b	33.5 _b	28.8	31.3	38.8 _b	a	38.2	45.6	
	20.0	20.3	9.1			36.6	38.5			44.7	54.6	
	30.0	30.7	14.0			48.5	49.2			53.8	67.5	

^a No data.

^b Extrapolated from 10 μm and 0.7 μm data.

^c Extrapolated assuming a lognormal distribution below 5 μm .

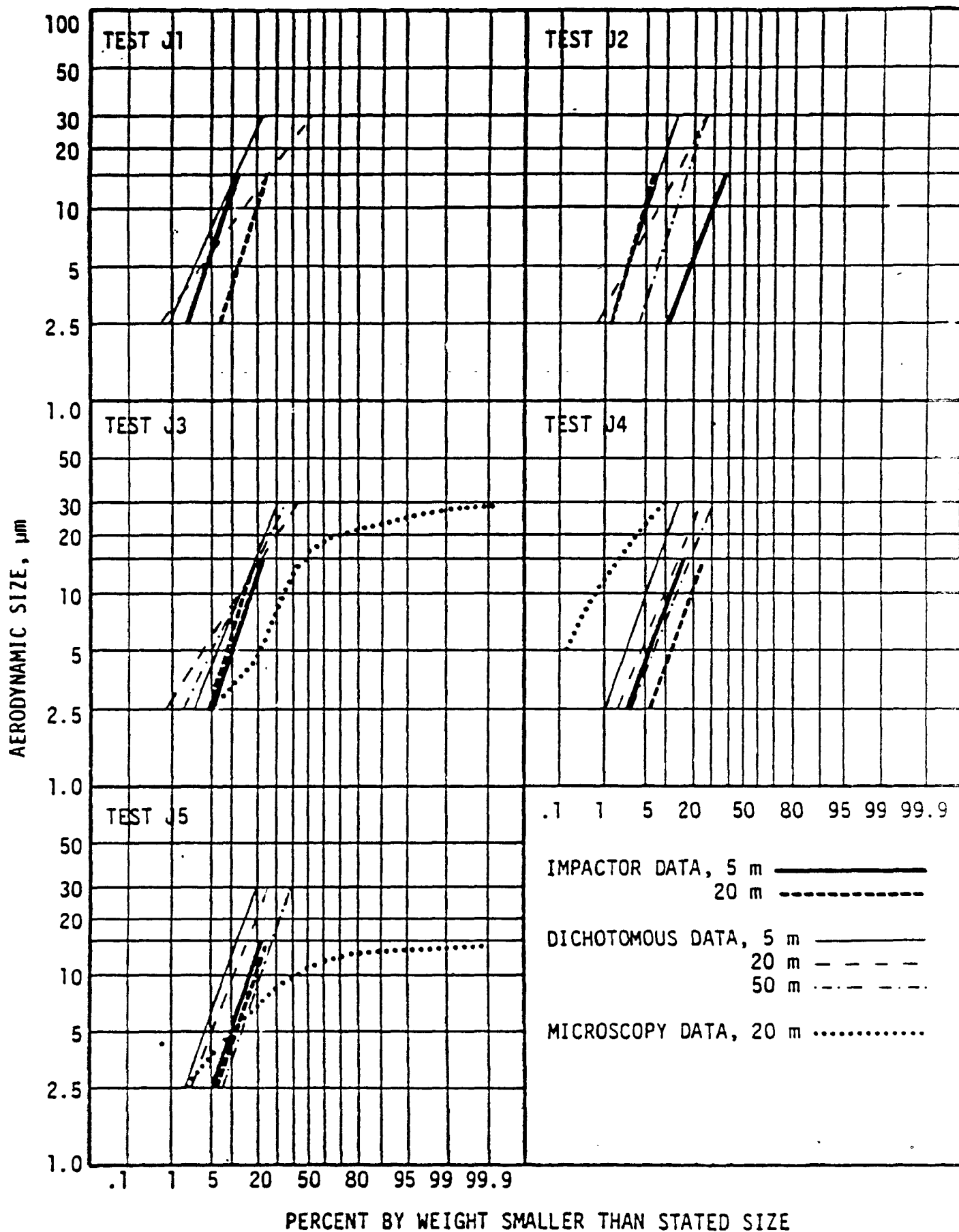


Figure 6-2. Particle size distributions from comparability tests on scrapers.

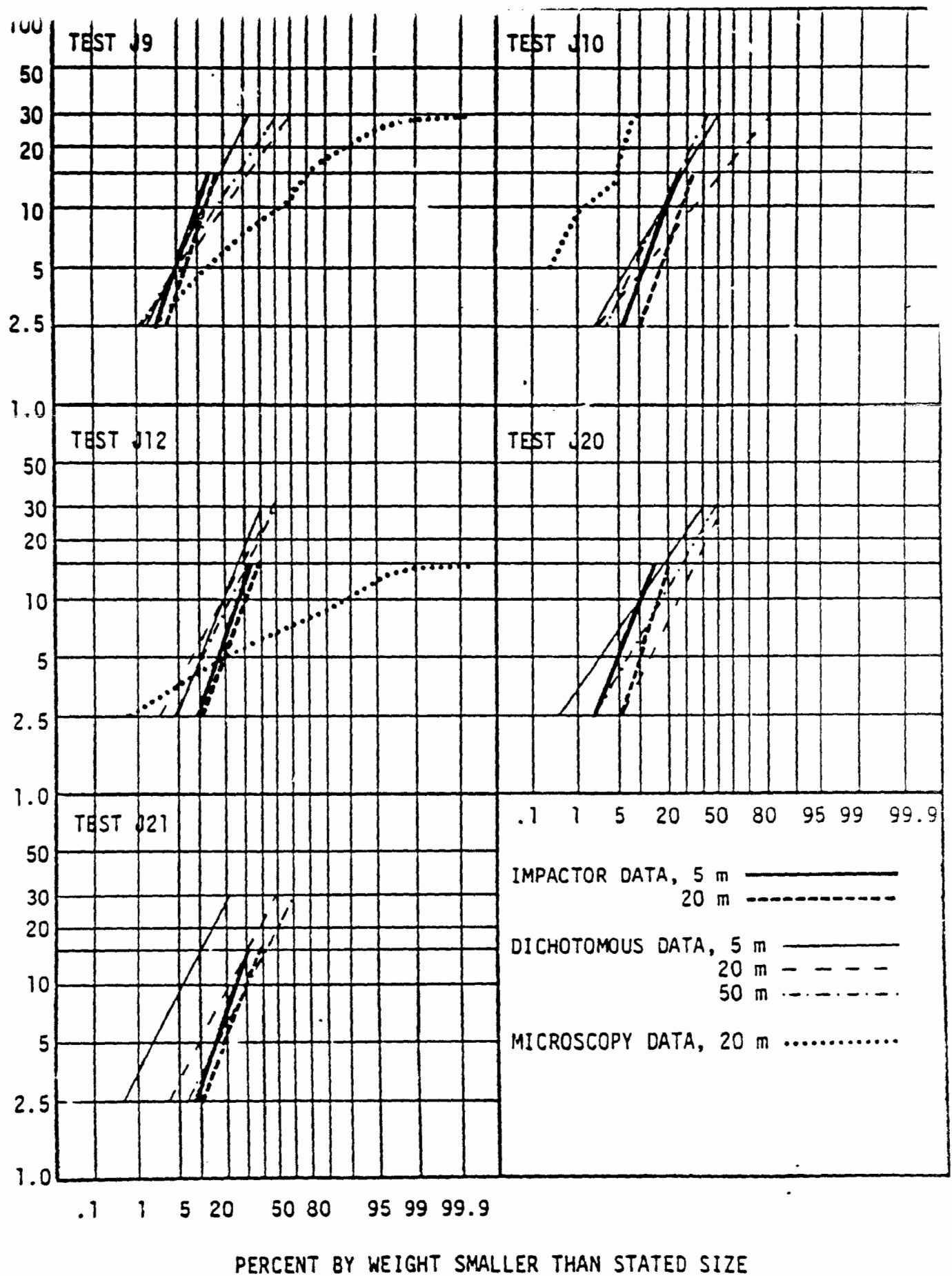


Figure 6-3. Particle size distributions from comparability tests on haul road.

particle types present and the primary purpose is to semiquantitatively estimate the relative amounts, microscopy is usually the best analytical tool available. However, as a pure particle sizing method, microscopy appears to be inadequate compared to available aerodynamic techniques.

In contrast, the dichotomous samplers and cascade impactors produced fairly consistent size distributions from test to test (as would be expected) and reasonably good agreement between methods. The cascade impactor data always indicated higher percentages of particles less than $2.5\ \mu\text{m}$, but approached the cumulative percentages of the dichot method for the 10 to $15\ \mu\text{m}$ sizes. This may reveal that the corrections to impactor data for particle bounce-through were not large enough.

Data from the dichots at 3 and 6 m heights and the impactors at 1.5 and 4.5 m heights had similar variations in size distribution with height. For both types of samplers, most of the tests (6 out of 10) showed more large particles on the lower sampler, but several tests showed larger particles on the upper sampler. This provides evidence that the plume is still not well formed at the 5 m distance from the source.

Comparison of size distributions taken at successive distances from the source revealed that the percentage of small particles increased from 5 m samples to 20 m samples in all but two cases out of 20. This finding is consistent with the premise of fallout of larger particles. However, reduction in mean particle size was not obvious in the comparison of corresponding data from 20 m and 50 m; only half the tests showed a further decrease in average particle size and some actually had larger average particle sizes.

The dichotomous samplers appeared to give the most reliable results, either by comparing the distributions taken at different distances in the same test or by evaluating the effects of corrections made to the raw data. As indicated in Section 4, handling problems with the dichot filter and light loadings on the fine particle stages prevented this from being a completely satisfactory sizing method for the large numbers of samples generated in the full study. Sampling precision errors resulting from these factors are quantified in the following subsection. These problems are discussed further in Section 12, Volume II.

The ratios of net fine particulate (less than $2.5\ \mu\text{m}$) and inhalable particulate to net TSP are also sizing measures of interest. These data for collocated samplers in the comparability study are presented in Table 6-2. The average ratio for all the fine particulate (FP) samples was 0.039, indicating a very low percentage of small particles in the plumes. As expected, this ratio increased with distance from the source due to fallout of larger particles but not of the fine particles. The average ratios at 5, 20, and 50 m downwind were 0.016, 0.042, and 0.062, respectively. Inhalable particulate constituted a much larger fraction of TSP--an average ratio of 0.52. Again, the differential effect of fallout on large particles

was evident. The average IS/TSP ratios at the three sampling distances were 0.36, 0.48 and 0.73.

Simultaneous Sampling

Samplers located at the same distance from the line sources (but not collected) showed only fair agreement in their measured concentrations. The average absolute relative difference in the measured TSP values was 17.8 percent; the average (signed) relative difference was 10.6 percent. The average absolute and signed relative differences at the three distances were:

<u>Distance</u>	<u>Av. diff., %</u>	<u>Signed diff., %</u>
5	25.3	17.7
20	13.5	11.5
50	13.7	2.7

Absolute relative difference for each pair is calculated as the absolute difference between values divided by the mean of the two values, expressed as a percent: Absolute rel. diff. = $\frac{|a-b|}{(a+b)/2}$

x100. Signed relative difference employs the same calculations, but the algebraic rather than absolute difference is used.

For IP and FP, the corresponding average absolute relative differences were 25.3 and 29.1 percent. Average signed differences were 8.9 and 17.7 percent, respectively. The IP and FP differences at the three sampling distances were:

<u>Distance</u>	<u>Avg. abs rel. diff, %</u>		<u>Avg. signed rel. diff, %</u>	
	<u>IP</u>	<u>FP</u>	<u>IP</u>	<u>FP</u>
5	19.4	37.9	3.6	26.9
20	36.6	25.7	30.4	10.1
50	19.9	23.6	0.1	16.2

These differences provide an estimate of sampling precision, although they could be attributed partially to actual differences in source strength at various locations along the line source, since the samplers were not collocated. The larger differences in TSP concentrations at the 5 m distance could be due to highly erratic concentrations in the immediate area of plume formation. No explanation was found for the large IP differences at the 20 m distance.

The previous discussion was based entirely on data generated by PEDCo. Both PEDCo and MRI operated equipment upwind of the sources. Measurements made by PEDCo and MRI samplers are compared in Table 6-3. The average absolute relative difference in upwind TSP concentrations was 19.9 percent, while the average absolute relative difference in measured TSP concentrations at 5 m downwind was 57.9 percent. These differences appeared to be primarily random, in that some were positive and others were negative and their signed averages were only 2.5 and 17.6 percent, respectively. The additional difference above 25.3 percent at 5 m downwind was attributed to such factors as different flow rates, nonuniform source strength, and slightly offset sampling times.

The measured IP concentrations at 5 m downwind had a 48.4 percent average absolute relative difference, also much higher than the simultaneous PEDCo IP samples, and the concentrations measured by the two groups had a systematic bias. PEDCo's values were consistently higher than MRI's. Both sets of units were calibrated and audited for flow rates, so the difference was suspected to be in the sample handling procedures, which were previously noted to be a major problem. Also, different sampling media were used during the comparability study--PEDCo used mesh-backed Teflon filters and MRI used ringed filters.

The precision of the basic measurement techniques, as evaluated in side-by-side sampling, do not agree with values used in the error analyses cited in Section 3, especially at the 5 m sampling distance. The precision of the hi-vol appears to be +25 percent or more at 5 m from the source, improving to about +15 percent at greater distances from the source. The precision of the dichotomous sampler for measuring the IP fraction appears to average +25 percent or more at all distances. For the error analysis of exposure profiling, this changes the random instrument error from 5 percent to at least 25 percent. For upwind-downwind sampling, the 18.8 percent estimate for hi-vol sampler measurements would still be appropriate if it were applied to samples taken at 20 m or more away from the source.

Comparative Emission Rates

The comparability study was conducted over a 2 week period. The meteorological, source activity, and soil conditions for each test are shown in Table 6-4. This table includes all the variables identified that might influence particulate emission rates.

The most important results of the comparability study, emission rates from simultaneous testing by exposure profiling and the upwind-downwind technique, are presented in Tables 6-5 and 6-6. Table 6-5 shows TSP emission rates and Table 6-6 the inhalable particulate (less than 15 μ m) fraction, both in units of lb/VMT.

Sampler/ location	Test	Measured concentration, $\mu\text{g}/\text{m}^3$				Rel diff, % ^c
		PEDCo sampler	Second PEDCo sampler	MRI sampler	Second MRI sampler	
Hi vol Upwind	J1	235		254	296	+16
	J2	13999		13803	14163	-0
	J3	8222 ^a		3620	10636	-14
	J4	184		226	176	+9
	J5	344		264	124	-56
	J9	285		339	440	+31
	J10	1106		1129	913	-8
	J12	821		1192	1064	+31
	J20	1201		1012	1020	-17
	J21	1060		780	1009	-17
					signed avg	-2.5
					absolute avg	19.9
5 m dwn	J1	3661	4649	-		-
	J2	10635	14407	b		-
	J3	17117 ^a	21580	24230		+22
	J4	2457	2719	2194		-16
	J5	3130	5732	1599		-94
	J9	5108	3926	7188		+46
	J10	5668	5009	10057		+62
	J12	2122	2137	819		-89
	J20	3042	4014	4833		+31
	J21	5145	7747	2051		-103
					signed avg	-17.6
					absolute avg	57.9
Dichot, IP 5 m dwn	J1	1254	1119	1033		-14
	J2	3659	4427	388		-165
	J3	9689	8761	5191		-56
	J4	724	742	529		-32
	J5	1750	2010	1446		-26
	J9	2842	1929	1102		-74
	J10	2748	1771	1825		-21
	J12	801	701	760		+1
	J20	2036	2222	1425		-40
	J21	2653	3764	1828		-55
					signed avg	-48.3
					absolute avg	48.4

a Some loose material in filter folder, concentration may be higher.

b Sampler only ran 12 of 34 min, concentration invalidated.

c See Page 103 for procedure to calculate relative difference.

The data in Tables 6-5 and 6-6 were examined for relationships between sampling methods, sources, and downwind distance. A standard statistical technique was used to determine whether statistically significant. This technique, called Analysis of Variance (ANOVA), was available as a computer program as part of the Statistical Package for the Social Sciences (SPSS). The basis of ANOVA is the decomposition of sums of squares. The total sum of squares in the dependent variable is decomposed into independent components. The program can be used to simultaneously determine the effects of more than one independent variable on the dependent variable. Much has been written about this technique, so further discussion has not been included here. Further information on it can be found in many standard statistical textbooks.

One of the assumptions upon which ANOVA is based is that input data are normally distributed. The TSP and IP emission rates in Tables 6-5 and 6-6 were both found to be skewed, so ANOVA was also run on the data after they were transformed to their natural logarithms. The relationships between emission rates and sampling methods, sources, and downwind distance were the same for the untransformed and transformed data. Therefore, the results with untransformed data are presented herein because they relate directly to the data in Table 6-5 and 6-6.

The outputs from the program are shown Tables 6-7 and 6-8. They consist of the ANOVA results and a multiple classification analysis (MCA). The MCA table can be viewed as a method of displaying the ANOVA results.

The data in Table 6-7 show that sampling method and downwind distance are significant variables for both TSP and IP ($\alpha = 0.20$). Source was not a significant variable and one of the interrelationships were significant.

Table 6-8 shows the deviation from the total sample mean for the three variables. Also shown are deviations after the effects of the other independent variables are accounted for. The minor changes in these deviations indicate that there are no significant relationships between variables.

The average percent difference between sampling methods (profiling versus upwind-downwind) was calculated from the data in Table 6-8 for both TSP and IP. The resulting differences were 24 and 52 percent, respectively, with profiling producing the higher values in both cases.

Both methods of sampling showed large overall reductions in TSP emission rates with distance. However, the profiling samples at 5 m did not fit the pattern of fairly regular reductions displayed at the other distances and with the upwind-downwind data. In six of ten tests, emission rates by profiling at 5 m were much lower than the corresponding rates at 20 m. These six pairs of inverted values were attributed to the systematic bias documented earlier in this section between PEDCo and MRI inhalable particulate concentrations, in which PEDCo's values were consistently

TABLE 6-5. CALCULATED SUSPENDED PARTICULATE EMISSION RATES
FOR COMPARABILITY TESTS

Test	Downwind distance, m	Emission rate, lb/VMT			Relative difference, %
		By profiler		By uw-dw TSP	
		Total particulate	<30 μm fraction		
<u>Scrapers</u>					
J1	5	41.4	8.6	10.6	+21
	20	29.1	15.4	11.4	-30
	50			7.8	
	100			2.4	
J2	5	66.5	9.4	18.6	+66
	20	59.9	15.9	16.8	+6
	50	40.0	8.3	7.2	-14
	100			5.3	
J3	5	125.0	50.2	35.6	-34
	20	52.6	24.5	17.8	-32
	50	23.5	8.2	9.8	+18
	100			2.2	
J4	5	27.5	3.9	5.7	+38
	20	22.4	4.8	5.2	+8
	50	15.6	4.0	4.0	0
	100			2.4	
J5	5	96.7	17.7	20.0	+12
	20	46.6	11.5	15.6	+30
	50	15.2	4.5	5.7	+24
	100			1.2	
<u>Haul roads</u>					
J9	5	51.4	15.2	14.1	-8
	20	35.7	22.5	13.6	-49
	50	17.8	8.3	11.1	+29
	100			5.1	
J10	5	54.1	33.0	12.0	-93
	20	20.3	18.5	8.8	-71
	50	7.1	3.4	3.2	-6
	100			neg	
J12	5	16.5	12.9	3.5	-115
	20	5.5	1.9	4.4	+79
	50	2.0	0.3	2.9	+162
	100			0.5	

(continued)

TABLE 6-5 (continued).

Test	Downwind distance, m	Emission rate, lb/VMT			Relative difference, % ^a
		By profiler		By uw-dw TSP	
		Total particulate	<30 μm fraction		
J20	5	36.6	12.3	6.4	-63
	20	31.3	17.7	4.3	-122
	50	20.6	10.7	2.8	-117
	100			neg	
J21	5	76.4	14.2	15.0	+5
	20	40.9	19.2	13.8	-33
	50	25.0	15.2	12.8	-17
	100			8.5	
Mean	5	59.2	17.7	14.2	-22
	20	34.4	15.2	11.2	-30
	50	18.5	7.0	6.8	-3
Std dev	5	33.0	13.8	9.3	(difference signed)
	20	16.3	7.2	5.2	
	50	10.9	4.5	3.6	

^a See Page 103 for procedure to calculate relative difference.

TABLE 6-6. CALCULATED INHALABLE PARTICULATE (<15 μm)
EMISSION RATES FOR COMPARABILITY TESTS

Test	Downwind distance, m	IP emission rate, lb/VMT		Relative difference, % ^c
		By profiler	By uw-dw	
<u>Scrapers</u>				
J1	5	4.2	3.1	-30
	20	7.2	3.5	-69
	50		3.2	
J2	5	4.0	2.5	-46
	20	6.8	2.4	-96
	50	5.2	2.0	-89
J3	5	26.1	14.0	-60
	20	11.0	4.2	-89
	50	4.1	3.6	-13
J4	5	1.7	1.0	-52
	20	2.4	0.9	-91
	50	2.2	1.3	-51
J5	5	10.0	5.8	-53
	20	5.4	1.1	-132
	50	2.5	1.4	-56
<u>Haul roads</u>				
J9	5	7.4	7.2	-3
	20	11.8	8.9	-28
	50	3.7	4.4	+17
J10	5	17.7	6.0	-99
	20	12.4	7.6	-49
	50	1.8	4.9 ^a	+93
J12	5	7.9	0.6	-172
	20	1.1	1.2	+9
	50	0.2	0.5	+86
J20	5	5.4	3.8	-35
	20	12.0	5.7 ^b	-71
	50	5.8	7.1 ^b	+20
J21	5	6.0	6.3	+5
	20	11.4	5.5	-70
	50	10.3	6.3	-48
lean	5	9.0	5.0	-57
	20	8.1	4.1	-66
	50	4.0	3.5	-13
std dev	5	7.4	3.9	(signed difference)
	20	4.2	2.8	
	50	2.9	2.2	

^a This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 13.6 μm .

^b These dichotomous sampler values could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 19.0 μm .

^c See Page 103 for procedure to calculate relative difference.

TABLE 6-7. ANALYSIS OF VARIANCE RESULTS

SP BY METHOD SOURCE DIST.	SOURCE OF VARIATION		SUM OF SQUARES	DF	MEAN SQUARE	SIGNIF OF F	
	MAIN EFFECTS		994.413	4	248.603	3.588	.012
	METHOD		119.001	1	119.001	1.717	.196
	SOURCE		57.492	1	57.492	.830	.367
	DIST		817.920	2	408.960	5.902	.005
	2-WAY INTERACTIONS		186.270	5	37.254	.538	.747
	METHOD	SOURCE	95.011	1	95.011	1.371	.248
	METHOD	DIST	44.826	2	22.413	.323	.725
	SOURCE	DIST	55.749	2	27.874	.402	.671
	3-WAY INTERACTIONS		21.643	2	10.821	.156	.856
	METHOD	SOURCE DIST	21.643	2	10.821	.156	.856
	EXPLAINED		1202.326	11	109.302	1.577	.137
	RESIDUAL		3256.810	47	69.294		
	TOTAL		4459.136	58	76.882		

P BY METHOD SOURCE DIST.	SOURCE OF VARIATION		SUM OF SQUARES	DF	MEAN SQUARE	SIGNIF OF F	
	MAIN EFFECTS		269.278	4	67.319	3.499	.014
	METHOD		129.377	1	129.377	6.724	.013
	SOURCE		28.422	1	28.422	1.477	.230
	DIST		111.478	2	55.739	2.897	.065
	2-WAY INTERACTIONS		76.587	5	15.317	.796	.558
	METHOD	SOURCE	.825	1	.825	.043	.337
	METHOD	DIST	41.533	2	20.767	1.079	.348
	SOURCE	DIST	33.984	2	16.992	.883	.420
	3-WAY INTERACTIONS		1.833	2	.917	.048	.954
	METHOD	SOURCE DIST	1.833	2	.917	.048	.954
	EXPLAINED		347.697	11	31.609	1.643	.118
	RESIDUAL		904.308	47	19.241		
	TOTAL		1252.005	58	21.586		

TABLE 6-8. MULTIPLE CLASSIFICATION ANALYSIS (ANOVA)

TSP BY METHOD SOURCE DIST.	GRAND MEAN = 12.08									ADJUSTED FOR INDEPENDENTS + COVARIATES	ADJUSTED FOR INDEPENDENTS + COVARIATES
	VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	ETA	UNADJUSTED DEV'N	BETA				DEV'N	BETA
METHOD											
Profiler 1		29	1.44			1.37					
Uw-dw 2		30	-1.40			-1.33					
				.16						.16	
SOURCE											
Scrapers 1		29	.98			.91					
Haul trucks 2		30	-.95			-.88					
				.11						.10	
DIST											
5 m 1		20	3.87			3.83					
20 m 2		20	1.10			1.06					
50 m 3		19	-5.23			-5.15					
				.43						.43	
MULTIPLE R SQUARED										.223	
MULTIPLE R										.472	

IP BY METHOD SOURCE DIST.	GRAND MEAN = 5.66									ADJUSTED FOR INDEPENDENTS + COVARIATES	ADJUSTED FOR INDEPENDENTS + COVARIATES
	VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	ETA	UNADJUSTED DEV'N	BETA				DEV'N	BETA
METHOD											
Profiler 1		29	1.51			1.46					
Uw-dw 2		30	-1.46			-1.41					
				.32						.31	
SOURCE											
Scrapers 1		29	-.73			-.74					
Haul trucks 2		30	.71			.72					
				.16						.16	
DIST											
5 m 1		20	1.38			1.37					
20 m 2		20	.47			.46					
50 m 3		19	-1.95			-1.92					
				.30						.30	
MULTIPLE R SQUARED										.215	
MULTIPLE R										.464	

higher and the average difference was 48.4 percent. MRI generated the the 5 m profiling data; PEDCo generated the 20 and 50 m data. This difference was important because the IP and FP concentration data are used to extrapolate the less than 30 μ m fraction in profiling calculations.

The IP emission data by both sampling methods displayed almost as much reduction with distance as the TSP data. This is a surprising finding, in that very little deposition of sub-15 μ m particles would be expected over a 50 m interval.

The reason for the relatively poor comparisons between emission rates obtained by the two sampling/calculation methods can be traced primarily to the precision of the sampling methods. MRI and PEDCo samplers located at the same distances from the source and operated simultaneously produced TSP concentrations that differed by an average of 58 percent, greater than the average difference of 24 percent in the resulting TSP emission rates. Similarly, a 48 percent average difference in IP concentrations explains much of the 52 percent difference in IP emission rates.

Both methods are entirely dependent on the measured IP and or/TSP values for calculating emission rates. The accuracy of the methods can improve on the precision of individual measurements to the extent that multiple measurements are used in the calculation of a single emission rate. Both profiling and upwind-downwind techniques as employed in the comparability study utilized two IP measurements, and upwind-downwind used two TSP measurement to obtain final emission rates at each distance.

Results from the two sampling methods were compared with each other rather than a known standard, so it is impossible to establish from the data which is more accurate. If the error analyses described in Section 3 were revised to reflect the sampling precisions reported above, exposure profiling would show lower total error levels than upwind-downwind sampling at the same distance from the source. For the distances routinely used for the respective methods in the remainder of the field work, upwind-downwind sampling would have lower indicated total error. Whichever sampling method is used, it appears from the modified error analyses that the current state-of-the-art in fugitive dust emission testing is ± 25 to 50 percent accuracy.

DEPOSITION RATES BY ALTERNATIVE MEASUREMENT METHODS

Analytical Approaches

Four different approaches for describing the deposition rate for each test were considered:

1. Reduction in apparent emission rate per unit distance from the source (deposition = dg/dx)

2. Reduction in apparent emission rate per unit time (deposition = $-dg/dt$); also, this deposition rate plotted as a function of total travel time away from source
3. Dustfall measurements at successive distances expressed as percentages of the calculated total particulate emission rate
4. Total percent reduction in apparent emission rate over 50 or 100 m compared with percent of emissions greater than 15 μ m diameter (under the assumption that most large particles settle out and few small ones do)

In the first approach above, deposition rate is the slope of a curve of TSP or IP emission rate versus distance, applied to either profiling or upwind-downwind data. Deviations from a smooth, idealized deposition curve were magnified by this method of determining the slope of a curve at different points. With the scatter in the emission data of Tables 6-5 and 6-6, calculated deposition rates varied tremendously, including many negative values.

Converting the deposition data to a time rather than distance basis in the second approach was an attempt to remove the effect of wind speed variation on deposition rates. The table of time deposition rates and plot of deposition rate versus total travel time had almost as much scatter as the data from the first approach. When the deposition rates were normalized to percents of the initial emission rate for that test, the data showed a perceptible relationship, as presented in Figure 6-4.

Dustfall, a direct measurement of particle deposition, could not be equated with the calculated TSP or IP values described above because dustfall contains deposition of all particle sizes, not just that in the TSP or IP size range. Net dustfall rates were compared with reductions in total particulate (TP) emission rates from the 5 m profiler to the 50 m profiler. However, the same scatter noted above in the profiling data combined with similar scatter in the dustfall data obscured any pattern in deposition rates.

All dustfall measurements were taken by collocated duplicate readings. The average difference for downwind duplicate measurements in the 10 tests was 40.5 percent, even greater than differences in concurrent TSP and IP measurements. In addition, several (13 out of 57) of the net dustfall readings were negative because the upwind value was higher than the downwind one. Allowing for the scatter in the data, dustfall rates appeared to agree better in magnitude with the TSP deposition rates calculated by the first approach than with TP desposition rates.

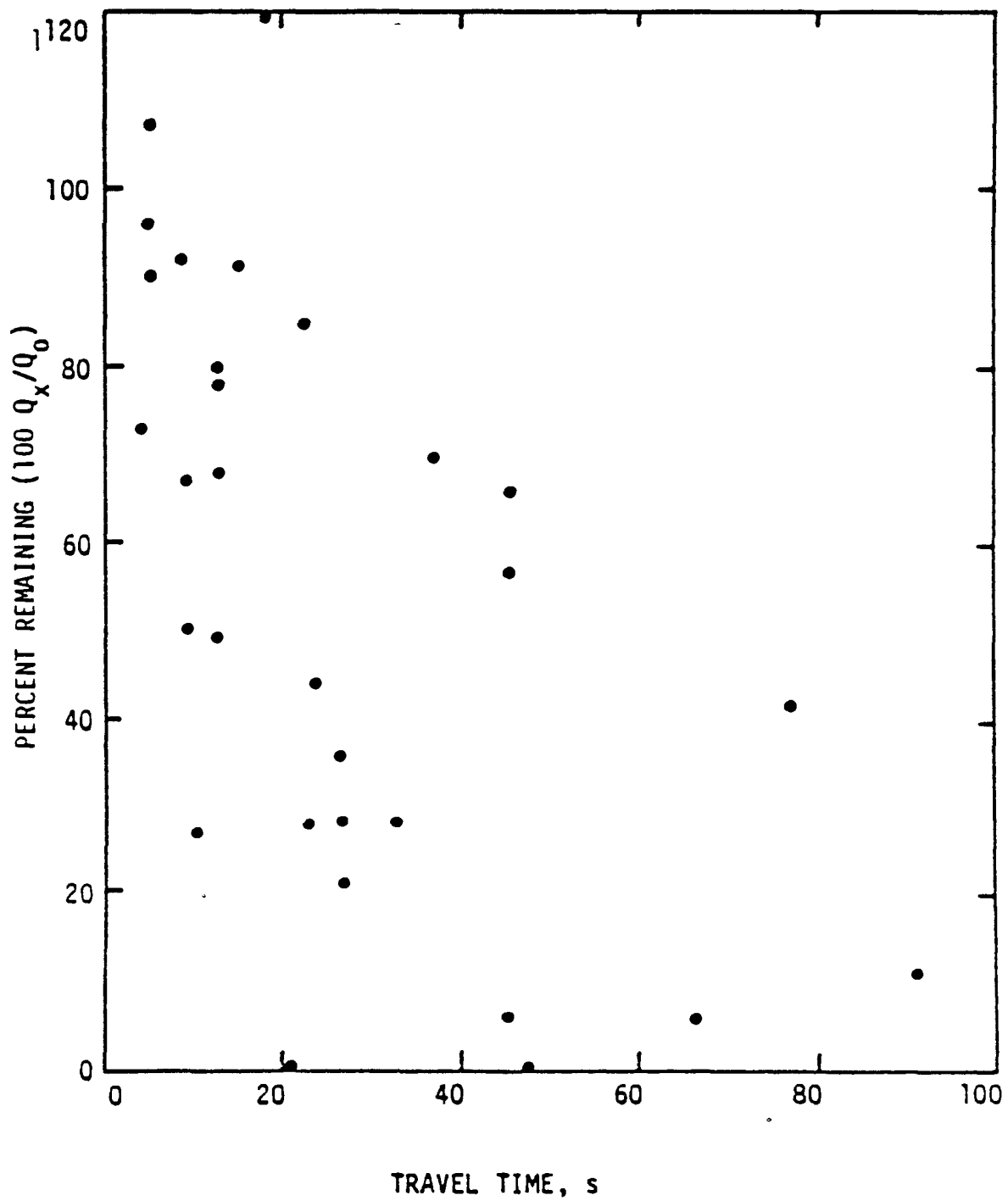


Figure 6-4. Deposition rates as a function of time.

The fourth approach evaluated for describing deposition in the comparability tests was to relate the measured deposition to the percent of particles in the plume susceptible to deposition. Particles greater than 15 μm were assumed to be highly susceptible to deposition, partially because this fractional value was readily available from the test data. However, none of the correlations between deposition rates and particles greater than 15 μm in the plume were found to be significant (at the 0.05 to 0.20 level):

<u>Distance</u>	<u>Size meas. method</u>	<u>No. tests</u>	<u>r</u>
5 m	Impactor	10	0.17
20 m	Impactor	10	0.29
20 m	Dichot	10	-0.36

No reason was identified for these low correlations.

Average Deposition

Although the approaches evaluated above did not provide a usable relationship for estimating the rate of deposition of particulate from the dust plumes, deposition was definitely occurring in the comparability tests. This was readily apparent from examination of the average emission rates at successive distances from the source, as shown at the bottom of Tables 6-5 and 6-6.

These reductions in average emission rate with distance are shown in Figure 6-5 in terms of depletion factors, the ratios between the depleted emission rate measured at distance x and the initial emission rate (Q_x/Q_0). Q_0 was the emission rate determined by either profiling or upwind-downwind sampling at 5 m, which was assumed to be the edge of the mixing cell and distance at which deposition actually began.

This depletion factor approach was applied to the individual test data to determine whether variables such as stability class, wind speed, or initial particle size distribution affected the deposition rate discernibly. The resulting data are presented in Table 6-9. Deposition rates did not appear to be closely related to any of the above three variables in the 10 comparability tests.

Theoretical Deposition Functions

Three different theoretical deposition functions have been widely used in atmospheric dispersion modeling to simulate dry particle deposition: source depletion, surface depletion, and tilted plume functions. The depletion factors for these three alternative functions for the first 200 m (200 m is greater than the sampling distances) are shown in Figure 6-6.

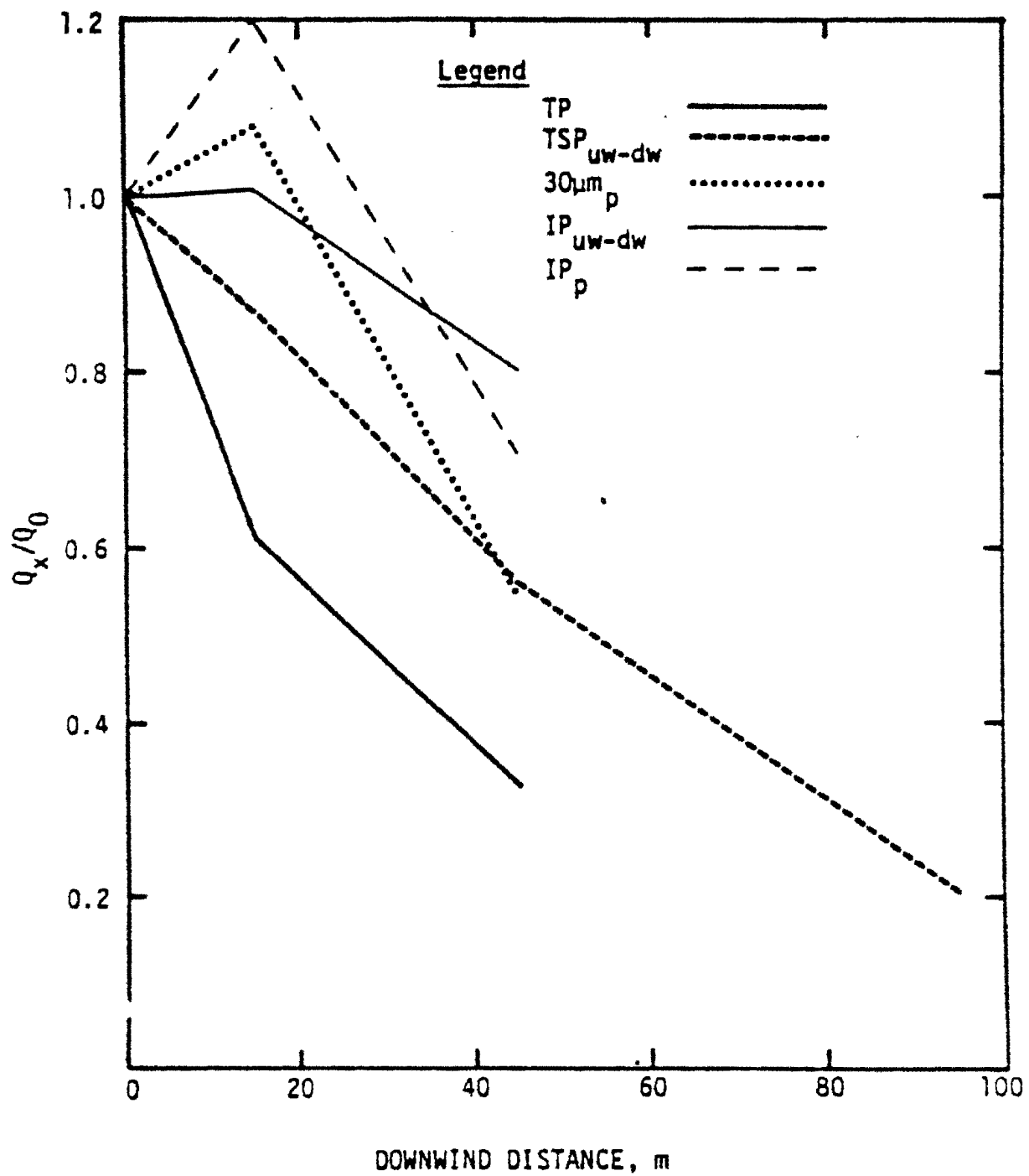


Figure 6-5. Average measured depletion rates.

The input conditions for all three functions were: wind speed = 1.0 m/s, gravitational settling velocity of monodisperse particles = 0.1 m/s, emiss height = 2.0 m, and stability class as indicated on the figure.

One observation that can be made from the curves, and that would be more obvious if the curves were extended beyond 200 m, is that much of the total deposition occurs within this first 200 m. However, these are theoretical curves and it should not be implied that the field study measurements at 100 m account for the bulk of deposition or provide a rough estimate of fully depleted emission rates. This could only be determined with actual measurements of deposition at distances of 1 km and beyond.

The tilted plume curve was closest of the three theoretical functions to the average deposition rates from the comparability study (plotted in Figure 6-5). There is no assurance that this function continues to provide the best fit at distances in the range of 1 to 20 km that are of greatest concern in dispersion modeling. Not that the tilted plume depletion is not very dependent on stability class; the test data did not appear to be closely related to stability class either.

The depletion factor in the tilted plume function is given in the following equation:

$$Q_x/Q_0 = 1 - \frac{1}{(1-n/2)(h u/xv_d - 1) + 2} \quad (\text{Eq. 27})$$

where n = Sutton's diffusion parameter, which varies by stability class:

	n
A	0.15
B	0.26
C-D	0.48
E-F	0.57

h = emission height, m

u = wind speed, m/s

x = downwind distance, m

v_d = deposition velocity, 10^{-2} m/s

The average deposition rates from Figure 6-5 are plotted together with tilted plume curves representing average test conditions (B stability, $u = 2.6$ m/s, and $h_0 = 2.0$ m) for four different v_d values in Figure 6-7. It was assumed that v_d and v_g (gravitational settling velocity); Stokes law $v_g = 0.00301\rho_0^2$) was used to calculate corresponding particle sizes for the theoretical deposition curves:

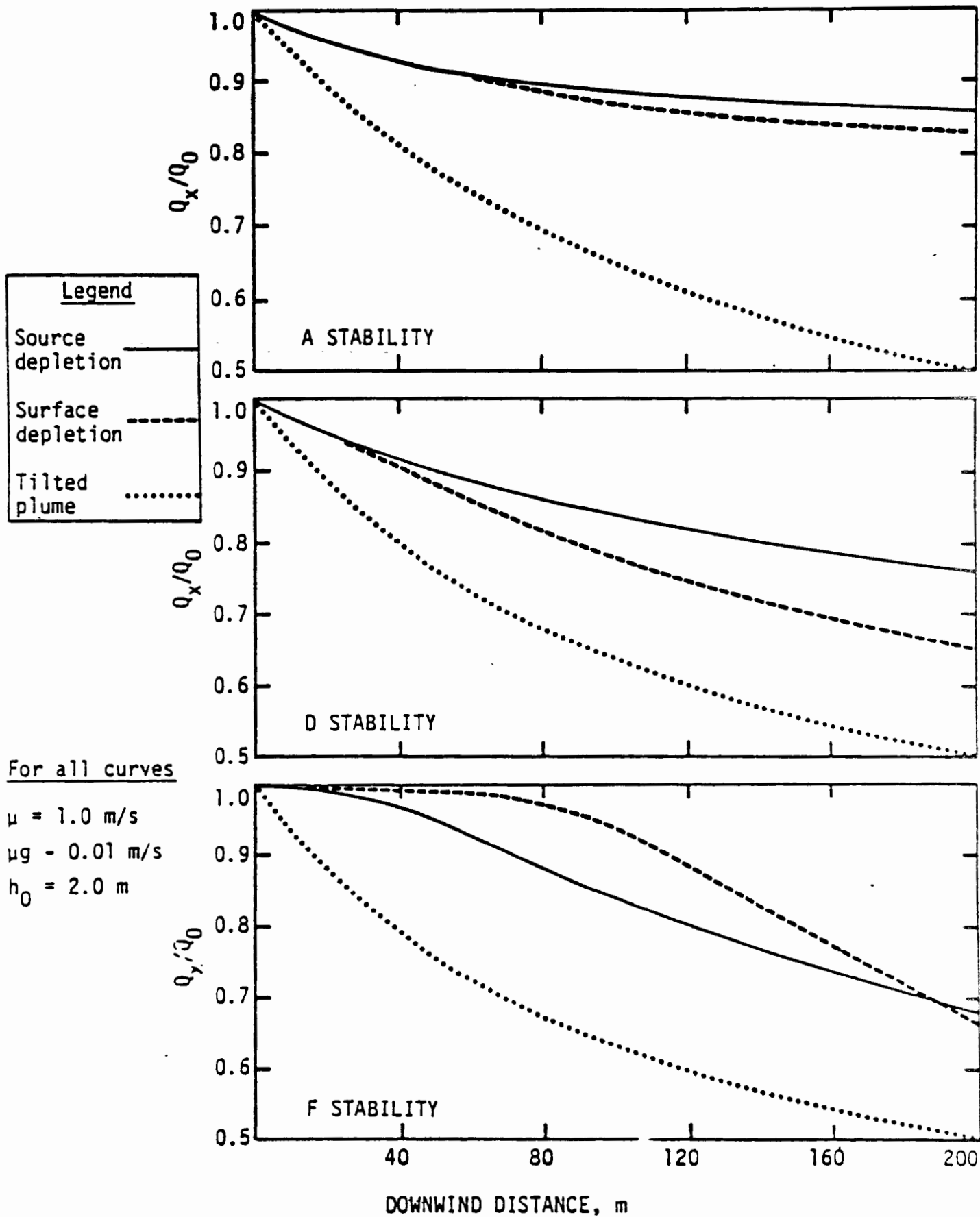


Figure 6-6. Depletion rates by theoretical deposition functions.

<u>v_g, cm/s</u>	<u>D, μm</u>	<u>Test curve best matched</u>
2	16	IP _{uw-dw} , IP _p
5	26	30 μ m _p
15	45	TSP _{up-dw}
30	63	TP

Actually, deposition rates for small particles onto the ground have been observed to be greater than can be explained by gravitational settling velocity, and the concept of a deposition velocity v_d greater than v_g has been developed to account for this faster deposition. Since v_g is less than or equal to v_d , the equivalent particle sizes tabulated above would also be smaller than shown. If the data from the comparability tests had been demonstrated to be more accurate than they were, the matching of theoretical and test data in Figure 6-7 could have been used to estimate a v_g/v_d relationship for calibrating a mining fugitive dust deposition function. The available data indicate a v_g/v_d ratio of about 0.8.

Summary of Deposition Results

Deposition was definitely occurring in the 10 comparability tests, with an average of 63 percent reduction in profiler 30 μ m emission rates in 50 m and 79 percent reduction in upwind-downwind TSP emission rates in 100 m. Deposition rates in individual tests were obscured by data scatter, so an empirical function could not be developed. However, the average deposition rates expressed as depletion factors (Q_x/Q_0) agreed reasonably well with theoretical deposition functions. Of the three theoretical functions examined, the test data appeared to agree best with the tilted plume model (subjective evaluation).

Dustfall data had less precision than the ambient measurements on which the emission rate depletion factors were based. Subsequently evaluation of dustfall data from tests other than the

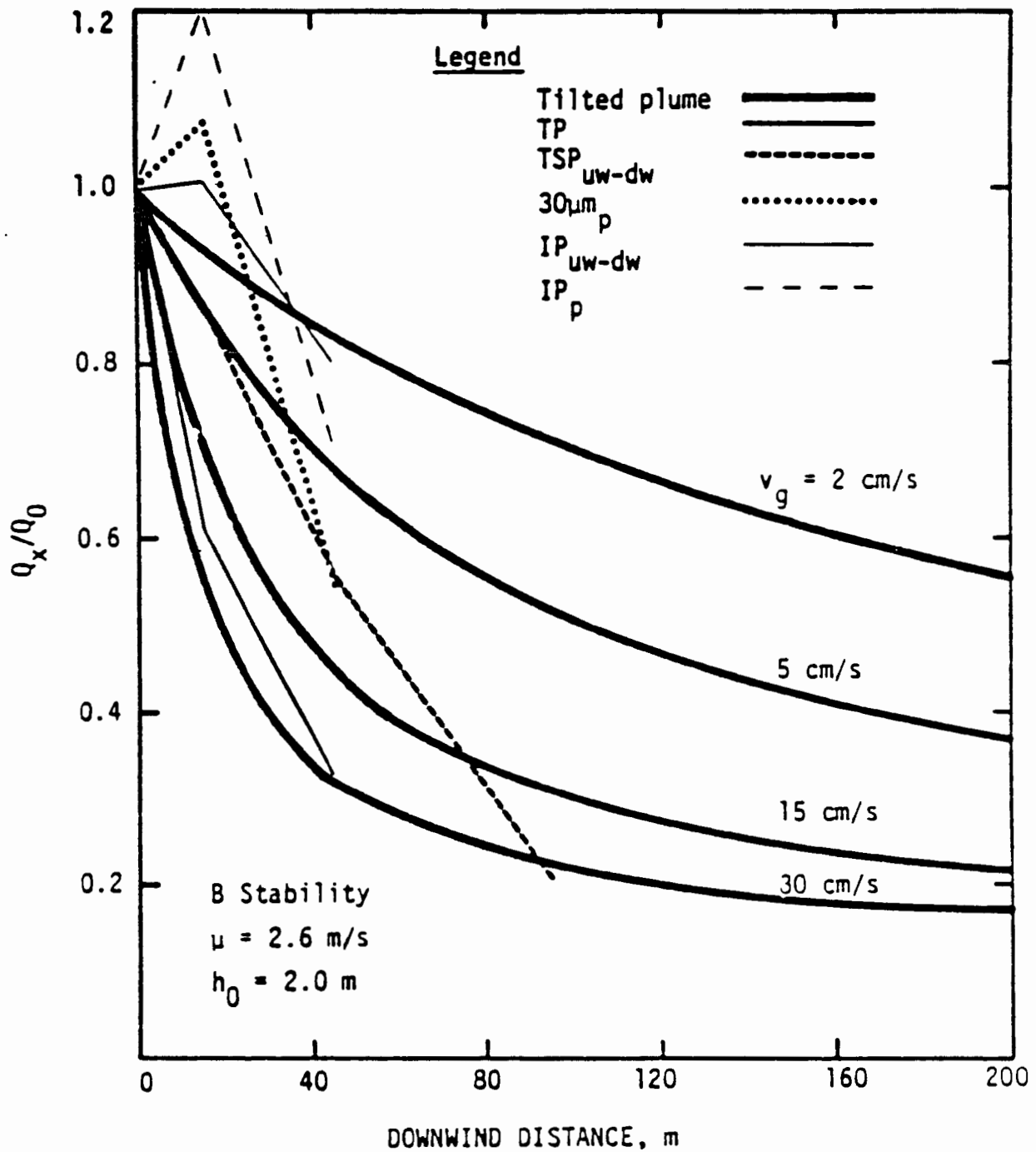


Figure 6-7. Average measured depletion rates compared to predicted tilted plume depletion.

comparability tests showed that this method is reproducible as long as there are not wind direction reversals during the sampling period. A full discussion of dustfall measurement as a method for quantifying deposition rates is presented in Section 12. A summary discussion of deposition is included in Section 14.

SECTION 7

RESULTS FOR SOURCES TESTED BY EXPOSURE PROFILING

SUMMARY OF TESTS PERFORMED

As previously discussed, exposure profiling was used to test particulate emissions from haul trucks, light-duty and medium duty vehicles, scrapers (travel mode) and graders. These sources were tested at three mines during the period July 1979 through August 1980.

A total of 63 successful exposure profiling tests were conducted at the three mines/four visits. They were distributed by source and by mine as follows:

<u>Source</u>	<u>Controlled/ uncontrolled</u>	<u>Number of tests</u>			
		<u>Mine 1</u>	<u>Mine 2</u>	<u>Mine 1W</u>	<u>Mine 3</u>
Haul trucks	U	6	6	3	4
	C	0	4	0	5
Light- and med.- duty vehicles	U	3	4	0	3
	C	2	0	0	0
Scrapers	U	5	6	2	2
Graders	U	0	5	0	2

Light and variable wind conditions were encountered at Mine 1 during the test period July-August 1979, with winds occasionally reversing and traffic-generated emissions impacting on the upwind sampling station. These events were termed "bad passes."

Table 7-1 lists the site conditions for the exposure profiling tests of dust emissions generated by haul trucks. The comparability tests are indicated by an asterisk after the run number. In addition to the testing of uncontrolled sources, watering of haul roads was tested as a control measure.

Table 7-2 gives the road and traffic characteristics for the exposure profiling tests of haul trucks. This source category exhibited a wide range of road and traffic characteristics, indicating a good

TABLE 7-1. EXPOSURE PROFILING SITE CONDITIONS - HAUL TRUCKS

Mine/Site ^a	Profiler						Meteorolo	
	Run ^b	Date	Start time	Sampling duration (min)	Vehicle passes		Temp. (°C)	Wi spe (m/
					Good	Bad		
Mine 1/Site 2	J-6	7/30/79	16:06	67	2	37	24.5	0
	J-9*	8/01/79	10:21	51	41	0	28.3	4
	J-10*	8/01/79	14:08	52	43	2	31.0	4
	J-11 ^d	8/01/79	17:39	48	40	0	30.5	4
	J-12*	8/02/79	10:50	49	18	1	26.7	0
	J-20*	8/09/79	14:10	49	23	0	23.0	2
	J-21*	8/09/79	16:51	26	13	1	25.0	
Mine 2/Site 1	K-1	10/11/79	10:21	86	65	0	14.6	
Mine 2/Site 3 (Watered)	K-6	10/15/79	11:03	177	84	0	17.8	
Mine 2/Site 3	K-7	10/15/79	14:50	53	57	0	23.5	
Mine 2/Site 3 (Watered)	K-8	10/16/79	11:02	105	43	0	10.3	
Mine 2/Site 3	K-9	10/16/79	13:18	89	63	0	12.0	
	K-10	10/17/79	10:37	65	40	0	10.6	
	K-11	10/17/79	12:05	64	50	0	12.5	
	K-12	10/17/79	13:38	58	43	0	15.5	
Mine 2/Site 3 (Watered)	K-13	10/23/79	10:47	73	78	0	4.0	
Mine 1/Site 5	L-1	12/07/79	14:04	92	57	0	0.7	

(continued)

potential for identifying and quantifying correction parameters. Most tests involved a blend of vehicle types dominated by haul trucks. Silt and moisture values were determined by laboratory analysis of road surface aggregate samples obtained from the test roads. Mean vehicle speeds and weights are arithmetic averages for the mixes of vehicles which passed over the test roads during exposure profiling.

Table 7-3 lists the site conditions for the exposure profiling tests of dust emissions generated by light- and medium-duty vehicles. In addition to the testing of uncontrolled roads, the application of calcium chloride to an access road was tested as a control measure.

Table 7-4 gives the road and traffic conditions for the exposure profiling tests of light- and medium-duty vehicles. Small variations in mean vehicle weight and mean number of vehicle wheels were observed for this source category. No access roads were available at Mine 2, so light-duty vehicles were tested at a haul road site.

Table 7-5 lists the site conditions for the exposure profiling tests of dust emissions generated by scrapers (travel mode). Table 7-6 gives the road and traffic conditions for the exposure profiling tests of scrapers. All scrapers tested were four-wheeled vehicles, which excluded this parameter from consideration as a correction factor.

Table 7-7 lists the site conditions for the exposure profiling tests of dust emissions generated by graders. Table 7-8 gives the road and traffic conditions for the exposure profiling tests of graders. All graders tested were six-wheeled vehicles and weighed 14 tons. Therefore, mean vehicle weight and mean number of vehicle wheels were excluded from consideration as correction factors.

RESULTS

The measured emission rates are shown in Tables 7-9 through 7-12 for haul trucks, light- and medium-duty vehicles, scrapers, and graders, respectively. In each case, emission rates are given for TP, SP, IP, and FP.

For certain runs, emission rates could not be calculated. For haul truck L-2, the profiler samples did not maintain a consistent flow rate. Haul truck run J-6 was not analyzed because of the predominance of bad passes. The emissions from run J-7, the access road treated with calcium chloride, were too low to be measured. Scraper run P-15 produced only a TP emission factor; questionable results from a single dichotomous sampler prevented calculation of reliable emission rates for SP, IP, and FP.

The means, standard deviations, and ranges of SP emission rates for each source category are shown below:

<u>Source</u>	<u>No. tests</u>	<u>SP emission rate (lbs/VMT)</u>		
		<u>Mean</u>	<u>Std. dev.</u>	<u>Range</u>
Haul trucks				
Uncontrolled	19	18.8	20.2	0.71-67.2
Controlled	9	4.88	3.44	0.60- 8.4
Light- and medium-duty vehicles				
Uncontrolled	10	4.16	3.73	0.64- 9.0
Controlled	2	0.35 ^a	a	a
Scrapers				
Uncontrolled	14	57.8	95.3	3.9 -355
Graders				
Uncontrolled	7	9.03	11.2	1.8 -34.0

^a On one of two tests, the emissions were below detectable limits.

As expected, the SP emission rates for controlled road sources were substantially lower than for uncontrolled sources. The mean emission rate for watered haul roads was 26 percent of the mean for uncontrolled haul roads. For light- and medium-duty vehicles, the mean emission rate for roads treated with calcium chloride was 8 percent of the mean for uncontrolled roads.

The average ratios of IP and FP to SP emission rates are:

<u>Source</u>	<u>Average ratio of IP to SP emission rates</u>	<u>Average ratio of FP to SP emission rates</u>
Haul trucks	0.50	0.033
Light- and medium-duty vehicles	0.63	0.112
Scrapers	0.49	0.026
Graders	0.48	0.055

As indicated, SP emission from light- and medium-duty vehicles contained a much larger proportion of small particles than did the other source categories.

The measured dustfall rates are shown in Tables 7-14 through 7-16 for haul trucks, light- and medium-duty vehicles, scrapers, and graders, respectively.

Flux data from collocated samplers are given for the upwind sampling location and for three downwind distances. The downwind dustfall fluxes decay sharply with distance from the source.

PROBLEMS ENCOUNTERED

Adverse meteorology created the most frequent difficulties in sampling emissions from unpaved roads. Isokinetic sampling cannot be achieved with the existing profilers when wind speeds are less than 4 mph. Problems of light winds occurred mostly during the summer testing at Mine 1. In addition, wind direction shifts resulted in source plume impacts on the upwind samplers on several occasions. These events, termed "bad passes," were confined for the most part to summer testing at Mine 1.

Bad passes were not counted in determining source impact on downwind samplers. Measured upwind particulate concentrations were adjusted to mean observed upwind concentrations for adjoining sampling periods at the same site when no bad passes occurred.

Another problem encountered was mining equipment breakdown or reassignment. On several occasions sampling equipment had been deployed but testing could not be conducted because the mining vehicle activity scheduled for the test road did not occur.

SECTION 8

RESULTS FOR SOURCES TESTED BY UPWIND-DOWNWIND SAMPLING

SUMMARY OF TESTS PERFORMED

Five different sources were tested by the upwind-downwind method-- coal loading, dozers, draglines, haul roads, and scrapers. However, haul roads and scrapers were tested by upwind-downwind sampling only as part of the comparability study, with the exception of six additional upwind-downwind haul road tests during the winter sampling period. Test conditions, net concentrations, and calculated emission rates for the comparability tests were presented in Section 6. Test conditions and emission rates for haul road tests are repeated here for easier comparison with winter haul road tests, but scraper data are not shown again. Haul roads were tested by the upwind-downwind method during the winter when limited operations and poor choices for sampling locations precluded sampling of dozers or draglines, the two primary choices.

A total of 87 successful upwind-downwind tests were conducted at the three mines/four visits. They were distributed by source and by mine as follows:

<u>Source</u>	<u>Number of tests</u>			
	<u>Mine 1</u>	<u>Mine 2</u>	<u>Mine 1W</u>	<u>Mine</u>
Coal loading	2	8		15
Dozer, overburden	4	7		4
Dozer, coal	4	3		5
Draglines	6	5		8
Haul roads	5		6	
Scrapers	5			

Test conditions for the coal loading tests are summarized in Table 8-1. Correction factors for this source may be difficult to develop: bucket capacities and silt contents did not vary significantly during the tests, nor did drop distances (not shown in the table). One variable not included in the table was type of coal loading equipment. At the first two mines, shovels were used; at the third mine, front-end loaders were used.

Test conditions for dozers are summarized in Tables 8-2 and 8-3 for dozers working overburden and coal, respectively. These two source categories exhibited a wide range of operating and soil characteristics in their tests--speed varied from 2 to 10 mph, silt contents from 3.8 to 1 percent, and moisture contents from 2.2 to 22 percent. This indicates a good potential for correction factors. Also, there is a possibility of producing a single emission factor for the two dozer operations.

Dragline test conditions are shown in Table 8-4. Bucket sizes for the different tests were all nearly the same, but large differences in drop distances (5 to 100 ft), silt contents (4.6 to 14 percent), and moisture contents (0.2 to 16.3 percent) were obtained. One dragline variable used in the preliminary data analysis for the statistical plan, operator skill, was not included in Table 8-4 because it was judged to be too subjective and of little value as a correction factor for predicting emissions from draglines. Also, it was not found to be a significant variable in the preliminary data analysis.

Test conditions for haul roads tested by upwind-downwind sampling are summarized in Table 8-5. Most of the tests for this source were done by exposure profiling, so this subset of tests was not analyzed separately to develop another emission factor. Instead, the calculated emission rates and test conditions for these tests were combined with the exposure profiling test data in the data analysis and emission factor development phase.

RESULTS

The apparent TSP emission rates calculated from the concentrations at each hi-vol sampler are shown in Tables 8-6 through 8-10 for coal loading, dozers (overburden), dozers (coal), draglines, and haul roads, respectively. These reported emission rates have not been adjusted for any potential correction factors. The individual emission rates are shown as a function of source-sampler distances in these tables. Distance is an important factor in the evaluation of deposition.

When the samples were evaluated for deposition as described in Section 5, only 21 out of the 87 upwind-downwind samples (including scrape) demonstrated distinct fallout over the three or four distances. The percentage of tests showing fallout was much higher for sources sampled as line sources than for sources sampled as point sources: 13 out of 25 (52 percent) for line sources compared to 8 out of 62 (12.9 percent) for point sources.

It was concluded that some problem exists with the point source dispersion equation because its results rarely indicate

deposition, although the same type and size distribution of emissions are involved as with the line source dispersion equation. The sensitivity of calculated emission rates to several inputs to the point source equation (such as initial plume width, initial horizontal dispersion, distance from plume centerline, and stability class) were examined, but no single input parameter could be found that would change the emission data by distance to show deposition.

The single-value TSP emission rates for each test determined from the multiple emission rate values are summarized in Table 8-11. The means and standard deviations for these tests are shown below:

<u>Source</u>	<u>No. tests</u>	<u>Units</u>	<u>Mean</u>	<u>Std dev</u>	<u>Range</u>
Coal loading	25	lb/ton	0.105	0.220	0.0069-1.09
Dozer, overburden	15	lb/h	6.8	6.9	0.9-20.7
Dozer, coal	12	lb/h	134.3	155.6	3.0-439
Bagline	19	lb/yd ³	0.088	0.093	0.003-0.400
Gravel road	11	lb/VMT	17.4	10.9	3.6-37.2
Grader	5	lb/VMT	18.1	11.4	5.7-35.6

It should be emphasized that the mean values reported here are not emission factors; they do not have any consideration of correction factors included in them.

Emission rates for coal loading varied over a wide range, from 0.0069 to 1.09 lb/ton. Rates at the third mine averaged an order of magnitude higher than at the first two mines. Since a front-end loader was used at the third mine and shovels at the first two, the wide differences in average emission rates may indicate that separate emission factors are required for these two types of coal loading.

Emissions from dozers working overburden varied over a moderate range. Much of that variation can probably be explained by the soil characteristics of the overburden being regraded: soil at the second mine, which in general had the lowest emission rates, had the highest moisture contents and lowest silt contents; soil at the third mine, which had the highest emission rates, was driest. The evaluation of these two correction parameters is described in Section 13.

Coal dozer emissions were grouped very tightly by mine. The averages, standard deviations, and ranges by mine show this:

<u>Mine</u>	<u>Mean</u>	<u>Std dev</u>	<u>Range</u>
1	24.1	10.9	16.1-40.1
2	6.1	3.0	3.0- 9.1
3	299	89.2	222-439

Coal characteristics are also expected to explain part of this variation, but it is doubtful that the very high emission rates at the third mine can be explained with just those parameters. Dozers working coal had considerably higher emission rates than dozers working overburden. The two sources probably cannot be combined into a single emission factor with available data unless some correction parameter reflecting the type of material being worked is incorporated.

Dragline emissions had greater variation within each mine than between mine averages. As with several of the other sources, emission rates at the third mine were highest and moisture contents of soil samples were the lowest. The only sample more than two standard deviations away from the mean was a 0.400 value obtained at the first mine. This potential outlier (its high value may be explained by correction parameters) was more than twice the next highest emission rate.

Haul roads had relatively little variation in emission rates for the tests shown. However, all these tests were taken at the same mine during two different time periods. For a more comprehensive listing of haul road emission rates from all three mines/four visits, the exposure profiling test data in Section 7 should be reviewed.

Average IP and FP emission rates for each test, along with IP emission rates calculated from each sampler, are presented by source in Tables 8-12 through 8-16. The values could be averaged without first considering deposition because dichotomous samplers were only located at the first two distances from the source (leaving only about a 30 m distance in which measureable deposition could occur) and because smaller particles do not have significant deposition. Although the IP data from the upwind-downwind tests have a large amount of scatter, no reduction in emission rates with distance is evident.

The average ratios of IP and FP to TSP emission rates are:

<u>Source</u>	<u>Av ratio of IP to TSP emission rates</u>	<u>Av ratio of FP to TSP emission rates</u>
Coal loading	0.30	0.030
Dozer, overburden	0.86	0.196
Dozer, coal	0.49	0.031
Dragline	0.32	0.032
Haul road	0.42	0.024

These values are different than the average ratios of net concentration because of the effect of deposition on calculation of the single-value TSP emission rates.

The overburden dozer IP/TPS ratios are much higher than for other sources because five of the 15 tests had IP concentrations much higher than TSP concentrations. When the IP concentration exceeds the TSP concentration, correction of the IP value to 15 μ m size from the actual (wind speed dependent) cut point cannot be performed by the method described on Page 83. For such cases in Table 8-13 (and Table 8-14 through 8-16), the uncorrected IP value were reported along with their estimated cut points. If the five tests with uncorrected IP data were eliminated, the average IP/TSP ratio would be 0.28, much closer to that of other sources. No explanation was found for the high IP concentrations compared to TPS concentrations for overburden dozers.

For all sources except overburden dozers, the IP and FP emission rate variabilities (as measured by the relative standard deviation) were about the same as TSP emission rate variabilities. Due to the four high dichotomous sample values, the IP and FP emission rates for overburden dozers had about twice the relative standard deviation as the TSP emission rates.

PROBLEMS ENCOUNTERED

The most common problem associated with upwind-downwind sampling was the long time required to set up the complex array of 16 samplers and auxiliary equipment. On many occasions, the wind direction would change or the mining operation would move while the samplers were still being set up.

Another frequent problem was mining equipment breakdown or reassignment. At various times, the sampling team encountered these situations: power loss to dragline; front-end loader broke down while loading first truck; dozer broke down, 2 hours until replacement arrived; dozer operator called away to operate frontend loader; and brief maintenance check of dragline leading to shutdown for the remainder of shift for repair.

A third problem was a typical operation of the mining equipment dragline sampling. One example was the noticeable difference in dragline operators' ability to lift and swing the bucket without losing material. Sampling of a careless operator resulted in emission rates two to five times as high as the previous operator working in the same location.

The dragline presented other difficulties in sampling by the upwind-downwind method. For safety reasons or because of topographic obstructions, it was often impossible to place samplers in a regular

array downwind of the dragline. Therefore, many samples were taken well off the plume centerline, resulting in large adjustment factor values in the dispersion equation calculations and the potential for larger errors. Estimating average source-to-sampler distances for moving operations such as draglines was also difficult.

Sampling of coal loading operations was complicated by the many related dust-producing activities that are associated with it. It is impossible to sample coal loading by the upwind-downwind method without also getting some contributions from the haul truck pulling into position, from a frontend loader cleaning spilled coal from the loading area, and from the shovel or frontend loader restacking the loose coal between trucks. It can be argued that all of these constitute necessary parts of the overall coal loading operation and they are not a duplication of emissions included in other emission factors, but the problem arises in selecting loading operations that have typical amounts of this associated activity.

Adverse meteorology also created several problems in obtaining samples. Weather-related problems were not limited to the upwind-downwind sampling method or the five sources samples by this method, but the large number of upwind-downwind tests resulted in more of these test periods being impacted by weather. Wind speed caused problems most frequently. When wind speeds were less than 1 m/s or greater than about 8 m/s, sampling could not be done. Extremely low and high winds occurred on a surprisingly large number of days, causing lost work time by the field crew delays in starting some tests, and premature cessation of others. Variable wind directions and wind shifts were other meteorological problems encountered. In addition to causing extra movement and set up of the sampling equipment, changes in wind direction also ruined upwind samples for some sampling periods in progress. Finally, several sampling days were lost due to rain.

SECTION 9

RESULTS FOR SOURCE TESTED BY BALLOON SAMPLING

SUMMARY OF TESTS PERFORMED

Blasting was the only source tested by the balloon sampling method. Overburden and coal blasts were both sampled with the same procedure, but the data were kept separate during the data analysis phase so that the option of developing separate emission factors was available. A total of 18 successful tests were completed--14 for coal blasts and 4 for overburden blasts. Three more blasts were sampled, but the balloon was hit and broken in one and the plumes missed the sampler arrays in two others; no attempt was made to calculate emission rates for these three tests.

The overburden was not blasted at the mine in North Dakota (second mine), so overburden blast tests were confined to the first and third mines. The resulting sample size of four is not large enough for development of a statistically sound emission factor.

The sampling array consisted of balloon-supported samplers at five heights plus five pairs of ground-based hi-vols and dichots to establish the horizontal extent of the plume. No measure of deposition rate was made with this configuration because all samplers were at the same distance from the source.

Samplers at Mine 2 were located in the pit for coal blasts, but samplers at Mines 1 and 3 were located on the highwall above the pit. Therefore, some (prior) deposition is included in the emission rate measured at the latter mines. These are the only emission rates in the study that are not representative of emissions directly from the source.

Test conditions for the blasting tests are summarized in Table 9-1. An extremely wide range of blast sizes was sampled--from 6 to 750 holes and from 100 to 9600 m². The variation in moisture contents was also quite wide. The only potential correction factor with a limited range during testing was the depth of the holes. All the holes for coal blasts were about 20 ft deep. Overburden holes had a range of 25 to 135 ft, but there are not enough data points to develop a correction factor.

RESULTS

TSP emission rates are shown in Table 9-2. The emission rates varied over a wide range, from 1.1 to 514 lb/blast. Blasting emissions at the first two mines were relatively low; those at the third mine were quite high. Some of the differences are expected to be explained by test conditions, which also varied over a correspondingly wide range. The values in Table 9-2 are as measured, and have not been adjusted for any potential correction factors.

The data subsets by mine were too small for statistics such as standard deviation to be meaningful. If the data are divided into subsets of coal and overburden blasts, the TSP emission rates are as follows:

<u>Type blast</u>	<u>No. samples</u>	<u>Mean, lb</u>	<u>Std dev</u>	<u>Range</u>
Coal	14	110.2	161.2	1.1-514
Overburden	4	106.2	110.9	35.2-270

The only sample that was more than two standard deviations away from the mean was the 514 lb value. However, this blast had more than three times as many holes as any other blast sampled, so it would not be considered an outlier.

Inhalable and fine particulate emission rates are presented in Table 9-3.. The IP emission rates ranged from 0.5 to 142.8 lb/blast and from 17 to 138 percent of TSP. The IP emission rates for blasts averaged 46 percent of the TSP rates, about the same ratio as the haul roads. Fine particulate averaged 5.0 percent of TSP, higher than for any other source. Coal blasts and overburden blasts did not have any obvious distinctions in their respective particle size distributions.

PROBLEMS ENCOUNTERED

Balloon sampling represented a substantial modification of the exposure profiling method and therefore a somewhat experimental technique. It was particularly difficult to apply blasting because technical limitations of the technique combined with the infrequency of blasting resulted in very few opportunities to perform the sampling.

This sampling method could not be used when ground level winds were greater than about 6 m/s because the balloon could not be controlled on its tether. At wind speed less than about 1 m/s, wind direction tended to vary and the sampling array could not be located with any confidence of being in the plume. Also, at low wind speeds, the plume from the blast frequently split or rose vertically from the blast site. Therefore, sampling was constrained to a fairly narrow range of wind speeds.

For safety reasons, a source-sampler distance of 100 m or more was usually required. At this distance, the plume could disperse vertically above the top sampler inlet under unstable atmospheric conditions.

Even though sampling was done at very large mines, only one or two blasts per day were scheduled. This often created difficulties in obtaining the prescribed number of blasting tests at each mine.

Since blasting was not a continuous operation, there was no continuous plume to provide assistance in locating the samplers. For coal blasts in particular, the portion of the plume below the high wall usually was channeled parallel to the pit but any portion rising above the high wall was subject to ambient winds and often separated from the plume in the pit.

Finally, representative soil samples could not be obtained for this source because of the abrupt change in the characteristics of the soil caused by the blast. The moisture contents reported in Table 9-1 were for samples of coal in place and overburden from drilling tests (both prior to blasting).

SECTION 10

RESULTS FOR SOURCES TESTED BY WIND TUNNEL METHOD

SUMMARY OF TESTS PERFORMED

As discussed previously, the wind tunnel method was used to test particulate emissions generated by wind erosion of coal storage piles and exposed ground areas. These sources were tested at three mine sites during the period October 1979 through August 1980.

A total of 37 successful wind tunnel tests were conducted at the three mines. Tests at Mine 1 took place in late autumn, with below normal temperatures and snowfall being encountered. Emissions tests were distributed by source and by mine as follows:

<u>Source</u>	Number of tests		
	<u>Mine 1</u>	<u>Mine 2</u>	<u>Mine 3</u>
Coal storage piles	4	7	16
Exposed ground areas	1	5	4

The decision of when to sample emissions from a given test surface was based on the first observation of visible emissions as the tunnel flow rate was increased. At Mines 1 and 2, if visible emissions in the blower exhaust were not observed at a particular tunnel flow rate, no air sampling was performed, but a velocity profile was obtained. Then the tunnel flow rate was increased to the next level and the process repeated. When visible emissions were observed, emission sampling was performed and then repeated at the same wind speed (but for a longer sampling time) to measure the decay in the erosion rate. At Mine 3, particle movement on the test surface was used as the indicator that the threshold velocity had been reached and that emission sampling should be performed. Five tests on coal piles and seven tests on exposed ground areas were conducted on surfaces where no erosion was visually observed, and in these cases no emissions sampling was performed.

Table 10-1 lists the test site parameters for the wind tunnel tests conducted on coal pile surfaces. The ambient temperature and relative humidity measurements were obtained just above the coal surface external to the tunnel.

Table 10-2 gives the tunnel test conditions for the wind erosion emission tests on coal surfaces. The equivalent speed at 10 m was determined by extrapolation of the logarithmic velocity profile measured in the wind tunnel test section above the eroding surface. The first friction velocity, which is a measure of the wind shear at the eroding surface, was determined from the velocity profile.

Table 10-3 gives the erosion-related properties of the coal surfaces from which wind-generated emissions were measured. The silt and moisture values were determined from representative undisturbed sections of the erodible surface ("before" erosion) and from the actual test surface after erosion; therefore, only one "before" condition and one "after" condition existed for each test site. The roughness height was determined from the velocity profile measured above the test surface at a tunnel wind speed just below the threshold value.

Table 10-3 lists the test site parameters for the wind tunnel tests conducted on exposed ground areas. The surfaces tested included topsoil, subsoil (with and without snow cover), overburden and scoria. For Runs J-28, K-31 through K-34, K-47 and K-48, no air sampling was performed, but velocity profiles were obtained.

Table 10-5 gives the tunnel test conditions for the wind erosion emission tests on exposed ground areas. Table 10-6 gives the erosion-related properties of the exposed ground surfaces from which wind-generated emissions were measured.

RESULTS

Table 10-7 and 10-8 present the wind erosion emission rates measured for coal pile surfaces and exposed ground areas, respectively. Emission rates are given for suspended particulate matter (particles smaller than $30\text{ }\mu\text{m}$ in aerodynamic diameter) and inhalable particulate matter (particles smaller than $15\text{ }\mu\text{m}$ in aerodynamic diameter).

For certain emission sampling runs, emission rates could not be calculated. No particle size data were available for run J-30. For exposed ground area runs P-37 and P-41, measured emissions consisted entirely of particles larger than $11.6\text{ }\mu\text{m}$ aerodynamic diameter (the cyclone cut point).

The means, standard deviations, and ranges of SP emission rates for each source category are shown below:

<u>Source</u>	<u>No. tests</u>	<u>S. emission rate (lbs/acre-s)</u>		
		<u>Mean</u>	<u>Std. dev.</u>	<u>Range</u>
Coal piles				
On pile, uncrusted	16	0.318	0.439	0.0150-1.52
On pile, crusted	7	0.0521	0.0415	0.00964-0.113
Surrounding pile	4	0.754	1.054	0.0303-2.27
Exposed ground areas				
Soil, dry	4	0.264	0.195	0.104-0.537
Soil, wet	1	0.0143		0.0143
Overburden	5	0.142	0.160	0.00698-0.329

It can be seen that natural surface crusts on coal piles are effective in mitigating wind-generated dust emissions. In addition, emissions from areas surrounding piles appear to exceed emissions from uncrusted pile surfaces but are highly variable.

With reference to the rates measured for exposed ground areas, emissions from more finely textured soil exceed emissions from overburden. As expected, the presence of substantial moisture in the soil is effective in reducing emissions.

Examinations of the conditions under which tests were conducted indicates (1) an increase in emission rate with wind speed and (2) a decrease in emission rate with time after onset of erosion. This must be considered in comparing emission rates for different source conditions.

PROBLEMS ENCOUNTERED

The only significant problem in this phase of the study was the unforeseen resistance of selected test surfaces to wind erosion. Threshold velocities were unexpectedly high and occasionally above the maximum tunnel wind speed. This occurred primarily because of the presence of natural surface crusts which protected against erosion. As a result, the testing of many surfaces was limited to determination of surface roughness heights.

Although testing of emissions was intended to be restricted only to dry surfaces, the occurrence of snowfall at Mine 1 provided an interesting test condition for the effect of surface moisture. This helps to better quantify the seasonal variation in wind-generated emissions.

SECTION 11

RESULTS FOR SOURCE TESTED BY QUASI-STACK SAMPLING

SUMMARY OF TESTS PERFORMED

Overburden drilling was the only source tested by the quasi-stack method. A total of 30 tests were conducted--11 at the first mine, 12 at the winter visit to the first mine, and 7 at the third mine. No drilling samples were taken at the second mine because the overburden was not shot, and hence not drilled, at that mine. No testing was done for coal drilling because it was not judged to be a significant source.

Sampling was done on the downwind side of the drill platform; the enclosure was to contain all the plume coming from beneath the platform. Four isokinetic sampling heads were located across the far side of the enclosure. Each collected particulate matter in a settling chamber and on a filter. Because of the proximity of the sampling inlets to the source (2 to 3 m), the assumption was made that the filter catch was the suspended material and the settling chamber was the settleable material.

Test conditions for the drill tests are summarized in Table 11-1. Testing took place over a wide range of drilling depths (30 to 110 ft) and soil silt contents (5.2 to 26.8 percent), so these can be evaluated as correction factors. However, there was very little variation in the moisture contents of the samples. No determination was made whether this was due to the undisturbed overburden material having a fairly narrow range of moisture contents or whether it was coincidence that all moisture contents were in the range of 7 to 9 percent. In either case, moisture content is not a candidate for a correction factor because of the narrow range of observed values.

The wind speeds reported in Table 11-1 are not ambient speeds; they are the average speeds measured by a hot-wire anemometer at the far end of the enclosure. In general, they were much lower than ambient because the wind was blocked by the drilling rig and platform. The speeds shown in the table are the averages for each sampling period of speeds and the sampling heads were set at to sample isokinetically. The four heads were adjusted individually based on wind speed measurements taken at that point in the enclosure. Wind speed profiles were observed to be fairly uniform across the enclosure, especially in comparison with traverses across a stack.

RESULTS

The results of the drill tests are shown in Table 11-2. The values labeled "filter" are suspended particulate, comparable to TSP emission rates by other sampling methods. No smaller size fractions than suspended particulate were obtained for this source. The filter catch averaged only 14.2 percent of the total catch (filter plus settling chamber), indicating that most of the material emitted from the drill holes was of large particle size, and therefore readily settleable. This appears to be a reasonable finding, since a large portion of the emissions were produced by an air blast as the drill first entered the ground.

The total emissions per test had much wider variation than the suspended portion (filter catch). However, the total emission values were not used for development of any emission factor, so this variation was of little consequence.

The units for the TSP emission rates are lb/hole. The overall range of emission rates was wide--0.04 to 7.29 lb/hole--but ranges for subsets from the individual mine visits were considerably narrower. The statistics for the three subsets by mine visit are:

<u>Mine</u>	<u>No. samples</u>	<u>Mean, lb/hole</u>	<u>Std dev</u>	<u>Range</u>
1	11	0.84	0.84	0.04-2.43
1W	12	1.98	1.21	0.06-3.38
3	7	4.73	1.95	1.79-7.29

None of the samples were outliers (more than two standard deviations away) from the mean value of their subsets. The mean TSP emission rate for the 30 samples was 2.20 lb/hole and the standard deviation was 1.97. Only one value, 7.29, was more than two standard deviations away from this mean. This distribution is prior to inclusion of correction factors, which are expected to explain part of the observed variation in emission rates.

PROBLEMS ENCOUNTERED

The quasi-stack sampling method had not been used previously on any open fugitive dust sources similar to those at surface mines. However, the method worked well for sampling drilling emissions and only a few problems were encountered. The most important problem was that part of the plume sometimes drifted outside the enclosure when a change in wind direction occurred. No method could be found to account for this in estimating source strength, so it was ignored in the calculations. The effect of emissions escaping the enclosure was to underestimate actual emission rate, possibly by as much as 20 percent (based on the maximum volume of visible plume outside the enclosure).

Another problem with the sampling method was that no particle size data were obtained. Collection of millipore samples for microscopic analysis was originally planned, but the particle size data obtained by microscopy in the comparability study did not agree well with that from aerodynamic sizing devices.

A third problem was securing representative soil samples. As the drilling progressed, soil brought to the surface sometimes changed in appearance as different soil strata were encountered. Usually, a composite of the different soils was collected to be submitted as the soil sample. However, the soil type discharged for the longest period of time or multiple samples could have been taken. Also, there was no assurance that soil appearance was a good indicator of changes in its moisture or silt content.

SECTION 12

EVALUATION OF RESULTS

EMISSION RATES

A total of 265 tests were conducted during the four sampling periods at three mines. The tests for each source were distributed fairly uniformly across the three mines, as previously shown in Table 3-8, despite difficulties in obtaining tests of particular sources at each mine. The total number of tests for each source was based on sample variance of data from the first two mines: required sample sizes were calculated by the two-stage method described in Section 5.

As in any fugitive dust sampling effort, several problems were encountered during the study:

Large average differences in concentrations were obtained for collocated samples, indicating imprecision of the sampling techniques.

Inability to control the mining operations led to some tests in which data had to be approximated or some operation cycles excluded.

Handling problems with the dichotomous filters may have contributed to an underestimate of emission rates in some cases.

Representative soil samples could not be obtained for some tests because of accessibility problems, etc., so moisture and silt values from prior or later tests had to be substituted.

However, the errors introduced by these problems appeared to be small in relation to the natural variance in emission rates of the sources as a result of meteorology, mining equipment, operation, etc. In other words, selection of time and place for sampling probably had far more impact on the resulting emission rates than problems associated with measurement of the rates.

The selection of mines may also have influenced final emission factors. Emission rates measured at Mines 1 and 2 were generally in the same range. However, the emission rates measured at Mine 3 were in general outside the range of values from Mines 1 and 2. Correction factors were used to explain the range in values so that the average rates employed in determining the final emission factors would not be biased by the high values from Mine 3.

For all three mines, the relative standard deviations, a measure of variation in the sample data, ranged from 0.7 to 1.5 for different sources. Emission rates for most sources varied over two orders of magnitude in sample size of 12 to 39. Similar variation was observed in some of the independent variables thought to have an effect on emission rates.

The remainder of this section is devoted primarily to three aspects of the test data--particle size distribution, deposition, and effectiveness of control measures. The evaluation of the independent variables and their effect on emission rates is discussed in Section 13.

PARTICLE SIZE DISTRIBUTIONS

Considerable effort was expended in the comparability study evaluating three particle sizing methods--cascade impactors, dichotomous samplers, and microscopy. The comparison of methods, presented in Section 6, showed that the cascade impactors and dichotomous samplers gave approximately the same particle size distributions. In contrast, the microscopy data varied widely. It was concluded that microscopy is a useful tool for semiquantitative estimates of various particle types but is inadequate for primary particle sizing of fugitive dust emissions.

Cascade Impactor Data

As mentioned in Section 3, greased substrates were used in cascade impactors operated at the third mine to minimize particle bounce-through. The effectiveness of this preventive measure was checked by comparing the relative amounts of particulate catch on the back-up filter and on the impactor substrates of cyclone/impactor sample with and without greased substrates.

In Table 12-1, cyclone/impactor samples of uncontrolled emissions from each source category at Mines 1 and 2 (where ungreased substrates were used) are compared with samples of the same sources from Mine 3. Sampling heights for the impactor varied slightly by mine, which introduces another variable into the comparison. It is evident from Table 12-1 that greasing produces little change in the proportion of material caught on the back-up filter. Only in the case of haul trucks does a positive effect of greasing appear. On the other hand, the single scraper emission sample collected at the third mine shows a larger portion of particulate on the back-up filter. Although comparisons of this type should ideally be based on collocated samplers, no readily identifiable pattern for the effect of greasing emerges from this comparison.

Dichotomous Sampler Data

At the outset of the study, it was hypothesized that, as the larger particles fell out of the plume downwind of a mining source, the fraction of the remaining suspended particulate less than $15\text{ }\mu\text{m}$ and less than $2.5\text{ }\mu\text{m}$ would increase. Further, it was expected that only a small percentage of the particulate generated by a source would be in the less than $2.5\text{ }\mu\text{m}$ range. The test data obtained from the dichotomous samples supported both of these hypotheses.

While the data produced the expected results, there were several inherent limitations in the sampling technique that were discovered during the study. These were: the small sample weights collected for the fine particle samples; the low ratio of net weight to tare weight of the filter media; and the variable particle size cut point of the inlet.

The small sample weights on the fine filters were attributed to two causes: the low volume of air collected and the small amount of particulate less than $2.5\text{ }\mu\text{m}$ present in the plumes. Since the flow rate of the sampler was so low, $1.0\text{ m}^3/\text{h}$, only a small amount of mass was collected when the concentrations were low. The net weight of the particulate collected on the fine quality assurance in weighing. These net weights were only a small fraction of the tare weight of the filter. Consequently, the potential weighing error was much higher for the dichotomous filters than for hi-vol filters, which collect a much greater mass. However, the number of filters checked that exceeded the $100\text{ }\mu\text{g}$ tolerance in weighing was almost the same for dichotomous filters (5 of 281) as it was for hi-vol filters (7 of 774), which had an allowable tolerance of 3.0 mg .

An associated problem was the filter media itself. The dust particles did not adhere well to the Teflon surface. Rather, the particulate remained on the surface of the filter where it was easily dislodged. Extensive quality assurance procedures were implemented for the handling of the filters to minimize particle losses. These procedures were discussed in Section 4.

The light loadings on the fine filter stages presented additional problems during the calculation procedures. A negligible mass on the fine filters resulted in a negligible concentration. For the upwind-downwind sampling, 25 percent of all the fine filters had calculated concentrations of zero. There was little variation in this number between sources. The individual percentages ranged from 18 to 30 percent. The problem was further complicated when upwind concentrations were subtracted from downwind concentrations. An additional 10 to 20 percent of the fine concentrations became negligible after accounting for upwind concentrations.

These negligible values, by themselves, were not a problem. The data simply indicated that there were no measureable emissions in the less than 2.5 μm size range. However, the particle size cut point of the inlet is dependent on wind speed (Wedding 1980). Consequently, measured coarse concentrations had to be corrected to a 15 μm cut point. This adjustment was based on an assumed lognormal distribution of particles in the 2.5 to 30 μm range. In order to determine the 15 μm value, a concentration different from zero was needed for the less than 2.5 μm size. As discussed in Section 5, the concentration resulting from the minimum detectable mass was substituted for any negligible downwind concentrations.

This substitution had the effect of artificially raising the fine particulate concentration for each source. This change resulted in an increase in average FP concentrations of about 10 percent.

Even though there were problems with the dichotomous sampler data, this sampler was chosen for generating the final particle size data for several reasons:

1. During the study design, the dichotomous sampler was the EPA method of choice for selective particle size sampling. As such, it is considered state-of-the-art for ambient particle size measurements.
2. The cascade impactor could not be conveniently used. Data from the comparability studies showed that comparison of dichotomous sampler and cascade impactor results was reasonable. However, no cascade impactor data were generated. Also, PEDCO did not use any impactors.
3. Both contractors used the same type of dichotomous sampler. As shown in Section 6, the dichotomous sampler produced internally consistent results. Therefore, it was expected that particle size data generated by both contractors would be consistent.
4. Based on the results of the comparability studies, the dichotomous sampler gave the most consistent results of the three methods evaluated. Extensive project resources were expended to find the most valid particle sizing method. Special quality assurance procedures were developed and implemented to control problems in the data. The precision of collocated dichotomous samplers and the number of filters that exceeded the quality assurance tolerance in weighing (5 out of 281) were about the same as that for hi-vols (7 out of 774).

Particle Size Distribution Data

The average fraction of particles less than 15 μm and less than 2.5 μm are shown in Table 12-2. The data for each source are expressed as fractions of TSP for upwind-downwind tests and as fractions of SP (less than 30 μm diameter particles) for profiling and wind tunnel tests. These fractions were calculated from the raw test results presented in Sections 6 through 11.

As shown in the table, IP fractions are reasonably consistent. They vary from 0.30 to 0.67. The FP/TSP ratios have a much wider variation, from 0.026 to 0.196. The 0.196 value for overburden dozers appears to be an anomaly. Excluding this value, the range is from 0.026 to 0.074. The high overburden dozer ratios are due to the assumption of minimum detectable concentrations on the fine filters combined with low TSP concentrations for most of these tests.

Also evident from the table is that the standard deviation values are generally higher for sources measured with the upwind/downwind technique as opposed to the profiler technique. This difference is inherent in the sampling configurations. Upwind/downwind data are generated from multiple downwind distances and are the average of several points. In contrast, profiler data are gathered at a single point 5 m from the source.

DEPOSITION

Data for quantifying deposition were generated in three ways:

1. For 48 profiling tests, deposition was measured by collocated dustfall buckets at 5, 20, and 50 m downwind of the source.
2. For 77 upwind-downwind sampling tests, deposition was determined by apparent source depletion with distance. Measurements were made at four downwind distances at a maximum distance of 200 m downwind of the source.
3. For 10 comparability tests, exposure profiling and upwind-downwind samplers were run on a common source so that simultaneous measurements by these methods could be compared. Downwind distances were 5, 20, and 50 m.

Dustfall

A consistent reduction in dustfall rate, with distance from the source was found in 38 of 48 successful exposure profiling tests. The average difference between collocated dustfall buckets was 42.6 percent.

The dustfall rates for each test were converted to equivalent depletion factors (ratio between the apparent emission rate, Q_x , at a distance x downwind and the initial emission rate, Q_0) by a four step procedure:

1. Total dustfall from 5 m to 20 m and from 20 m to 50 m was calculated by multiplying the average dustfall rate over each distance times the distance. The resulting total dustfall values were in units of mg/m-min.
2. The initial emission rate for each test corresponding to the dustfall rates was total particulate (TP). The TP emission rate was converted from lb/VMT to mg/m-min, using the number of vehicle passes and the sampling duration of the test.
3. The total dustfall values for each distance were divided by the initial emission rate to determine the fraction of TP emissions deposited over that distance.
4. The depletion factor, or fraction of initial emissions remaining airborne, for TP to any distance (20 to 50 m in this case) was 1.0 minus the total fraction deposited by that distance.

The calculated depletion factors for each profiling test in which dustfall measurements were taken (excluding the comparability tests) are shown in Table 13-3. Deposition, measured as dustfall and expressed as a fraction of initial emissions, appeared to be very uniform from test to test and from source to source. This was evident from the low standard deviations compared to mean values.

The deposition rates by test were correlated with several potential variables such as wind speed and particle size distribution. These analyses did not reveal any significant relationships that could form the basis for an empirical deposition function.

Apparent Source Depletion

Consistent source depletion over the three or four downwind sampling distances was evident in only 13 of 77 upwind-downwind tests. The average depletion factors at all downwind distances were substantially greater than 1.0 (indicating plume enhancement rather than depletion).

The average TSP depletion factors for each source sampled by the upwind-downwind method are presented in Table 12-4. Every one of the sources except haul roads displayed an increase in apparent emission rates with distance.

The standard deviations of the depletion factors displayed two characteristics: relative standard deviations (RSD) consistently increased with distance from the source; and the RSD values were fairly high, indicating much variation in results from the individual tests.

Interestingly, the haul road tests had similar depletion rates to the comparability tests (which were conducted on haul roads and scrapers) when differences in wind speed were considered. This observation led to another comparison--between tests in which the source was sampled as a line source and those in which it was sampled as a point source. The 15 line source tests had average depletion factors less than 1.0, but did not demonstrate continuing deposition with increasing distance. In contrast, the point source tests had average depletion factors of 1.36, 1.35, and 1.52 at three successive distances from the source. The IP data could not be effectively analyzed for source depletion because dichotomous samplers were placed at only the first two distances in all upwind-downwind tests after the comparability tests.

Comparability Study

A discussion of deposition data from the comparability studies is contained in Section 6. Data are summarized in Figure 6-7. Dustfall data were not meaningful because of data scatter. For exposure profiling, the 30 μ m depletion factors at 20 m and 50 m were found to be 108 percent (source enhancement) and 55 percent. Corresponding TSP data for upwind-downwind sampling was found to be 87 percent and 56 percent. The data for 50 m from both measurement techniques indicated considerably greater source depletion than was found in 44 exposure profiling tests with dustfall measurements (Table 12-3).

Comparison of Sources of Deposition Data

Data analyzed with respect to deposition were dustfall buckets from profiling tests; source depletion from upwind-downwind tests; and profiling data from the comparability study. These analyses did not reveal any significant relationships that could form the basis for an empirically derived deposition function. Because these analyses were non-productive and the primary method of measuring deposition (apparent source depletion in upwind-downwind sampling) gave unstable results, a deposition function cannot be presented at this time. However, several conclusions can be drawn.

Based on experience gained from this study, it is recommended that future dustfall measurement be performed with the following considerations:

1. Dustfall measurements at various distances downwind of the source should be accompanied by a coincident upwind measurement that is subtracted as a background value. Dustfall data for a

test should be invalidated if the upwind sample is impacted by the source as a result of wind reversal.

2. The measurements should be done in duplicate to reduce error and so that the precision of the measurement can be assessed.
3. Measurements should be taken at distances greater than 50 m to quantify the continuing fallout of particles. However, at greater distances, collection of a detectable mass of dustfall during a short sampling period may be a problem.

The principal shortcoming of the technique is that the data presented are for total particulate, which in general are of less interest than TSP or IP data.

The upwind-downwind source depletion data which indicated source enhancement in the majority of tests was misleading. Poor results have been attributed to three main causes.

First, many of the sources tested by upwind-downwind required placement of the first row of samplers at relatively large distances from the source (30-60 m compared to 5-10 profiling). A large part of the deposition may already have occurred prior to this first distance, resulting in apparent emission rates of about the same magnitude at the four downwind distances, rather than decreasing with distance from an emission rate measured immediately downwind of the source.

The second suspected cause was that reentrainment may actually be increasing downwind concentrations. Most of the source listed in Table 12-4 were, by necessity, tested with the samplers placed on recently-disturbed surfaces adjacent to the sources. Haul roads were an exception, in that stable vegetated areas adjacent to the roads could be selected as sampling locations.

The third suspected cause of an upward bias in emission rates with distance was the point source dispersion equation. If equivalent data are input to the point and line source dispersion equations, the line source version will usually indicate a greater reduction in apparent emission rates with distance. The sensitivity of calculated emission rates to several parameters in the point source equation but not in the line source equation were evaluated, but no single parameter was isolated that could be masking the reduction in apparent emission rates with increase in distance.

Because of these three identified problems, it is recommended that additional deposition measurements be made on line sources where reentrainment near downwind samplers is minimized.

ESTIMATED EFFECTIVENESS OF CONTROL MEASURES

Two control measures for unpaved roads and mine areas were tested as part of this study. The controls were calcium chloride/watering and watering only. Table 12-5 summarizes the results obtained. No control cost data were obtained.

At Mine 1, two tests of an unpaved access road treated with calcium chloride were performed. According to plant personnel, calcium chloride (Dow Peladow) had been applied at a density of 0.6 gallon of 30 percent solution per square yard of road surface, approximately three months prior to testing. This road was watered four times each day to maintain the effectiveness of the calcium chloride. Watering occurred about one hour before testing, but no rewatering was done during a test. Three tests of an uncontrolled access road at Mine 1 were performed to establish the uncontrolled emission rate for the calculation of control efficiency. As indicated in Table 12-5, the control efficiency calculated from the average controlled and uncontrolled emission rates was 95 percent for SP and IP and 88 percent for FP.

At Mine 2, four tests of a watered haul road and four tests of the same road without watering were performed to determine the control efficiency of watering. The measured watering rate was 0.05 gallon per square yard of road surface about 5 minutes prior to start of sampling. No rewatering was done during testing. As indicated in Table 12-5, a mean control efficiency of approximately 60 percent was achieved, with no appreciable dependence on particle size. A similar series of tests performed at Mine 3 to determine the effectiveness of haul road watering yielded a mean control efficiency of about 70 percent. Watering of the loading areas at Mine 3 reduced coal loading emissions an average of 78, 81, and 68 percent for TSP, IP, and FP, respectively.

Although no quantitative data on the effectiveness of calcium chloride as a dust control measure for unpaved roads was found in the literature, references were found that contained data evaluating watering as a dust control measure for haul roads. The estimated control efficiency of 50 percent for watering, as reported by Jutze and Axetell (1974), has been cited in several recent primary references on fugitive dust control. Actual test data reported on watering of haul roads in surface coal mines (U.S. Environmental Protection Agency 1978a) showed a control efficiency value of 31 percent was reported (PEDCo Environmental 1980) for watering of haul roads in a stone quarry.

The efficiency values for watering of haul roads obtained in this study (Table 12-5) were higher than the previously reported values and the original estimate of 50 percent. The efficiency values for calcium chloride are consistent with reported values of initial control efficiency exceeding 90 percent for other chemical treatment measures: lignin sulfonate applied to haul roads in a taconite mine and petroleum resin applied to a steel plant road (Cowherd, et al. 1979).

SECTION 13

DEVELOPMENT OF CORRECTION FACTORS AND EMISSION FACTOR EQUATIONS

The method for developing correction factors was based on multiple linear regression (MLR), as described in Section 5. To summarize the method briefly, values for all variables being considered as possible correction factors were tabulated by source with the corresponding TSP emission rates for each test, then the data were transformed to their natural logarithms. The transformed data were input to the MLR program, specifying the stepwise option and permitting entry of all variables that increased the multiple regression coefficient (initially allowing the program to determine the order of entry of the variables).

The MLR output of greatest interest with the significance of each variable. In nontechnical terms, significance is the probability that the observed relationship between the independent and dependent variables is due to chance. If the significance was less than 0.05, the variable was included as a correction factor; if it was between 0.05 and 0.20, its inclusion was discretionary; and if above 0.20, the variable was not included. The correction factors were multiplicative because of the \ln transformation; the power for each significant correction factor was specified in the MLR output as the coefficient (B value) for that variable in the linear regression equation.

This MLR analysis could not be employed with data from the wind erosion sources because sequential tests were found to be related and were grouped, thus reducing the number of independent data points. With the large number of potential correction parameters in relation to data points, regression analysis was not feasible.

MULTIPLE LINEAR REGRESSION ANALYSIS

The stepwise multiple linear regression program that is the nucleus of the correction factor development procedure is explained in moderate detail in Appendix A. Further information on it can be found in the following three references: Statistical Methods, Fourth Edition (Snedecor 1946); Applied Regression Analysis (Draper and Smith 1965); and SPSS, Second Edition (Nie 1975).

The independent variables that were evaluated as possible correction factors are listed in Table 13-1. An assessment was made during the MLR analysis to determine the portion of the total variation in the emission factors explained by the correction factors (multiple regression coefficient squared) and whether additional variables should have been considered. The data for each of these variables were presented in tables throughout Sections 7 through 11, and have not been repeated here.

The data were all transformed to their natural logarithms prior to running MLR. The presumption that the ln transformation would provide better final emission factor equations was based on three considerations: the data sets all had high relative standard deviations indicating that the distributions of the emission factor were skewed to the right (i.e., a long upper tail); the homogeneity of variances (a condition for any least squares analysis) was increased; and multiplicative correction factors were preferable to additive ones.

More than one MLR was usually required to obtain the final MLR equations with its associated significance and regression coefficients (B values). Second and third runs were needed to eliminate a data point shown to be an outlier, to remove a variable highly correlated with another, to remove a variable with significance of 0.05 to 0.20 that entered the stepwise regression ahead of another variable still being evaluated, or to eliminate a dummy variable (such as a source subcategory or control/no control) after its significance had been determined. The sequence of MLR runs with the TSP data for each source is documented by presenting in Table 13-2 the results of the first run for each source (with all the variables included), a description in Table 13-3 of all changes made to get to the final run, and in Table 13-4 the results of the final run.

The multiple regression (correlation) coefficient, R , is a measure of how well the variables in the equation explain variations in emission rate. (Actually, R^2 is the portion of the total variation explained by the use of the specified variables). Significance, the second reported statistic, estimates the change that the observed correlation for a particular variable is due to random variation. Finally, the residual relative standard deviation measures the amount of variability left in the transformed data set after adjustment as indicated by the regression equation. In the transformed data set, the mean logarithmic values can be quite small. Consequently, the relative standard deviations are larger than normally encountered in regression analysis.

Several independent variables were fairly significant (less than 0.20) when they entered the regression equations, but were not included as correction factors in the final emission factors. The reasons for omitting these potential correction factors are explained below, by source:

TABLE 13-1. VARIABLES EVALUATED AS CORRECTION FACTORS

Source	Sample size ^a	Variables evaluated	Units
Drill, overburden	30	Silt Moisture Depth of drilling	% % ft
Blasting	18	Material blasted (coal or overburden) No. of holes Area blasted Depth of holes Moisture Distance to samplers Wind speed Stability class	- - ft ^{2b} ft % m m/s -
Coal loading	25	Equipment type Bucket size Moisture	- yd ³ %
Dozer	27	Material worked Dozer speed Silt Moisture Wind speed	- mph % % m/s
Dragline	19	Drop distance Bucket size Silt Moisture	ft ₃ yd ₃ % %
Scrapers	15	Silt Weight Vehicle speed Wheels Silt loading Moisture Wind speed	% tong _b mph - g/m ² % m/s
Graders	7	c	c
Light- and medium-duty vehicles	10	c	c
Haul trucks	27	c	c

^a Uncontrolled runs only.

^b Originally reported in metric units the variable values were converted to english units.

^c Same as for scrapers.

TABLE 13-3. CHANGES MADE IN MULTIPLE LINEAR REGRESSION RUNS (TSP)

Source	Change made	Run No.	Reason
Drill	Remove two data points	2	Outliers
Blasting, all	Specify moisture as first variable	2	Moisture had $R = -0.72$ vs. area with $R = 0.73$
Coal loading, all	Eliminate bucket size, add control	2	Bucket size was to the 12.3 power
	Remove one data point	3	Outlier
Dozer, all	Remove one data point	2	Outlier
Dragline	Remove one data point	2	Outlier
Scraper	Drop wheels, moisture, and silt loading	2	Wheels did not vary appreciably, moisture and silt loading difficult to quantify
	Add moisture; remove anisokinetic runs; drop wind	3	Moisture needs to explain low emissions at mine. Four anisokinetic runs (low winds) eliminated
Graders	Drop wheels, weight, moisture, and silt loading	2	Wheels and weight did not vary appreciably, moisture and silt loading difficult to quantify
Light- and medium-duty vehicles			
Haul trucks	Drop wind speed, vehicle speed, anisokinetic runs	2	Three anisokinetic runs (low winds) eliminated, vehicle speed correlation inconsistent with previous studies
	Remove K-7 and L-1	3	Outlier and run unrepresented by vehicle mix

Drills/Silt - This variable was highly significant but was inversely rather than directly related to emission rate. Therefore, the last potential correction factor for this source is eliminated; the reported emission factor is simply the geometric mean of the observed values.

Blasts/ No. of holes - This variable was highly correlated with another independent variable, area blasted, which entered the regression equation before number of holes.

Coal loading/Bucket size - Bucket size was related to emission rate by a power of -12.3 in the regression equation, primarily because of the very narrow range of bucket sizes tested--14 to 17 yd³. Also, bucket size only had a correlation of 0.05 with emission rate.

Dozer, all/Dozer speed - Although equipment speed was significant in the combined data set, it was not significant in either of the subsets (coal dozers or overburden dozers).

Dragline/Silt - In the first run, silt was not a significant variable. However, when an outlier was removed, it became highly significant but was inversely rather than directly related to emission rate

Scrapers/Vehicle speed - This parameter was significant at the 0.111 level, in the discretionary range. It was omitted because of its high correlation with silt which entered the equation earlier.

Light- and medium-duty vehicles/Weight - This was omitted to preserve the simplicity of the resulting equation in light of the high correlation between emission factor and moisture, the first parameter entered.

Haul trucks/Vehicle speed - Inverse relationship with emission rate was inconsistent with all previous studies.

Haul trucks/Weight - This parameter was omitted because its coefficient was negative, which is difficult to justify from the physics of the problem.

These relationships conflicted with previous experience in fugitive dust testing. While the actual relationship may be similar to that indicated by the MLR equation, some confirmation in the form of additional data was thought to be needed before including these dubious parameters as correction factors.

The transformations, initial MLR runs, adjustments, and additional MLR runs were done by the same procedures with the IP emission data as with the TSP data, using the same values of the independent variables.

The results are summarized in an analogous series of three tables-- Tables 13-5, 13-6 and 13-7. As indicated in Table 13-6, very few changes were required from the initial runs of the IP data, with the benefit of the prior TSP runs. For every source, the same independent variables were highly significant for IP as for TSP.

EMISSION FACTOR PREDICTION EQUATIONS

The prediction equations obtained from the MLR analyses are summarized in Table 13-8. These equations were taken directly from the MLR runs described in Tables 13-4 and 13-7, with the coefficients in the Table 13-8 equations being the exponentials of the MLR equation constant terms and the exponents for each term being the B values. These equations give estimates of the median value of the emission factors for given value(s) of the correction factor(s). (The coefficients and exponents are from the intermediate MLR step that includes only the significant variables that appear in the final equation.) All but four of the independent variables in the equations in Table 13-8 are significant at the 0.05 level or better. The four variables in the discretionary range (0.05 to 0.20) that were included are: L in haul truck TSP equation, $a = 0.146$; A in the coal blasting IP equation, $a = 0.051$; M in the overburden IP equation, $a = 0.71$; and S in the grader IP equation, $a = 0.078$. The geometric mean values and ranges of the correction factors are summarized in Table 13-9.

CONFIDENCE AND PREDICTION INTERVALS

A computational procedure for obtaining confidence and prediction intervals for emission factors is described in Appendix B at the end of this volume of the report. An example of this computation is given here for coal loading emission data versus the moisture content correction factor.

Figure 13-1 summarizes the results of this example and also includes the observed emission factors. The line in the center of the graph is the predicted median emission rate estimated by the geometric mean. The inside set of curves give the confidence interval for the "true median" as a function of moisture content (M), and the outside set of curves give the prediction interval for an individual emission factor. The intervals vary in length as a function of M . The widths of the intervals are measures of the precision of the estimated factors. These precisions are comparable to those of existing emission factors as illustrated in Section 14.

TABLE 13-5. RESULTS OF FIRST MULTIPLE LINEAR REGRESSION RUNS (IP)

Source	Variable (in order of MLR output)	Multiple R	Significance	Rel. std dev.
Drill	N/A			9.54
Blasting, all				0.753
	Moisture	0.81	0.015	0.367
	Depth of holes	0.88	0.040	0.330
	Area blasted	0.92	0.000	0.451
	Wind speed	0.93	0.210	0.321
	No. of holes	0.94	0.225	0.312
	Material blasted	0.95	0.272	0.307
	Dist. to samplers	0.95	0.313	0.305
Blasting, coal ^a	Stability class	0.95	0.841	0.323
				0.933
	Moisture	0.86	0.000	0.490
	Areas blasted	0.91	0.050	0.421
	No. of holes	0.93	0.146	0.392
	Wind speed	0.94	0.202	0.373
	Dist. to samplers	0.96	0.248	0.360
	Stability class	0.96	0.489	0.373
Coal loading, all				0.235
	Moisture	0.49	0.017	0.210
	Control	0.66	0.017	0.185
	Equipment type	0.67	0.576	0.189
Dozer, all				1.569
	Material worked	0.71	0.000	1.132
	Moisture	0.91	0.000	0.683
	Silt	0.94	0.006	0.579
	Dozer speed	0.97	0.001	0.449
Dozer, coal ^a				0.682
	Moisture	0.91	0.000	0.291
	Silt	0.96	0.012	0.213
	Dozer speed	0.96	0.420	0.216
Dozer, overburden ^a				8.262
	Silt	0.77	0.004	5.550
	Moisture	0.85	0.071	4.830
	Dozer speed	0.87	0.290	4.756
Dragline				0.259
	Moisture	0.49	0.032	0.232
	Drop distance	0.69	0.015	0.197
	Silt	0.72	0.281	0.196
	Bucket size	0.73	0.582	0.200

(continued)

TABLE 13-8. PREDICTION EQUATIONS FOR MEDIAN EMISSION RATES

Source	Prediction equations		FP/TSP ratios median value	Units
	TSP	IP		
Drill	1.3	None ^a	None ^a	lb/hole
Blasting, all	$\frac{961 A^{0.8}}{D^{1.8} M^{1.9}}$	$\frac{2550 A^{0.6}}{D^{1.5} M^{2.3}}$	0.030	lb/blast
Coal loading	$1.16/M^{1.2}$	$0.119/M^{0.9}$	0.019	lb/ton
Dozer, all				
Coal	$78.4 s^{1.2}/M^{1.3}$	$18.6 s^{1.5}/M^{1.4}$	0.022	lb/h
Overburden	$5.7 s^{1.2}/M^{1.3}$	$1.0 s^{1.5}/M^{1.4}$	0.105	lb/h
Dragline	$0.0021 d^{1.1}/M^{0.3}$	$0.0021 d^{0.7}/M^{0.3}$	0.017	lb/yd ³
Scrapers	$(2.7 \times 10^{-5}) s^{1.3} W^{2.4}$	$(6.2 \times 10^{-6}) s^{1.4} W^{2.5}$	0.026	lb/VMT
Graders	$0.040 s^{2.5}$	$0.051 s^{2.0}$	0.031	lb/VMT
Light- and medium-duty vehicles	$5.79/M^{4.0}$	$3.72/M^{4.3}$	0.040	lb/VMT
Haul trucks	$0.0067 w^{3.4} L^{0.2}$	$0.0051 w^{3.5}$	0.017	lb/VMT

^a Test method allowed for measurement of TSP only.

s = silt content, %
A = area blasted, ft²
D = depth of holes, ft
M = moisture content, %
d = drop distance, ft

W = vehicle weight, tons
S = vehicle speed, mph
w = number of wheels
L = silt loading, g/m²

TABLE 13-9. TYPICAL VALUES FOR CORRECTION FACTORS

Source	Correction factor	GM ^a	Range ^b		Units
			Min.	Max.	
Blasting	Moisture	17.2	7.2	38	Percent
	Depth	25.9	20	135	Ft
	Area	18,885	1076	103,334	Ft ²
Coal loading	Moisture	17.8	6.6	38	Percent
Dozers, coal	Moisture	10.4	4.0	22.0	Percent
	Silt	8.6	6.0	11.3	Percent
ovb.	Moisture	7.9	2.2	16.8	Percent
	Silt	6.9	3.8	15.1	Percent
Draglines	Drop distance	28.1	5	100	Ft
	Moisture	3.2	0.2	16.3	Percent
Scrapers	Silt	16.4	7.2	25.2	Percent
	Weight	53.8	36	70	Tons
Graders	Speed	7.1	5.0	11.8	mph
Light- and medium-duty vehicles	Moisture	1.2	0.9	1.7	Percent
Haul trucks	Wheels	8.1	6.1	10.0	Number
	Silt loading	40.8	3.8	254.0	g/m ²

^a GM = antilog {ln (correction factor)}, that is, the antilog of the average of the ln of the correction factors.

^b Range is defined by minimum (Min.) and maximum (Max.) values of observed correction factors.

To summarize the information contained in these curves for confidence intervals, the following information is presented:

1. Prediction equation for the median emission factor from Table 13-8: $TSP, lb/ton = 1.16M^{1.2}$.
2. Geometric mean and range (maximum and minimum values) of moisture content correction factor from Table 13-9: GM = 17.8 percent, 6.6 to 38 percent.
3. Estimated median emission factor at the geometric mean (GM) of the correction factor from Table 13-10: 0.034 lb/ton.
4. Ninety-five percent confidence intervals for the median emission factor (the median value for a large number of tests over one year) at the GM of each correction factor from Table 13-10: 0.023 lb/ton to 0.049 lb/ton.
5. Ninety-five percent prediction intervals for an individual emission factor (approximately one hour) at the GM of the correction factor from Table 13-10: 0.005 lb/ton to 0.215 lb/ton.

The confidence and prediction interval data are given only for one value of the correction factor(s) in order to simplify the presentation. The widths of the intervals of the GM are indicative of the widths at other values provided one uses a percentage of the median value in deriving the confidence and prediction limits. For example, for the coal loading data the lower confidence limits are approximately 50 to 70 percent of the median value, the upper limits are 140 to 170 percent of the median value; the lower prediction limits are 15 percent of the median value and the upper limits are 630 percent (or 6.3 times) of the median value. The coal loading data are slightly more variable than data for other sources and hence the limits are proportionately wider than for the other sources.

Fine particulate (FP) emission factors were not developed by the same series of steps as were the TSP and IP factors, because of the larger variances expected in these data sets and the many tests with negligible readings. However, the relative standard deviations calculated from data in Table 12-2 indicate variability approximately the same as for TSP and IP data. The geometric mean ratios of FP to TSP presented in Table 13-8 are proposed for use with the TSP emission factor equations to derive FP emission factors. The FP emission factor is obtained by multiplying the median FP/TSP ratio times the calculated TSP emission factor for each source.

TABLE 13-10. EMISSION FACTORS, CONFIDENCE AND PREDICTION INTERVALS

Source	TSP/IP	Emission factor, median value ^a	Units	95% confidence interval for median ^b		95% prediction interval for emission factor	
				LCL ^b	UCL ^b	LPL	UPL
Drills	TSP	1.3	lb/hole	0.8	2.0	0.1	12.7
Blasting, all	TSP IP	35.4 13.2	lb/blast	22.7 8.5	55.3 20.7	5.1 2.0	245.8 87.9
Coal loading, all	TSP IP	0.034 0.008	lb/ton	0.023 0.005	0.049 0.013	0.005 0.001	0.215 0.071
Dozers, all coal	TSP IP	46.0 20.0	lb/h	35.5 13.2	59.6 30.4	18.1 4.5	117.0 90.2
ovb.	TSP IP	3.7 0.88	lb/h	2.6 0.59	5.3 1.3	0.91 0.21	15.1 3.7
Draglines	TSP IP	0.059 0.013	lb/yd ³	0.046 0.009	0.075 0.020	0.020 0.002	0.170 0.085
Lt.- and med.-duty vehicles	TSP IP	2.9 1.8	lb/VMT	2.3 1.6	3.9 2.0	1.35 0.64	6.4 5.0
Graders	TSP IP	5.7 2.7	lb/VMT	3.2 1.4	9.9 5.3	1.14 0.39	28.0 18.5
Scrapers	TSP IP	13.2 6.0	lb/VMT	10.0 4.3	17.7 8.9	5.2 1.8	33.1 20.2
Haul trucks	TSP IP	17.4 8.2	lb/VMT	12.8 5.7	23.4 11.0	4.3 1.8	68.2 33.7

- ^a These exact values from the MLR output are slightly different than can be obtained from the equations in Table 13-8 and the correction factor values in Table 13-9 due to the rounding of the exponents to one decimal place.
- ^b LCL denotes lower confidence limit. UCL denotes upper confidence limit.

EMISSION FACTORS FOR WIND EROSION SOURCES

In nearly all of the tests of of wind erosion emissions from the surface of coal piles and exposed ground areas, the SP and IP emission rates were found to decay sharply with time. An exception was the sandy topsoil tested at Mine 3; in that case, an increase in emission rate was observed, probably because of the entrainment effect of infiltration air as the loose soil surface receded below the sides of the wind tunnel. The concept of erosion potential was introduced in Section 5 to treat the case of an exponentially decreasing quantity of erodible material on the test surface. The erosion potential is the total quantity of particles, in any specified particle size range, present on the surface (per unit area) that can be removed by erosion at a particular wind speed.

The calculation of erosion potential necessitated grouping of sequential tests on the same surface. In effect, this reduced the number of independent data points for coal and overburden emissions from 32 to 16. As a result, the decision was made not to subject these data to regression analysis because of the large number of potentially significant correction parameters in relation to the number of emission measurements for any given surface type and condition.

Table 13-11 lists the calculated values of erosion potential classified by erodible surface type and by wind speed at the tunnel centerline. For the most part, the test wind speeds fit into 3-mph increments; values of erosion potential for the few runs performed at other wind speeds are listed under the nearest wind speed category. Whenever erosion potential is given as a range, the extremes represent two data points obtained at nominally the same conditions.

Erosion potential was calculated using Equation 22 (Chapter 5), which is repeated here:

$$\frac{\ln \left(\frac{M_0 - L_1}{M_0} \right)}{\ln \left(\frac{M_0 - L_2}{M_0} \right)} = \frac{t_1}{t_2} \quad (\text{Eq. 22})$$

where

M_0 = erosion potential, i.e., quantity of erodible material present on the surface before the onset of erosion, g/m².

TABLE 13-11. CALCULATED EROSION POTENTIAL VERSUS WIND SPEED

Surface	Mine	Test series	Erosion potential, lb/acre				
			26 mph ^a	29 mph ^a	32 mph ^a	35 mph ^a	38 mph ^a
<u>Coal</u>							
Area surrounding pile	1	J-26 J-26 and 27	> 140 ^b			470 ^b	
On pile, uncrusted	2	K-45 and 46 K-40 and 41 K-39 K-42 and 43		230	480		550 ^b 370
On pile, lightly crusted tracks ^c	3	P-20 P-31 and 32 P-20 to 22 P-20 to 24 P-31 to 35	68 ^b 30	140	260 130 ^b		
On pile furrow	3	P-27 and 28 P-27 to 30				70	90
<u>Overburden</u>	2	K-35 and 36 K-37				90 40 ^b	
<u>Scoria</u> (roadbed material)	2	K-49 and 50				100	

^a Wind speed measured at a height of 15 cm above the eroding surface.

^b Estimated value.

^c Erosion loss may have occurred prior to testing.

t = cumulative erosion time, s

L_1 = measured loss during time period 0 to t_1 , g/m²

L_2 = measured loss during time period 0 to t_2 , g/m²

Alternatively, Equation 22 can be rewritten as follows:

$$\left(1 - \frac{L_2}{M_0}\right) = \left(1 - \frac{L_1}{M_0}\right) \frac{t_2}{t_1} \quad (\text{Eq. 22a})$$

An iterative calculation procedure was required to calculate erosion potential from Equation 22 or 22a. Further, two cumulative loss values and erosion times obtained from back-to-back testing of the same surface were required. Each loss value was calculated as the product of the emission rate and the erosion time.

For example, Runs P-27 and P-28 took place on a coal pile furrow at a tunnel centerline wind speed of 36 mph. The incremental losses were calculated as follows:

$$\text{P-27: } 0.0386 \text{ g/m}^2\text{-s} \times 120 \text{ s} = 4.63 \text{ g/m}^2$$

$$\text{P-28: } 0.00578 \text{ g/m}^2\text{-s} \times 480 \text{ s} = 2.77 \text{ g/m}^2$$

Thus the values substituted into Equation 22 for this test series were:

$$L_1 = 4.63 \text{ g/m}^2$$

$$t_1 = 120 \text{ s}$$

$$L_2 = 4.63 + 2.77 = 7.40 \text{ g/m}^2$$

$$t_2 = 120 + 480 = 600 \text{ s}$$

A value of $M_0 = 10$ was selected and substituted into the right-hand side of equation 22a and the left-hand side was solved for M_0 . The resulting value of 7.75 was then substituted back into the right-hand side to obtain a new solution--7.48. Additional substitutions were made and the iteration procedure converged quickly to 7.46 for erosion potential (M_0), indicating that only a small additional loss (0.06 g/m²) would have occurred if the tunnel had been operated beyond the 600-s time period at the same wind speed. The corresponding nonmeric value for the erosion potential is 67 lb/acre, which rounds to 70 lb/acre.

Data from unpaired runs (J-26, J-27, K-39, P-20, and K-37) were used to derive estimated values of erosion potential. Except for J-26, the erosion times were long enough so that the measured losses approximated the corresponding erosion potentials.

Note that whenever a surface was tested at sequentially increasing wind speeds, the measured losses from the lower speeds were added to the losses at the next higher speeds and so on. This reflects the hypothesis that, if the lower speeds had not been tested beforehand, correspondingly greater losses would have occurred at the higher speeds.

The emissions from the coal pile at Mine 3 appear to be significantly lower than the coal pile emissions measured at Mines 1 and 2. The coal pile at Mine 3, which had been inactive for a period of days, was noticeably crusted; but attempts were made to test areas where relatively fresh vehicle tracks were present. It is not known what percentage of the erosion potential of these test areas may have been lost because of brief periods of high winds which typically occurred with the evening wind shift. The coal pile furrow tested at Mine 3 had a much greater portion of large chunks of coal (exceeding 1 inch in size) on the surface, in comparison with the scraper and truck tracks.

The uncrusted overburden and scoria surfaces tested at Mine 2 exhibited emission rates that were much lower than the coal surfaces tested, except for the coal pile furrow. This reflects the larger portion of nonerodible coarse aggregates present on these non-coal surfaces.

The wind speeds that were used in the testing (Table 13-11), which exceeded the threshold for the onset of visually observable emissions, corresponded to the upper extremes of the frequency distributions of hourly mean wind speeds observed (at a height of 5-10 m) for most areas of the country. For flat surfaces, the wind speed at the centerline of the wind tunnel, 15 cm above the surface, is about half the value of the wind speed at the 10 m reference height. However, for elevated pile surfaces, particularly on the windward faces, the ratio (u_{15}/u_{ref}) may approach and even exceed unity. It should be noted that small but measureable erosion may have occurred at the threshold velocity.

In estimating the magnitude of wind generated emissions, wind gusts must also be taken into account. For the surfaces tested, typically about three-fourths of the erosion potential was emitted within 5 min of cumulative erosion time. Therefore, although the mean wind speeds at surface coal mines will usually not be high enough to produce continuous wind erosion, gusts may quickly deplete the erosion potential over a period of a few hours. Because erosion potential increases rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1-mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed ground area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

Although vehicular traffic alters the surface by pulverizing surface material, this effect probably does not restore the full erosion potential, except for surfaces that crust before substantial wind erosion occurs. In that case, breaking of the crust over the area of the tire/surface contact once again exposes the erodible material beneath.

The emission factor for wind generated emissions of a specified particle size range may be expressed in units of lb/acre-month as follows:

$$\text{Emission Factor} = f \cdot P(u^+_{15}) \quad (\text{Eq. 29})$$

where f = frequency of disturbance, per month

$P(u^+_{15})$ = erosion potential corresponding to the observed (or probable) fastest mile of wind for the period between disturbances, after correcting the fastest mile to a height of 15 cm (as described below), lb/acre.

$P(u^+_{15})$ is taken directly from Table 13-11 for the type of surface being considered. Interpolation or limited extrapolation of erosion potential data may be required.

When applying Equation 29 to an erodible surface, a modified form of Equation 18 (page 84) is used to correct the fastest mile of wind from the reference anemometer height at the reporting weather station to a height of 15 cm. The correction equation is as follows:

$$u_{15}^+ = u_{\text{ref}}^+ \frac{\left(\ln \frac{15}{z_0} \right)}{\ln \left(\frac{h_{\text{ref}} - h_{\text{surf}}}{z_0} \right)} \quad (\text{Eq. 30})$$

where u_{15}^+ = corrected value of the fastest mile, mph

u_{ref} = value of the fastest mile measured at the reference height, mph

h_{ref} = height of the reference anemometer above ground, cm

h_{surf} = height of the eroding surface above ground, cm

z_0 = roughness height of the eroding surface, cm

An estimated value of the roughness height for the surface being considered may be obtained from Table 13-12.

Equation 30 is restricted to cases for which $h_{\text{ref}} - h_{\text{surf}} \geq 15$ cm. Because the standard reference height for meteorological measurement is 10 m, this restriction generally allows for piles as flat upper surfaces as high as about 9.85 m and conical piles as high as 19.7 m. However, there may be situations which do not conform to the above restriction; for example, when the meteorological measurement height is as low as 5 m. As a default value for these cases, u_{15} is set equal to u_{ref} , i.e., no height correction is made for the measured fastest mile.

Values of h_{surf} in Equation 30 reflect the extent to which the eroding surface contour penetrates the surface wind layer. Clearly for flat ground surfaces, $h_{\text{surf}} = 0$. For an elevated storage pile with a relatively flat upper surface, h_{surf} represents the height of the upper surface above ground. For conical shaped piles, one-half the pile height is used as a first approximation for h_{surf} . In the case of elevated storage pile surfaces, the emission factor equation (Equation 29) is expressed per unit area of contact between the pile and the ground surface.

To illustrate the application of Equation 29, the following hypothetical example is offered. A coal surge pile planned for a new mine development will have a relatively flat upper surface with an average height of 6 m. The pile will be disturbed at nearly regular intervals every 3 months by adding coal to or removing coal from the surface using trucks and front-end loaders. During periods between disturbance, it is anticipated that light crusting will occur. The fastest mile data for the nearest weather station is shown in Table 13-13, representing a 5-year length of record.

The height of the reference meteorological instrument is 8.0 m above the ground.

To derive the annual average emission factor, the year is divided into quarterly periods. The fastest mile for each period is determined, and the average value is calculated. From Table 13-13, the 3-month fastest mile values of 47, 38, 45, and 41 mph yield an average of 43 mph. Next, Equation 30 is used to correct the average fastest mile from the reference height of 8 m to 15 cm above the 6-m height of the upper pile surface. A value of 0.06 cm is used as the roughness height for a lightly crusted coal pile surface, as taken from Table 13-12. Substitution of these data into Equation 30 yields:

$$u_{15}^+ = 43 \frac{\ln \frac{15}{0.06}}{\ln \frac{800-600}{0.06}} = 29 \text{ mph}$$

From Table 13-11, the SP erosion potential for 29 mph on a lightly crusted coal pile is 140 lb/acre. Substitution into Equation 29 yields:

$$\text{SP emission factor} = \frac{0.33}{\text{mo}} \times 140 \frac{\text{lb}}{\text{acre}} = 46 \frac{\text{lb}}{\text{acre-mo}}$$

Using the appropriate IP/SP ratio from Table 13-12, the corresponding IP emission factor is $46 \times 0.55 = 25 \text{ lb/acre-mo}$.

One notable limitation in the use of Equation 29 is its application to active piles. Because the fastest mile is recorded only once a day, use of the daily fastest mile to represent a surface disturbed more than once per day will result in an over-estimate of emissions.

The approach outlined above for calculation of emission factors appears to be fundamentally sound, but data limitations produce a large amount of uncertainty in the calculated factors. Even though the erosion potential values are judged to be accurate to within a factor of two or better for the surface tested, it is not known how well these surfaces represent the range of erodible surface conditions found at Western surface coal mines. Additional uncertainty results from the use of Equation 30 to correct the fastest mile values to a height of 15 cm above the erodible surface. Taking all the sources of uncertainty into account, it is thought that the wind erosion emission factors derived for surfaces similar to those tested are accurate to within a factor of about three.

The levels of uncertainty in SP and IP emission factors derived by the technique outlined in this section could be reduced substantially by gathering more data to better define:

1. Relationship of erosion potential to wind speed.
2. Relationship between approach wind speed and the distribution of surface wind speed around basic pile shapes of varying size.
3. Relationship of erosion potential to surface texture.
4. Effect of crusting.

Previous research on wind erosion of natural surfaces could provide some insight into the nature of these effects. Soil loss resulting from wind erosion of agricultural land has been the subject of field and laboratory investigation for a number of years. This research has focused on the movement of total soil mass, primarily sand-sized aggregates, as a function of wind and soil conditions (Bagnold 1941; Chepil and Woodruff 1963). Only relatively recently, however, have field measurements been performed in an effort to quantify fine particle emissions produced during wind erosion of farm fields (Gillette and Blifford 1972; Gillette 1978).

Until further research is accomplished, it is recommended that wind erosion factors be used with full consideration of their uncertainty and preliminary nature. It is recommended that their use be restricted to estimates of emissions relative to other mine sources and that they not be used for estimating the ambient air impact of wind erosion at surface coal mines.

SECTION 14

EVALUATION OF EMISSION FACTORS

COMPARISON WITH PREVIOUSLY AVAILABLE EMISSION FACTORS

As noted in Section of this report, a number of TSP emission factors for surface coal mining operations were available in the published literature prior to this study. However, only those factors reported by the U.S. Environmental Protection Agency (1978a) were based on actual testing in surface coal mines. Other investigators (Cowherd et al. 1979, McCalden and Heidel 1978, and Dyck and Stukel 1976) have reported emission factors for vehicular traffic on unpaved roads expressed in the form of predictive equations. Their factors were not developed with any data from surface coal mines, but were based on field data from unpaved roads of similar characteristics.

Cowherd et al. (1979) used the exposure profiling method to develop a predictive emission factor equation for vehicular traffic on unpaved roads. Their equation was developed from measurement of emissions from a wide range of vehicle types (weighing from 2 to 157 tons) traveling on rural roads, roads at steel plants, and haul roads at a taconite mine.

The emission factor equation developed by McCalden and Heidel (1978) was developed from upwind-downwind tests of light-duty vehicles traveling on five unpaved roads in the Tucson, Arizona area. The downwind samplers were located 50 feet from the test roads.

Dyck and Stukel (1976) used the upwind-downwind sampling method to measure emissions from a single 4-1/2 ton flat-bed truck traveling over access roads at construction site in Illinois. Vehicle weight was varied by placing sand bags on the truck bed. Downwind samplers were located at 50 to 150 feet from the test road.

Table 14-1 compares emission factors from the present study with emission factors reported by EPA and those reported by the other investigators cited above. The factors listed for the present study are medians of the TSP emission factors measured for each source category. The factors listed by EPA (1978a) are averages of those reported for each of the five mines tested.

The other factors listed for unpaved roads were calculated from the respective emission factor equations, using the necessary average correction parameter values obtained in the present study.

In three of five cases, the average emission factor obtained in this study is essentially the same as that reported by EPA in 1978. The factors obtained for access roads are about the same as those calculated from the predictive equations of other investigations. However, the factors obtained in the present study for haul trucks, scrapers, and graders are smaller than those calculated from the predictive equations of other investigators.

STATISTICAL CONFIDENCE IN EMISSION FACTORS

Confidence intervals associated with the emission factors were presented in Table 13-10. They are shown again, expressed as fractions of the corresponding emission factors, in Table 14-2. Also shown in this table are the relative errors predicted in Table 4 of the Second Draft Statistical Plan (June 1980). (For purposes of calculation, the half-width of the confidence interval divided by the median is equal to the relative error.) Comparison of the 80 percent confidence intervals and 20 percent risk level relative errors reveals that the actual confidence intervals were smaller, and therefore better, than the estimated or predicted error levels in 7 out of 10 cases. These results were achieved because correction factors were able to explain a large portion of the sample variance for almost every source.

The confidence intervals as a fraction of the emission factor averaged about -0.20 to +0.24 at the 80 percent confidence level and about -0.30 to +0.43 at the 95 percent confidence level. In comparison, 12 of the most widely used particulate emission factors in EPA's Compilation of Air Pollutant Emission Factors, AP-42 (1975), had an average 80 percent confidence interval of +0.28 and an average 95 percent confidence interval of +0.45, according to a published analysis of AP-42 factors (PEDCo Environmental 1974). Information extracted from Table 2-12 of the published analysis is presented in Table 14-3. Considering the greater variability inherent in emission rates for fugitive dust sources than for most industrial process or combustion sources, the mining emission factors reported herein appear to be on a par with factors in AP-42 that have been given a ranking of A.

With the confidence intervals achieved for all sources, additional sampling using the same techniques to improve precision of one or more factors does not seem to be warranted. However, it should be noted that these emission factors are still limited in their applicability to Western mines and to the ranges of correction parameter conditions over which the present tests were conducted. Also, the number of mines represented is small (only three), hence, the mine to mine differences are not yet fully documented.

PARTICLE SIZE RELATIONSHIPS

Emission factors were developed specifically for the IP and TSP size ranges, with full data analyses being devoted to each. Because of data analysis problems associated with the very low concentrations of FP, the emission factors for this size fraction were not calculated by profiling, upwind-downwind dispersion equations, etc. Instead, net concentrations for all tests were expressed as a fraction of TSP; the geometric mean fraction for tests of each source was applied to the TSP emission factor for that source to calculate the FP emission factor.

The suspended particulate (SP) emission factors from profiling tests are not actually TSP, but the fraction of total emissions less than $30\text{ }\mu\text{m}$ in aerodynamic diameter. Several references in the literature cite $30\text{ }\mu\text{m}$ as the approximate particle size for 50 percent collection efficiency by the hi-vol sampler. Since TSP is not a clearly defined size distribution, this was the best approximation that could be made from the profiling samples, which collect all particle sizes in the plume nondiscriminately.

From the median emission factors for IP and TSP (Table 13-10), size distributions of emissions appeared to be fairly uniform from source to source. IP and TSP ratios varied from 0.22 to 0.62. The IP to TSP emission factor ratios were similar to those of the IP to TSP net concentrations (shown in Table 12-2), but were not the same because of the independent MLR analyses employed to develop the emission factors for TSP and IP. Also, the emission factor ratios are based on geometric rather than arithmetic means. The IP to TSP ratios were lower than typical in ambient air. However, these ratios were measured at the sources. As the emissions proceed downwind, greater deposition of the TSP fraction should increase the ratio.

The FP and TSP emission factor ratios were derived directly from the geometric mean ratios of their net concentrations, and are the same as were shown in Table 13-8. One of the sources had a ratio that was an apparent anomaly--overburn dozers, with an FP to TSP ratio of 0.105. Overburden dozer tests were usually conducted with no visible plume and low downwind concentrations, with accompanying potential for particle size distributions skewed toward smaller particles. With the exception of this source, the range of median FP to TSP ratios by source was 0.017 to 0.040.

For the two sources that constitute the majority of emissions at most mines, haul trucks and scrapers, the average FP to TSP ratios were 0.017 and 0.026, respectively. Because mining emissions are mechanically generated dust, a low percentage of fine particulate would be expected in the TSP emissions. It is not possible to compare the size distribution data from this study with that from previous fugitive dust sampling studies because particle size sampling problems make previous data suspect.

Recognizing that there are still several unresolved problems with generating fine particle data for fugitive dust sources, it is concluded that data from the present study are reasonable based on their consistency and the observed agreement between dichotomous and cascade impactor data.

HANDLING OF DEPOSITION

The emission factors in Table 13-10 were all developed from sampling right at the source. The present test data and information from numerous other studies indicate fairly rapid deposition of these emissions as they move away from the source. Therefore, any ambient air quality analysis using these emission factors should have some provision for considering deposition or fallout.

Different subsets of tests and alternative measurement techniques (dustfall and apparent source depletion as discussed in Section 12) produced greatly varying deposition rates with distance, from no deposition to an average of 79 percent reduction in TSP in the first 100 m. Only a small part of the differences could be explained by parameters such as wind speed and stability class. The net result of the large discrepancies was that test data from the study could not be used to develop a deposition function for application with the emission factors. An empirically-derived function would have been limited to about the first 200 m anyway.

Selection from among available theoretical deposition models is outside the scope of this study, especially since none of the three that were compared with test data matched well in the majority of the tests. Of the three theoretical deposition functions, the tilted plume model is the most simplistic and shows the most rapid deposition over the first several km. The other two models, source depletion and surface depletion, display similar rates and represent supposed options between computational ease and greater accuracy. According to a published review of the two models, source depletion overestimates deposition at all distances in comparison with the more accurate surface depletion functions (Horst 1977). However, for the distances and emission heights of interest in mining analyses, the reported differences were minimal (less than 10 percent).

All three deposition modes¹ require an estimate of settling velocity, a value usually not available. From the brief analysis of observed deposition rates shown in the table on Page 6-28, possible values are 2 cm/s for the IP fraction and 10 cm/s for TSP.

SECTION 15

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF EMISSION FACTORS

Emission factors for 12 significant sources of particulate emissions at surface coal mines were developed from extensive sampling at three different Western mines. Five sampling techniques--exposure profiling, upwind-downwind, balloon sampling, wind tunnel testing, and quasi-stack--were used on the 12 different source types, to best match the advantages of a particular sampling technique to the characteristics of a source. Sampling was conducted throughout the year so that measured emission rates would be representative of annual emission rates. The resulting emission factors are summarized in Table 15-1.

The factors for TSP and IP are in the form of equations with correction factors for independent variables that were found to have a significant effect (at the 0.146 or better risk level) on each source's emission rates. The ranges of independent variables (correction factors) over which sampling was conducted, and for which the equations is valid, are shown in Table 15-1.

The units for the emission factors and correction factors were selected for ease in obtaining annual activity rates and average parameter values, respectively. The equations are also appropriate for estimating short-term emission rates. For any correction factor that cannot be accurately quantified, a default value equal to its geometric mean (GM) value can be used, see Table 13-9. For each source, the FP emission factor is obtained by multiplying the calculated TSP emission factor by the FP fraction shown in Table 15-1.

The 80 and 95 percent confidence intervals for each of the TSP and IP emission factors, based on sample size and standard deviation, were previously presented in Table 13-10. The average 80 percent confidence interval for TSP was -20 to +24 percent of the median value. By comparing confidence intervals for the present emission factors with those for factors published by EPA in their Compilation of Air Pollutant Emission Factors, AP-42 (1975), it was determined that the present factors should receive an A ranking.

Emission factors were reported for three size ranges--fine particulate ($<2.5\ \mu\text{m}$), inhalable particulate ($<15\ \mu\text{m}$), and total suspended particulate (no well-defined upper cut point, but approximated as $40\ \mu\text{m}$). The fairly consistent ratios of FP and IP to TSP for different sources indicate that fugitive dust sources at mines all have similar size distributions. Most of the particle sizing data were obtained with dichotomous samplers.

The emission factors in Table 15-1 are all for uncontrolled emission rates. Control efficiencies of a few control measures were estimated by testing, as reported in Table 12-5. These control efficiencies should be applied to the calculated emission factors in cases where such controls have been applied or are anticipated. However, many of the dust-producing operations are not normally controlled.

The design and field work for this study have received far more review and quality assurance checks than any similar projects in air pollution control. However, because of the large variations in emission rates over time for mining sources and the imprecision of key sampling instruments while sampling in dense dust plumes, the added care in conducting the study did not result in appreciable better sampling data with which to develop the emission factors.

LIMITATIONS TO APPLICATION OF EMISSION FACTORS

The emission factors are designed to be widely applicable through the use of correction factors, but they still have some limitations which should be noted:

1. The factors should be used only for estimating emissions from Western coal mines. There is no basis for assuming they would be appropriate for other types of surface mining operations or for coal mines located in other geographic areas without further evaluation.
2. Correction factors used in the equations should be limited to values within the ranges tested (see Table 15-1). This is particularly important for correction factors with a large exponent, because of the large change in the resulting emission factor associated with a change in the correction factor.
3. These factors should be combined with a deposition function for use in ambient air quality analyses. After evaluation of the deposition data from this study, no empirical deposition function could be developed. Any function subsequently developed from these data should have provision for further deposition beyond the distance of sampling in this study (100-200 m).

4. The factors were obtained by sampling at the point of emission and do not address possible reductions in emissions in order to account for dust being contained within the mine pit.
5. As with all emission factors, these mining factors do not assure the calculation of an accurate emission value from an individual operation. The emission estimates are more reliable when applied to a large number of operations, as in the preparation of an emission inventory for an entire mine. The emission factors are also more reliable when estimating emissions over the long term because of short-term source variation.
6. Appropriate adjustments should be made in estimating annual emissions with these factors to account for days with rain, snow cover, temperatures below freezing, and intermittent control measures.
7. The selection of mines and their small number may have biased final emission factors, but the analysis did not indicate that a bias exists.
8. The confidence intervals cited in Table 13-10 estimate how well the equations predict the measured emission rates at the geometric mean of each correction factor. For predicting emission rates from a mine not involved in the testing or for predicting rates under extreme values of the stated range of applicability of the correction factors, confidence intervals would be wider.
9. Error analyses for exposure profiling and upwind-downwind sampling indicated potential errors of 30 to 35 percent and 30 to 50 percent, respectively, independent of the statistical errors due to source variation and limited sample size.
10. Geometric means were used to describe average emission rates because the data sets were distributed lognormally rather than normally. The procedure makes comparison with previous emission factors difficult, because previous factors were all arithmetic mean values.
11. Wind erosion emission estimates should be restricted to calculation of emissions relative to other mining sources; they should not be included in estimates of ambient air impact.

REMAINING RESEARCH

A comprehensive study such as the present one that has evaluated alternative sampling and analytical techniques is bound to identify areas where additional research would be valuable. Also, some inconsistencies surfaced during the data analysis phase, when it is too late to repeat any of the field studies. Therefore, a brief list of unresolved problems has been compiled and is presented here.

1. Sampling at Midwestern and Eastern coal mines is definitely needed so that emission factors applicable to all surface coal mines are available.
2. A resolution of which deposition function is most accurate in describing fallout of mining emissions is still needed. Closely related to this is the need for a good measurement method for deposition for several hundred meters downwind of the source (dustfall is recommended for measurements up to 100 or 200 m). In the present study, both the source depletion and dustfall measurement methods were found to have deficiencies.
3. A method for obtaining a valid size distribution of particles over the range of approximately 1 to 50 μm under near-isokinetic conditions is needed for exposure profiling. The method should utilize a single sample for sizing rather than building a size distribution from fractions collected in different samplers.
4. The emission factors presented herein should be validated by sampling at one or more additional Western mines and comparing calculated values with the measured ones.
5. Standardized procedures for handling dichotomous filters should be developed. These should address such areas as numbering of the filters rather than their petri dishes, proper exposure for filters used as blanks, transporting exposed filters to the laboratory, equilibrating filters prior to weighing, and evaluation of filter media other than Teflon for studies where only gravimetric data are required.
6. One operation determined in the study design to be a significant dust-producing source, shovel/truck loading of overburden, was not sampled because it was not performed at any of the mines tested. Sampling of this operation at a mine in Wyoming and development of an emission factor would complete the list of emission factors for significant sources at Western coal mines (See Table 2-1).

7. Further study of emission rate decay over time from eroding surfaces is needed. In particular, more information should be obtained on the effect of wind gusts in removing the potentially erodible material from the surface during periods when the average wind speed is not high enough to erode the surface.
8. More testing of controlled sources should be done so that confidence in the control efficiencies is comparable to that for the uncontrolled emission rates.

APPENDIX A

STEPWISE MULTIPLE LINEAR REGRESSION

Multiple linear regression (MLR) is a statistical technique for estimating expected values of a dependent variable, in this case particulate emission rates, in terms of corresponding values of two or more other (independent) variables. MLR uses the method of least squares to determine a linear prediction equation from a set of simultaneously-obtained data points for all the variables. The equation is of the form:

$$\text{Emission rate} = B_1x_1 + B_2x_2 + \dots + B_nx_n + \text{constant}$$

where x_1 to x_n = concurrent quantitative values for each of the independent variables

B_1 to B_n = corresponding coefficients

The coefficients are estimates of the rate of change in emission rates produced by each variable. They can be determined easily by use of an MLR computer program or with a programmed calculator. Other outputs of the MLR program are:

1. A correlation matrix. It gives the simple correlation coefficients of all of the variables (dependent and independent) with one another. It is useful for identifying two interdependent (highly correlated--either positive or negative) variables (two variables that produce the same effect on emission rates), one of which should be eliminated from the analysis.
2. The multiple correlation coefficient (after addition of each independent variable to the equation). The square of the multiple correlation coefficient is the fraction of total variance in emission rates that is accounted for by the variables in the equation at the point.
3. Residual coefficient of variability. This is the standard deviation of the emission rates predicted by the equation (with the sample data set) divided by the mean of the predicted emission rates, expressed as a percent. If a variable eliminates some sample variance, it will reduce the standard deviation and hence the relative coefficient of variability.

4. Significance of regression as a whole. This value is calculated from an F test by comparing the variance accounted for by the regression equation to the residual variance. A 0.05 significance level is a 1 in 20 change of the correlation being due to random occurrence.
5. Significance of each variable. This is a measure of whether the coefficient (B) is different than 0, or that the relationship with the dependent variable is due to random occurrence. Variables that do not meet a prespecified significance level may be eliminated from the equation.
6. Constant in the equation.

The multiple correlation coefficient, unlike the simple correlation coefficient, is always positive and varies from 0 to 1.0. A value of zero indicates no correlation and 1.0 means that all sample points lie precisely on the regression plane. Because of random fluctuations in field data and inability to identify all the factors affecting emission rates, the multiple coefficient is almost never zero even when there is no real correlation and never 1.0 even when concentrations track known variables very closely. Therefore, it is important to test for statistical significance.

The form of MLR in the program used in this study was stepwise MLR. Variables were added to the equation in order of greatest increase in the multiple correlation coefficient, with concentrations then adjusted for that variable and regressed against the remaining variables again. The procedure can be ended by specifying a maximum number of variables or a minimum F value in the significance test. In subsequent runs, the order of entry of variables was sometimes altered by specifying that a certain variable be entered first or last.

In order to satisfy the requirement that the variables be quantitative, some were input as dummy variables with only two possible values. For example, in an MLR run of all blasts, one variable had a value of 0 for all coal blasts and 1 for all overburden blasts. The significance of this variable determined whether there was a significant difference between coal and overburden blast emission rates, and the B value was a direct measure of the difference between the two average emission rates after adjustment for other variables in the MLR equation.

A statistically significant regression relationship between independent variables and particulate emission rates is no indication that the independent variables cause the observed changes in emission rate, as both may be caused by a neglected third variable.

APPENDIX B

CALCULATIONS FOR CONFIDENCE AND PREDICTION INTERVALS

The computational procedures for confidence and prediction intervals for emission rates are illustrated in this appendix using TSP emission rates for coal loading as a function of moisture content (M). The data are tabulated in Table B-1 for convenience, that is, the moisture, %, and the observed emission rate, lb/ton, for each of the 24 tests. The arithmetic average (\bar{X}), standard deviation (s), and geometric mean (GM) are given at the bottom of the table.

Confidence Interval

The computational procedure for confidence intervals is as follows:

1. The first step in the analysis is to perform a linear regression analysis. In this example, the dependent variable is the logarithm of the emission rate ($\ln E$) and the independent variable is the logarithm of moisture ($\ln M$). (Natural logarithms, i.e., to base e are used throughout this discussion).
2. The prediction equation for the mean $\ln E$ is given by:

$$\hat{\ln E} = b_0 + b_1 (\ln M - \overline{\ln M}) \quad (B-1)$$

where

$\hat{\ln E}$ is the predicted mean for $\ln E$ as a function of M

b_0, b_1 are the regression coefficients estimated from the data

$\ln M$ is the \ln of moisture content

$\overline{\ln M}$ is the arithmetic average of $\ln M$
($\overline{\ln M} = 2.882$ for this example)

TABLE B-1. TSP EMISSION RATES FOR COAL LOADING, LB/TON

Test number	Moisture, %	Observed emission, lb/ton
1	22	0.0069
2	22	0.0100
3	38	0.0440
4	38	0.0680
5	38	0.0147
6	38	0.0134
7	38	0.0099
8	38	0.0228
9	38	0.0206
10	38	0.0065
11	11.9	0.1200
12	11.9	0.0820
13	11.9	0.0510
14	18	0.0105
15	18	0.0087
16	18	0.0140
17	12.2	0.0350
18	11.1	0.0620
19	11.1	0.0580
20	11.1	0.1930
21	11.1	0.0950
22	6.6	0.0420
23	6.6	0.3580
24	6.6	0.1880
\bar{X}	21.42	0.0639
s	12.64	0.0819
GM	17.85	0.0337

5. The geometric mean of the emission factor E is given by:

$$\exp \{\ln \hat{E}\} \quad (\text{B-6})$$

and this estimates the median value of E as a function of M. It should be noted that the mean value of E is estimated by:

$$\exp \{\ln \hat{E} + \frac{1}{2} s^2\} \quad (\text{B-7})$$

Throughout the remainder of this discussion the GM values are used as estimates of the corresponding median emission value.

6. The confidence interval for the median value of E as a function of M is obtained by:

$$\exp \{\ln \hat{E} \pm t s(\ln \hat{E})\} \quad (\text{B-8})$$

where $\ln \hat{E}$ and $s(\ln \hat{E})$ are obtained from Equations B-2 and B-4, respectively, and t is read for the desired confidence level from a standard t table available in almost any statistical test (e.g., Hald's tables²). Substituting values of M in Equation (B-8) (and B-2 and B-4) yields the results plotted in Figure 13-1 and repeated here for convenience as Figure B-1. One must not go beyond the limits for observed M because there are no data or theory to support the extrapolation.

The 95 percent confidence limits for the median E at the GM of M (i.e., $\exp \{2.882\} = 17.85\%$) are:

$$\exp \{\ln \hat{E} \pm 2.074 s(\ln \hat{E})\}$$

where

$$\ln \hat{E} = -3.385$$

$$s(\ln \hat{E}) = [0.0318 + 0.0637(0)]^{\frac{1}{2}} = 0.178$$

and the upper (UCL) and lower (LCL) 95 percent confidence limits are:

$$95\% \text{ Limits } \begin{cases} \text{UCL} = 0.049 \text{ lb/ton} \\ \text{LCL} = 0.023 \text{ lb/ton} \end{cases}$$

Similarly, the 80 percent confidence limits are given by:

$$\exp \{\ln \hat{E} \pm 1.321 s(\ln \hat{E})\}$$

or

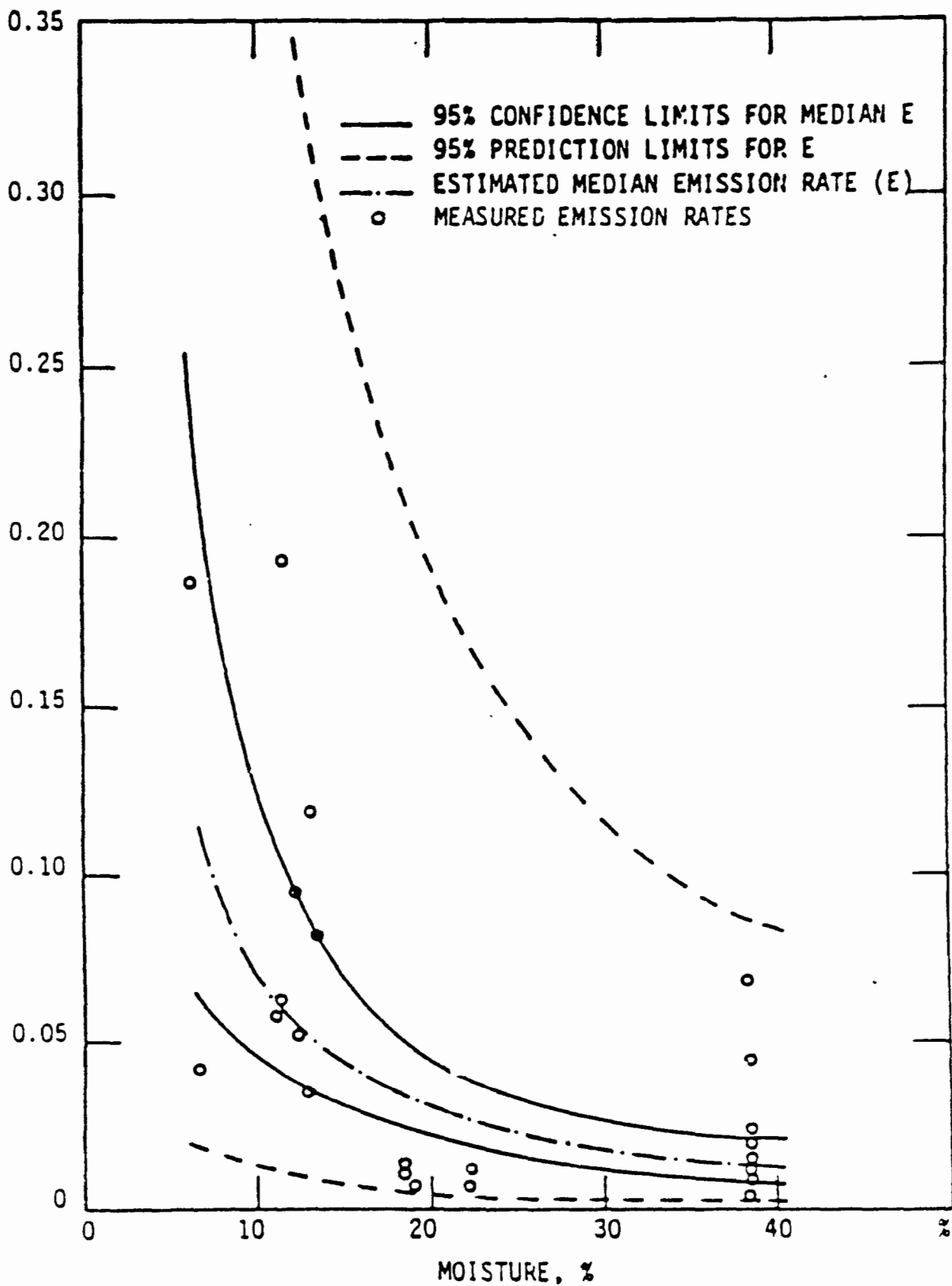


Figure B-1. Confidence and prediction intervals for emission factors for coal loading.

$$\begin{aligned} 80\% \text{ Limits } \{ & \text{UCL} = 0.043 \text{ lb/ton} \\ & \text{LCL} = 0.027 \text{ lb/ton} \end{aligned}$$

The median value is:

$$\exp \{ \ln \hat{E} \} = 0.0339$$

The above confidence limits are also expressed below as percentages of the predicted median, 0.0339.

$$95\% \text{ Limits } \{ \begin{aligned} \text{UCL} &= 1.45 \times \text{predicted median} \\ \text{LCL} &= 0.68 \times \text{predicted median} \end{aligned}$$

$$80\% \text{ Limits } \{ \begin{aligned} \text{UCL} &= 1.27 \times \text{predicted median} \\ \text{LCL} &= 0.80 \times \text{predicted median} \end{aligned}$$

These limits are a measure of the quality of the prediction of the median emission E for given M on the basis of the data from the three mines. The widths of these confidence intervals are consistent with data typically reported by EPA as stated in Section 15.

One application of these limits would be to estimate the median annual emissions based on a large number of tons of coal loaded at the mine with GM moisture content of 17.85 percent. If the moisture content deviates from this value (17.85%), it is necessary to calculate the interval at the appropriate value of M using Equation (B-8).

Because of the complication in presenting the complete results for all sources and pollutants as in Figure B-1, the confidence intervals are presented only for the correction factors (M in this example) at their GM value. Table 13-10 contains these data for all sources and pollutants.

Prediction Interval

The confidence interval previously described gives a measure of the quality of the data and of the predicted median which is applicable only for a large number of operations relative to the emission factor of interest. In the example in this appendix, this would imply a large number of coal loading operations (or tonnage of coal loaded). There will be applications in which the number of operations is not large and a prediction interval is desired which is expressed as a function of the number of operations. The calculation of this interval follows the first three steps of that for the confidence interval; the subsequent steps, starting with Step 4, are as follows:

4. The standard deviation of an individual predicted ln emission factor is:

$$s(\ln E) = [s^2(\ln \hat{E}) + s^2]^{\frac{1}{2}}$$

$$= \left[\frac{s^2}{N} + s_1^2 (\ln M - \overline{\ln M})^2 + s^2 \right]^{\frac{1}{2}} \quad (B-9)$$

For the coal loading data,

$$s(\ln E) = [0.0318 + 0.0637 (\ln M - 2.882)^2 + 0.764]^{\frac{1}{2}} \quad (B-10)$$

5. The prediction interval for an emission factor E is:

$$\exp \{ \ln \hat{E} \pm t s(\ln E) \}$$

For the coal loading data, this interval is given by:

$$\exp \{ \ln \hat{E} \pm t [0.0318 + 0.0637 (\ln M - 2.882)^2 + 0.764]^{\frac{1}{2}} \} \quad (B-11)$$

The results are plotted in Figure B-1 as a function of M. For the GM of M (i.e., $\ln M = 2.882$), the prediction limits are:

95% Limits{ UPL = 0.215 lb/ton
LPL = 0.005 lb/ton

80% Limits{ UPL = 0.110 lb/ton
LPL = 0.010 lb/ton

6. The prediction interval for an individual value is obviously much wider than the corresponding confidence interval for a median value. If it is desired to predict the emissions based on a number of operations, say N (e.g., N tons of coal), the confidence interval is given by

$$\exp \{ \ln \hat{E} \pm t [s^2(\ln E) + \frac{s^2}{N}]^{\frac{1}{2}} \} \quad (B-12)$$

that is, the last term in Equation B-9 is divided by N instead of 1. Note that as N becomes large this result simplifies to that of Equation (B-8).

Test for Normality

One of the major assumptions in the calculations of the confidence and prediction intervals is that the \ln residuals (deviations of the $\ln E$ from $\ln \hat{E}$) are normally distributed, hence the lognormality assumption for the original (and transformed data). A check for normality was performed on the \ln residuals for six data sets with the largest number of data values. In two of the six cases the data deviated from normality (these two cases were TSP and IP emissions for Blasting). Based on these results, the lognormal assumption was made because of both computational convenience and adequate approximation for most of the data.

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1. Hald, A. Statistical Theory with Engineering Applications. John Wiley and Sons, Inc. New York. 1952
2. Hald, A. Statistical Tables and Formulas. John Wiley and Sons, Inc. New York. 1952.

Appendix G

U.S. DEPARTMENT OF COMMERCE
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PB-253 092

TECHNICAL MANUAL FOR MEASUREMENT OF FUGITIVE EMISSIONS
UPWIND/DOWNWIND SAMPLING METHOD FOR INDUSTRIAL EMISSIONS

RESEARCH CORPORATION OF NEW ENGLAND

PREPARED FOR
INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY

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FOR MEASUREMENT OF
FUGITIVE EMISSIONS:
UPWIND/DOWNWIND SAMPLING METHOD
FOR INDUSTRIAL EMISSIONS

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1.0 OBJECTIVE

The objective of this procedures document is to present a guide for the utilization of the Upwind-Downwind Sampling Strategy 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. Upwind-downwind 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 Portland cement manufacturing plant 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 stack 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 emissions using the upwind-downwind measurement method described in Section 2.1.3 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.

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. The method is especially applicable to situations in which enclosed sources are too numerous or physically configured to preclude the application of the quasi-stack method to each source. Sampling is, in general, limited to a mixture of all uncontrolled emission sources within the enclosure and requires the ability to make low velocity exhaust air measurements and mass balances of small quantities of materials entering and leaving the enclosure through 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. These features are embodied in the typical

industrial sources and their emitted pollutants listed in Table 2-1.

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

TABLE 2-1

UPWIND-DOWNWIND SAMPLING METHOD
APPLICATION TO TYPICAL INDUSTRIAL FUGITIVE EMISSION SOURCES

Industry	Source	Particulate Emissions	Gas & Vapor Emissions	Industry	Source	Particulate Emissions	Gas & Vapor Emissions	Industry	Source	Particulate Emissions	Gas & Vapor Emissions
Coke Making	Coal Handling	Coal Dust	-	Electric Furnace Steel	Scrap & Sinter Delivery	Iron Dust	-	Coal Gasification	Coal Delivery & Storage	Coal Dust	-
	Coal Storage	Coal Dust	-		Lime & Silica Delivery	Steel Dust	-		Coal Transfer	Coal Dust	-
	Charging Ovens	Coal Dust, Tars	HC, CO, NO ₂ , N ₂ S, SO ₂ , NH ₃ , Pyridine			Dust	-		Waste Transfer	Dust	Hydrocarbons, N ₂ S, NH ₃ , SO ₂ , Phenol
	Coking, Door & Oven Leaks	Coke Dust, Tars	HC, CO, NO ₂ , N ₂ S, NH ₃ , CS ₂ , Phenol			-	-		Scrubber Solids	Dust	Hydrocarbons
	Coke Pushing	Coke Dust, Tars	HC, CO, N ₂ S, NH ₃ , MCM, Phenol		Dust Transfer & Storage	Fume Dust	-		Settling Pond	-	N ₂ S, SO ₂ , NH ₃ , Phenol, Hydrocarbons
	Quenching (Controlled but some leaks)	Coke Dust, Tars	HC, CO, N ₂ S, NH ₃ , MCM, SO ₂ , Phenol		Storage Ponds for Slagging Waste Water	-	N ₂ S, SO ₂	Petroleum Refining	Crude Transfer	-	Hydrocarbons, RSH, N ₂ S
Primary Aluminum	Coke Handling	Coke Dust	-	Iron & Steel Foundries	Coke, Silica Sinter Delivery & Storage	Dust	-		Crude Storage	-	Hydrocarbons, RSH, N ₂ S
	Coal Storage	-	-		Pollution Control Equipment Transfer & Storage	Dust	-		Distillate Storage	-	Hydrocarbons
	Bauxite Handling & Storage	Ore Dust	-	Coal	Mining	Coal Dust	-		Distillate Transfer	-	Hydrocarbons
	Alumina Calcining & Preparation	Alumina Dust	-		Hauling	Coal Dust	-		Gasoline Storage & Transfer	-	Hydrocarbons
Primary Copper	Alumina Storage	Alumina Dust	-		Storage & Transfer	Coal Dust	-		Leakage in Drains & Sewers	-	Hydrocarbons, N ₂ S, HF, Phenols
	Mining	Dust	-		Screening & Crushing	Coal Dust	-		Waste Water Storage & Transfer	Dust	N ₂ S, SO ₂ , NH ₃ , Phenols, HF, Hydrocarbons
	Hauling	Dust	-		Transfer	Coal Dust	-		Process Leaks	Tars	N ₂ S, SO ₂ , NH ₃ , Phenols, HF, Hydrocarbons
	Tailings Pond	Dust	-	Asphalt	Drying	Coal Dust	Hydrocarbons, CO	Phosphate Fertilizer	Gasoline Terminal Loading	-	Hydrocarbons
Sand & Gravel	Slag Dump	-	SO ₂		Storage Piles	Coal Dust	-		Mining	Dust	-
	Quarrying	Dust	-		Waste Transfer	Dust	-		Storage Piles	Dust	-
	Truck Hauling	Dust	-		Gravel Delivery	Dust	-		Rock Transfer (Truck, Conveyor)	Dust	-
	Delivery & Storage	Dust	-		Asphalt Storage	Tars	Hydrocarbons, Odors		Settling Pond	-	-
	Rock Transfer	Dust	-		Storage Piles	Dust	Hydrocarbons, Odor		Cypsum Pile	Dust	-
	Crushing & Screening	Dust	-		Asphalt Batching	Dust, Tars	Hydrocarbons, Odor	Phosphate Fertilizer	Product Storage	Dust	Fluorides
	Drying (Leakage)	Dust	-		Drier & Slinger	Dust, Tars	Hydrocarbons, Odor		Product Delivery	Dust	Fluorides
	Product Storage	Dust	-		Reactor Discharge	Dust, Tars	Hydrocarbons, Odor		-	-	-
	Product Loading	Dust	-		Reactor Charge	Dust, Tars	Hydrocarbons, Odor		-	-	-
	Product Delivery	Dust	-		Product Transfer	Dust, Tars	Hydrocarbons, Odor		-	-	-

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 PROGRAM PROCEDURES

This section describes the procedures required to successfully complete a testing program utilizing the upwind-downwind 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	<p>Drawings:</p> <ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Access routes to the areas Where Test Equipment/Instrumentation Will Be Located Names, Extension, 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 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 Upwind-Downwind Sampling Strategies

The upwind-downwind sampling method, as described in Section 2.1.3, is used to quantify the emissions from a source to the ambient atmosphere by measuring pollutant levels in the atmosphere. Upwind measurements are made within the ambient air approaching the site of the source, using sampling equipment suitable for the specific emissions to be measured, to determine the baseline concentration of pollutants in the air. Downwind measurements are made of the air within the cloud of pollutants emitted by the source, using sampling equipment similar to that used for the upwind measurements, to determine the total of the ambient air and the source's contribution to the concentration of pollutants. The pollutants contributed by the source to the cloud at the sampling locations are determined as the difference between the measured upwind and downwind concentrations. Measurement of the wind speed and direction at the site are combined with the pollutant concentrations at the sampling locations in diffusion equations to back-calculate the source strength of the emissions. Section 3.4 and 3.5 describe the equipment used for sampling, the criteria for sampling system design, sampling techniques, and data reduction procedures for respectively, survey and detailed upwind-downwind sampling programs.

3.4 Survey Upwind-Downwind Measurement System

A survey measurement system, as defined in Section 2.3, is designed to provide gross measurements of emissions to determine whether any constituents should be considered for more detailed investigation. A survey upwind-downwind measurement system in its simplest form utilizes

a single upwind sampler for the determination of the concentration of the pollutants of concern in the ambient air approaching the source of the emissions and two or three identical downwind samplers for the determination of the pollutant concentration and distribution in the ambient air leaving the source. These data, combined with measurements of the ambient air wind speed and direction, are used to calculate the emission rate of the source.

3.4.1 Sampling Equipment

Pollutants that may be measured by the upwind-downwind technique are limited to those that can be airborne for significant distances, i.e., particulates and gases. The gross measurement requirements for survey sampling of particulates are best satisfied by high volume filter devices to provide data on the average emission rate, particle size distribution, and particle composition. Particle charge transfer or piezoelectric mass monitoring devices may be utilized for continuous or semi-continuous sampling of intermittent emission sources where peak levels must be defined.

Gaseous emissions in survey programs are usually grab-sampled for laboratory analysis using any of a wide variety of evacuated sampling vessels or chemical bubblers. Continuous or semi-continuous sampling of specific gases may be accomplished using such devices as continuous monitor flame ionization detectors (for hydrocarbons) and automated flame photometric devices (for sulfur dioxide).

3.4.2 Sampling System Design

The number and location of the devices used to collect samples is extremely important to the successful completion of a survey upwind-downwind sampling program, especially since the program is designed for minimum cost and provides for no replication of samples. The design of the sampling system is influenced by such factors as source complexity and size, site location and topography, and prevailing meteorological conditions which govern the distribution of the pollutant cloud in the ambient atmosphere. Most situations will in general fit into some combination of the following parameters:

Source - Sources may be either homogeneous, emitting a single type or mixture of pollutants from each and every emission location, or heterogeneous, emitting different types or mixtures of pollutants from different locations. The resultant cloud of pollutants will, for a homogeneous source, be homogeneous. The pollutant cloud for a heterogeneous source may be either heterogeneous or, as a result of mixing by suitably directed or turbulent ambient air flow, homogeneous. The physical size of a source will determine the extent of the pollutant cloud and may influence its homogeneity, the proximity of different emissions to each other largely influencing the degree of mixing in the cloud for a given downwind distance.

Site - Sites in general may be open on level terrain with free access of ambient air from all sides, partially obstructed by hills or buildings that interfere with or influence the ambient air flow either up- or downwind, or located in a valley between hills or large buildings that influence the air flow both up- and downwind. Each type of topography will influence the extent and homogeneity of the pollutant cloud depending on the direction of the wind flow relative to the obstructions.

Meteorology - The direction of the prevailing wind determines the basic location of upwind and downwind samplers. It will influence the pollutant cloud in every instance except that of a homogeneous cloud at an open level site. In other instances, the wind may be directed generally across or parallel to obstructing hills or valleys which may result in channeling, lofting, or swirling of the air flow across the site that will distort the pollutant cloud.

The homogeneity of the ambient air approaching the measurement site, while not in the strict sense a meteorological condition,

may affect the composition and distribution of different pollutants within the pollutant cloud. Contributions from sources upwind of the site may result in variations in the pollutant concentrations in the ambient air passing over the site and thus in the pollutant cloud as well.

Wind speed, which can affect the cloud's size and distribution, need not be considered as a governing design factor since it is to some degree controllable by scheduling to avoid periods of either excessive wind velocity or calm conditions. Wind speeds within normal limits are taken into consideration in data reduction calculations.

Table 3-2 presents a matrix of 20 possible combinations of these parameters (cloud homogeneity, site topography, wind direction and ambient air homogeneity). The simplest combination, that of a homogeneous cloud in an open level site with homogeneous ambient air, would typically require a single upwind sampler and two downwind samplers located within the cloud. The complexity of the sampler system design is, in general, increased by changes in the parameters as follows:

Cloud Homogeneity. A heterogeneous cloud will generally limit the placement of the downwind samplers to the portion of the cloud that contains the combined emissions from the various sources. It may also require the addition of samplers in the cloud to provide data on the extent of the effects of the heterogeneity and the consequent variability of the pollutant distributions. This parameter will not affect the upwind samplers.

Site Topography. Depending on the relationship of the topography obstructions and the wind direction, this parameter may affect both upwind and downwind samplers. Hills and valleys may cause lofting or depression of the pollutant cloud, requiring sampler elevation on towers or limiting the downwind distance of samplers within the cloud. They may also provide funnelling effects that limit the dispersion of the cloud and restrict the lateral positioning of the downwind samplers. Upwind sampler locations may be restricted by lofting or depression of the ambient air approaching the site.

Wind Direction. Changes in this parameter alone are not generally a major factor in the sampling system design. They will dictate

TABLE 3-2

MATRIX OF SAMPLING SYSTEM DESIGN PARAMETERS

Cloud Homogeneity	Site Topography	Wind Direction	Ambient Air Homogeneity	Cloud Homogeneity:
Homogeneous (1)	Open (1)	Not a Factor (0)	Homogeneous (1)	Homogeneous - Sources at site all emitting same pollutants.
			Heterogeneous (2)	- Sources of different pollutants grouped so that emissions are mixed before sampling.
	Hill (2)	Parallel to Hill (1)	Homo (1)	Heterogeneous - Sources at site emitting identifiably different pollutants - no mixing before sampling.
			Hetero (2)	
		Over Hill (2)	Homo (1)	Site Topography:
			Hetero (2)	Open - Site on flat terrain ambient air access from any direction unhindered.
	Valley (3)	Down Valley (1)	Homo (1)	Hill - Site close enough to rise in terrain or large buildings to cause channeling or lofting of ambient air.
			Hetero (2)	Valley - Site between rises in terrain or large buildings.
		Across Valley (2)	Homo (1)	Wind Direction:
			Hetero (2)	Parallel to Hill - Wind across site channeled against side of hill. Usually changes shape of pollutant cloud and distribution of pollutants within cloud.
Heterogeneous (2)	Open (1)	Not a Factor (0)	Homogeneous (1)	Across Hill - Wind across site from or to hill top. Can cause lofting or depression of pollutant cloud.
			Heterogeneous (2)	Down Valley - Wind across site channeled against sides of hills.
	Hill (2)	Parallel to Hill (1)	Homo (1)	Across Valley - Wind across site from hill to hill.
			Hetero (2)	Ambient Air Homogeneity:
		Over Hill (2)	Homo (1)	Homogeneous - Pollutants in approaching air evenly distributed.
			Hetero (2)	Heterogeneous - Pollutants in approaching air measurably different at points over site. Usually caused by emissions from nearby upwind external source.
	Valley (3)	Down Valley (1)	Homo (1)	
			Hetero (2)	
		Across Valley (2)	Homo (1)	
			Hetero (2)	

changes in the design in combination with other factors such as site topography, described above, or the presence of external sources, which may influence the homogeneity of the approaching ambient air, described below.

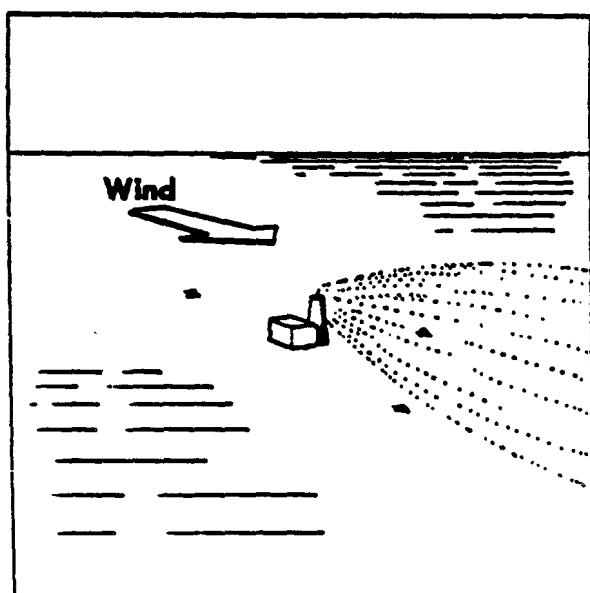
Ambient Air Homogeneity. The presence of external emission sources that may result in variations in the pollutant concentrations and distributions in the air approaching a site may require the addition of samplers both upwind and downwind to ensure that the measurements of the pollutants of interest are not unduly influenced or masked. Samplers typically are required within and outside of the external source cloud both upwind and downwind.

Typical sampler locations for selected source site configurations illustrating some of these effects are sketched in Figure 3-1. The configurations are identified by a four-digit number referring, in left-to-right order, to the numbers assigned to the parameters identified in the matrix of Table 3-2. A configuration with a homogeneous cloud emitted at a valley site with cross-valley wind direction and homogeneous ambient air is thus identified as 1321.

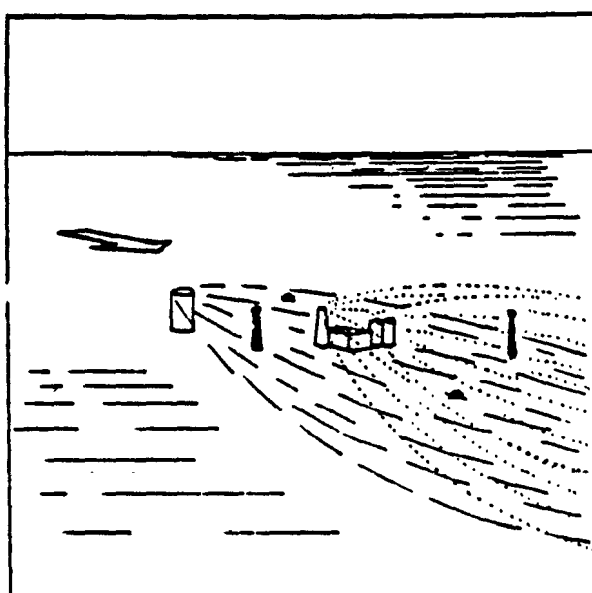
3.4.3 Sampling Techniques

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.

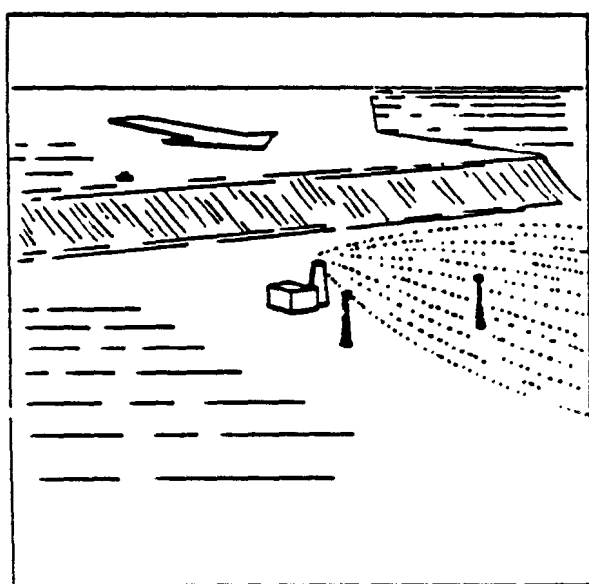
Each of the various sample collection and analysis methods has an associated lower limit of detection, typically expressed in terms of micrograms of captured solid material and either micrograms or parts per million in air of gases. Samples taken must provide at least these



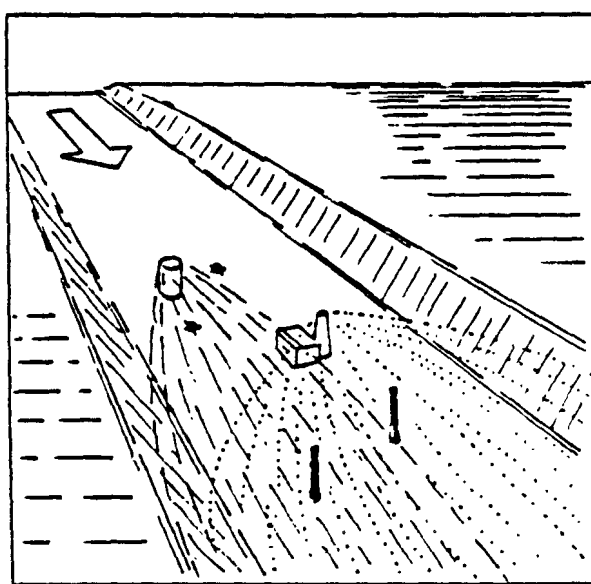
1101



2102



1221



2311

Legend







-  Homogeneous cloud source
-  Heterogeneous cloud source
-  External source
-  Sampler
-  Source cloud
-  External source cloud

Fig. 3-1. Typical sampler locations for selected source site configurations.

minimum amounts of the pollutants to be quantified. The amount (M) of a pollutant collected is the product of the concentration of the pollutant in the air (χ) and the volume of air sampled (V), thus,

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

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 (V) is the product of its flow rate (F) and the sampling time (T),

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

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 sampling location 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 Equation 3-1:

$$F \text{ (cubic meters/minute)} = M \text{ (micrograms)} / \chi \text{ (micrograms/cubic meter)} \times T \text{ (minutes)}. \quad (3-1)$$

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.

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.

Sampler location is also important in obtaining representative data. Downwind sampler location is especially critical to ensure that samples are taken at points known to be within the pollutant cloud at measurable concentrations. A rough estimate of acceptable downwind sampler locations may be made utilizing the basic equation⁽¹⁾ for the diffusion of gases and particulates in the atmosphere from a ground-level source: $\chi = Q/\pi Ku$, where

χ = pollutant concentrations at receptor point, gm/m³
 Q = source emission rate, gm/sec
 K = product of standard deviations of vertical and horizontal pollutant distribution, m²
 u = wind speed, m/sec

This equation assumes a Gaussian distribution of pollutants in both the vertical and horizontal directions and no deposition or reaction of pollutants at the earth's surface.

By rearranging terms, the product of the standard deviations (K), which are functions of the downwind distance (x) of the receptor from the source, may be determined as a function of easily estimated or measured parameters in Equation 3-2:

$$K = Q/\pi\chi u, \quad (3-2)$$

(1) Turner, D. Bruce, "Workbook of Atmospheric Dispersion Estimates," U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 999-AP-26, Revised 1969.

where

Q is estimated from published emission factors,
x is set equal to a selected value related to
the sampling method detection limit and
u is measured at the site.

The maximum downwind sampler distance from the source along the axis of the wind direction (x) may then be determined from the curves of Figure 3-2, which relate K and x for various atmospheric stability categories. These categories are listed and explained in Table 3-3.

When suitable x-distances, which may be any distance less than the maximum determined from Figure 3-2, have been selected, cross-wind distances (y) perpendicular to the x-axis that will ensure that samples are taken within the limits of the cloud must be determined. Maximum cross-wind distances, which are a function of the distribution of the pollutant concentrations within the cloud, are plotted as a function of x in the curves of Figure 3-3 for the same atmospheric stability categories used in determining x. Downwind samplers should in general be located at two different x-distances within the limits of the maximum as determined above and at cross-wind y distances less than the maximum indicated in Figure 3-3 on opposite sides of the wind direction axis.

Upwind samplers should ideally be located on the wind direction axis just far enough upwind to prevent sampling the backwash of the pollutant cloud. A minimum upwind distance of $x_{\max}/10$, where x_{\max} is determined using x equal to the sampling method's lower detection limit, will usually be sufficient.

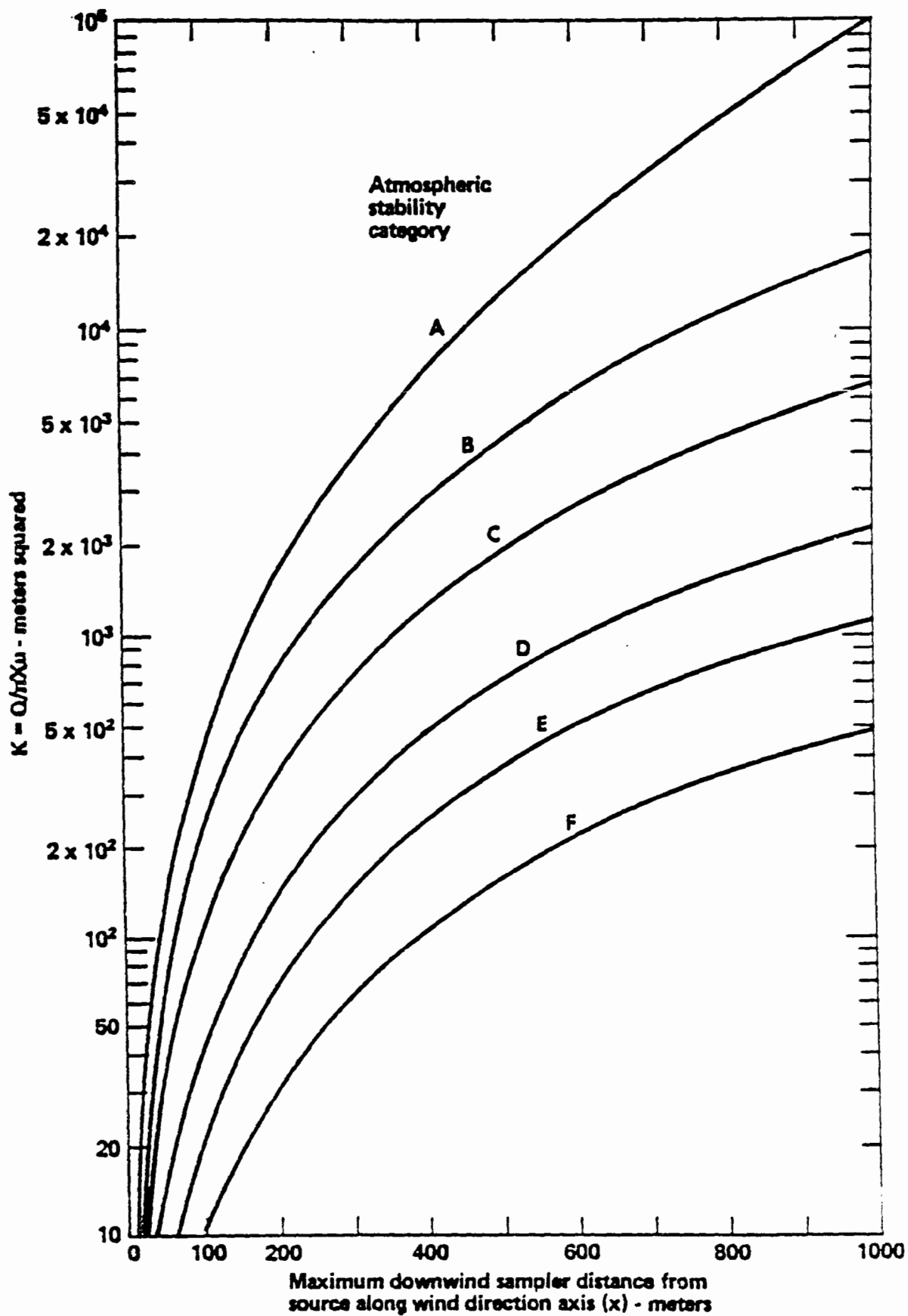


Fig. 3-2. Maximum downwind sampler distances.

TABLE 3-3

ATMOSPHERIC STABILITY CATEGORIES

Wind Speed m/sec	Day*			Night	
	Solar Altitude†			Overcast or > 50% Clouds	< 50% Clouds
	> 60°	35°-60°	15°-35°		
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

*Day is one hour after sunrise to one hour before sunset.

†Solar altitude may be determined from Table 170, Solar Altitude and Azimuth, Smithsonian Meteorological Tables. Use neutral class D for overcast conditions at any wind speed. - Partial cloud cover (60 percent to 85 percent) will reduce effective solar altitude one division (e.g., from > 60° to 35°-60°) for middle clouds and two divisions (e.g., from >60° to 15°-35°) for low clouds.

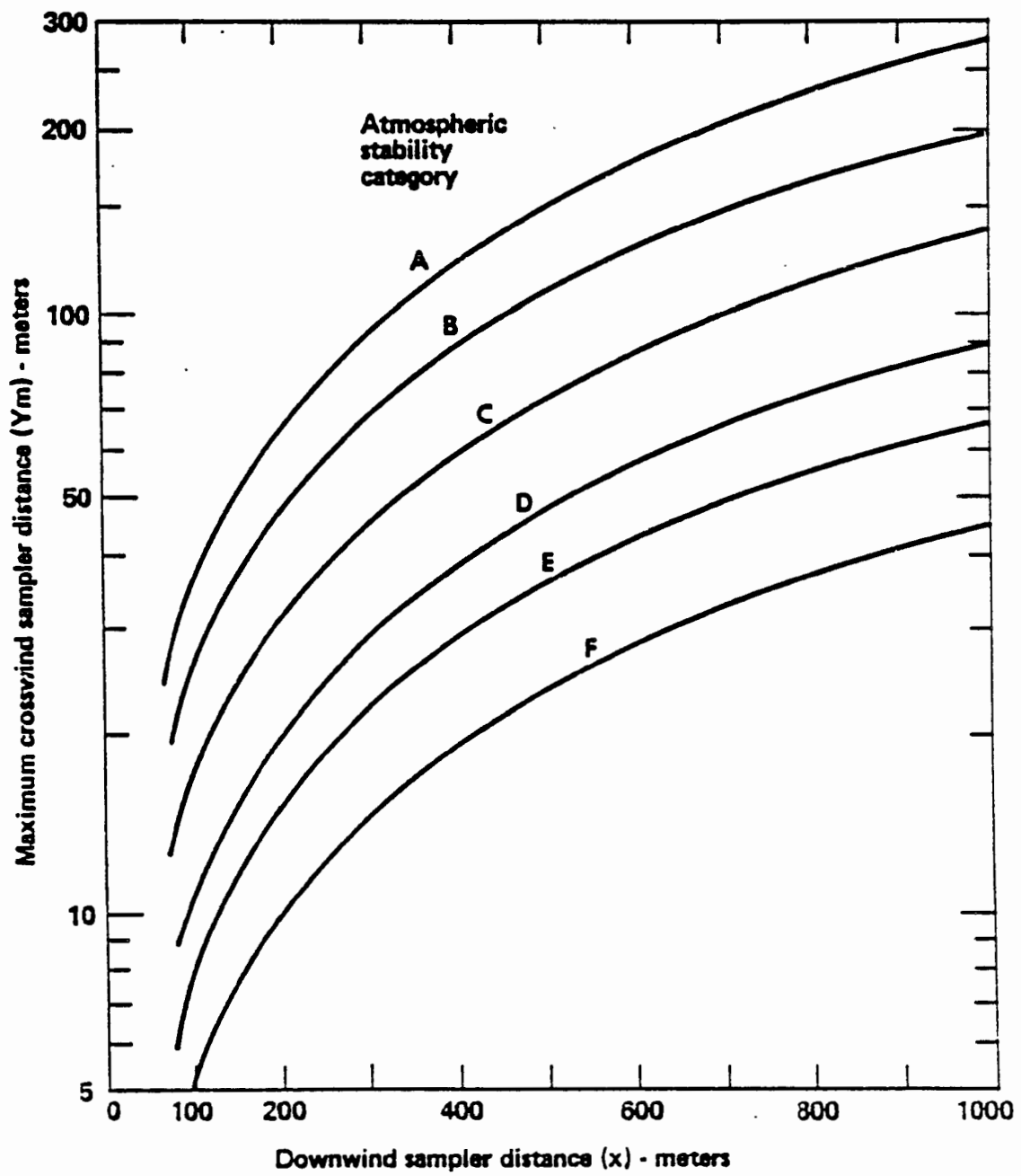


Fig. 3-3. Maximum crosswind sampler distances.

To illustrate the application of the equations and curves presented in this section, assume a source emitting particulates into a four meter per second wind at an estimated rate of 10 grams per second, and a sampler with a lower detection limit of .001 gram and flow rate of 0.67 cubic meter per minute. For a sampling time of 10 minutes, the required pollutant concentration, χ , at the sampler is $\chi = M/FT$, where

$$\begin{aligned} M &= .001 \text{ gram} \\ F &= 0.67 \text{ cubic meter/minute} \times 1.5 \text{ adjustment factor} = \\ &\quad 1 \text{ cubic meter/minute} \\ T &= 10 \text{ minutes, and} \\ \chi &= .001/10 = 10^{-4} \text{ grams/cubic meter} \end{aligned}$$

The product of the pollutant cloud's standard deviations, K , is found in Equation 3-2, $K = Q/\pi\chi u$, where

$$\begin{aligned} Q &= 10 \text{ grams/second} \\ \chi &= 10^{-4} \text{ grams/cubic meter} \\ u &= 4 \text{ meters/second, and} \\ K &= 10/\pi \times 10^{-4} \times 4 = 8 \times 10^3 \text{ meters squared} \end{aligned}$$

To measure the emissions during midday with clear skies, Table 3-3 indicates an atmospheric stability category B for the four meter/second wind. Figure 3-2 for $K = 8 \times 10^3$ and category B indicates a maximum sampler downwind distance of 680 meters. Figure 3-3 for $x = 680$ meters and category B indicates a maximum cross-wind distance of 145 meters.

Downwind samplers must then be located within the limits of a triangle with an apex at the source, an altitude of 680 meters along the wind direction axis and a base 145 meters wide on each side of the axis.

The upwind sampler should be located along the wind direction axis at a minimum distance of $x_{\max}/10 = 68$ meters from the source.

A more detailed description of the application of this method is presented in the appendix.

3.4.4 Data Reduction

When the sampling program has been completed and the samples have been analyzed to yield pollutant concentrations in such terms as micrograms per cubic meter in the ambient air at each downwind sampling site, the measured upwind concentrations are subtracted to yield the concentration provided by the source at each sampler. These values are then back-calculated through known diffusion equations that take into account the variables of topography and meteorology to produce statistical distributions of the concentrations within a pollutant cloud generated by a given source. These calculations yield source strengths of the emissions in such terms as grams per unit time. A library of computer programs to assist in the performance of the calculations is maintained in the User's Network for Applied Models of Air Pollution (UNAMAP) at the Environmental Protection Agency's Research Triangle Computer Center.⁽¹⁾ Additional programs may be obtained through many environmental consultants.

3.5 Detailed Upwind-Downwind Measurement System

A detailed measurement system is designed to more precisely identify and quantify specific pollutants that a survey measurement or equivalent data indicate as a possible problem area. A detailed system

⁽¹⁾ Bulletin American Meteorological Society, Vol. 56, No. 12, December, 1975.

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 terms of equipment, time, and manpower and yields data detailed and dependable enough for direct action toward achieving emissions control. Detailed systems in general employ sampling arrays or networks to measure the concentration and distribution of specific pollutants in the ambient air approaching and leaving a source. These actual measurements of the pollutant distribution within a cloud and the variations in meteorological conditions during the sampling period replace the assumptions utilized in survey sampling systems. Detailed systems are frequently employed to compare emissions at different process or operating conditions to determine which conditions dictate the need for emission control.

The data provided by the sampling arrays are processed in conjunction with more detailed meteorological data which are taken simultaneously to determine source emission rates and ambient distributions in much the same manner as the simpler survey systems.

3.5.1 Sampling Equipment

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

Particulate samples are collected using 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 reviewed in Section 3.4.2 for the design of a survey sampling system are generally applicable to the design of a detailed system. The need for replacement of survey assumptions as to pollutant distribution with actual measured values, however, most frequently requires the design of a sampling array or network that will provide samples of a distribution at various distances downwind of the source in both the horizontal and vertical directions. Sampler locations may generally be determined in the same manner as those for a survey system. For detailed measurements, each location must provide for sampling across a section of the pollutant cloud horizontally and/or vertically. Horizontal distributions may be measured by adding a number of samplers (usually at least two) at either side of the survey sampler location at distances estimated to yield significantly different pollutant concentrations. Vertical distributions may be measured by placing a tower of suitable height at each survey sampler location

and adding samplers over a range of heights on each tower. Combinations of horizontal and vertical distributions may be measured by placing a grid of horizontally and vertically spaced samplers at each survey sampler location. Actual numbers of samplers, their spacing, and heights of towers required must be determined for each location. A rough guide for estimating the required spacing is presented in Section 3.5.3.

3.5.3. Sampling Techniques

The guidelines presented in Section 3.4.3 for the design and location of samplers for a survey system are applicable to detailed systems. The assumption of a Gaussian distribution of pollutants in the cloud, sufficient for data reduction in survey systems is reasonable as a rough guide to locating samplers within the pollutant cloud as in Section 3.4.3, and for the spacing of sampling arrays as outlined below.

The approximate concentration of a specific pollutant within a cloud in which concentrations vary in accordance with a Gaussian distribution at a given downwind distance from the source is greatest at ground level on the wind direction axis of the cloud. Assigning this concentration the unit value x_0 , the concentration (x) at any crosswind distance (y) from the axis is expressed as

$$x = x_0 e^{-\frac{1}{2}[F(y)]^2}$$

The term $F(y)$ may be expressed as y/y_m , where y_m is the maximum crosswind sampler distance determined from Figure 3-3. The relationship x/x_0 is plotted as a function of y/y_m in Figure 3-4. This may be used to

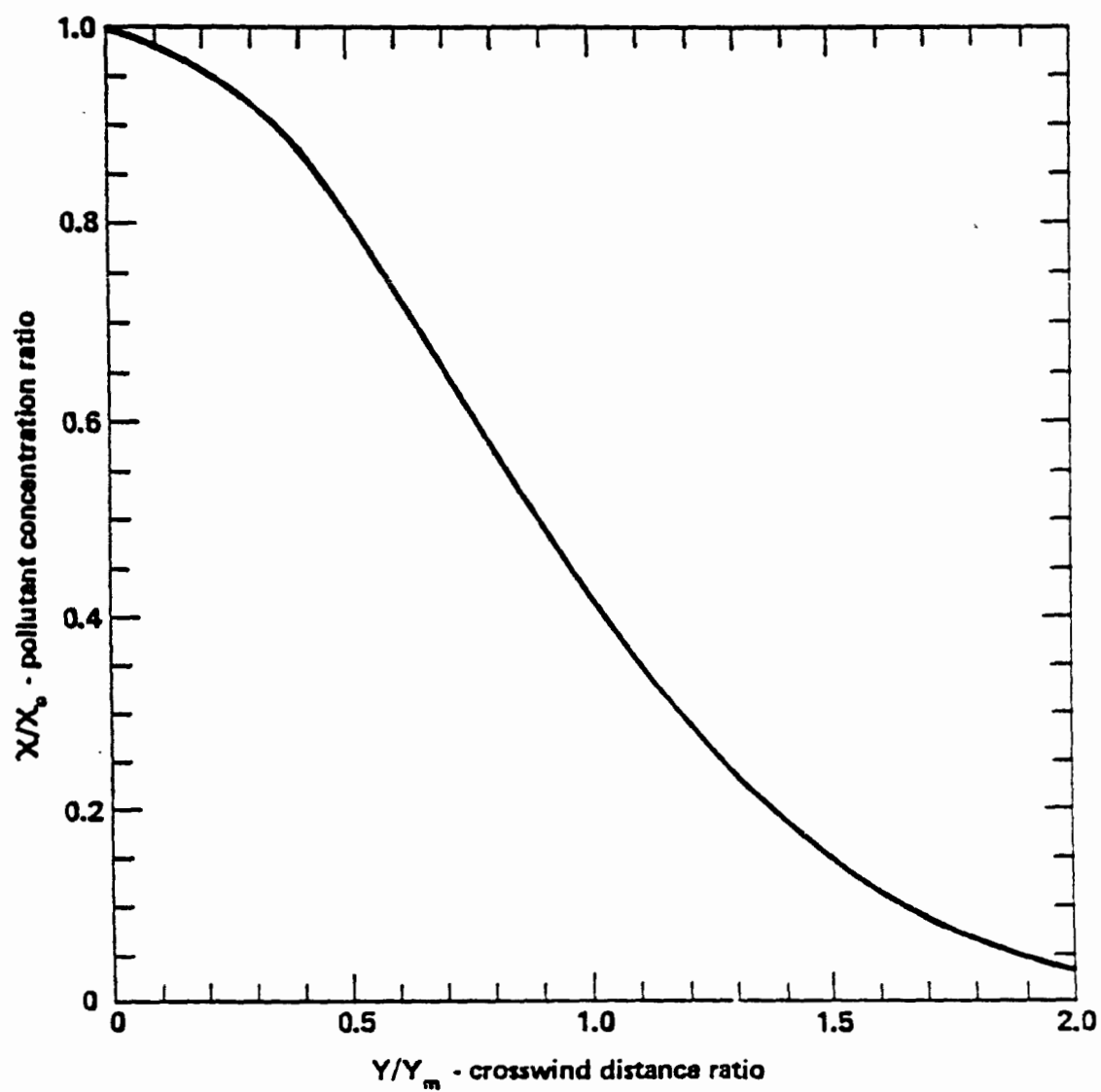


Fig. 3-4. Pollutant concentration ratios for crosswind locations.

determine the probable concentration at a sampler location relative to the concentration at the axis and the concentrations at lateral distances from that location to assist in the horizontal spacing of samplers in an array.

The concentration in the vertical direction from any ground level point will decrease as the height, Z , increases in a similar relationship. The ratio of the concentration at the elevated point to that at ground level, χ_h/χ , is plotted in Figure 3-5 as a function of Z/Z_m , where Z_m is a function of the downwind distance from the source and the atmospheric stability as plotted in Figure 3-6. Figure 3-5 may be used to determine the relative concentrations at elevated points to assist in the design of sampling towers and the vertical spacing of samplers in an array or grid.

In general, arrays should be designed to provide data at concentrations approximately two to four times greater or less than the concentration at a selected ground level sampling point. Physical limitations at the site or very unstable atmospheric conditions will often preclude the compliance with this design guideline by limiting the available horizontal positions or by requiring an impractical tower height. In such situations, the need to adjust the requirements of the guideline must be recognized and the array designed to compensate for the limitations.

Upwind sampling arrays will generally be less complex than downwind arrays unless a nearby pollutant source results in a heterogeneous ambient air mix. In this case, the guidelines for downwind array design presented in this section may have to be applied to the upwind array

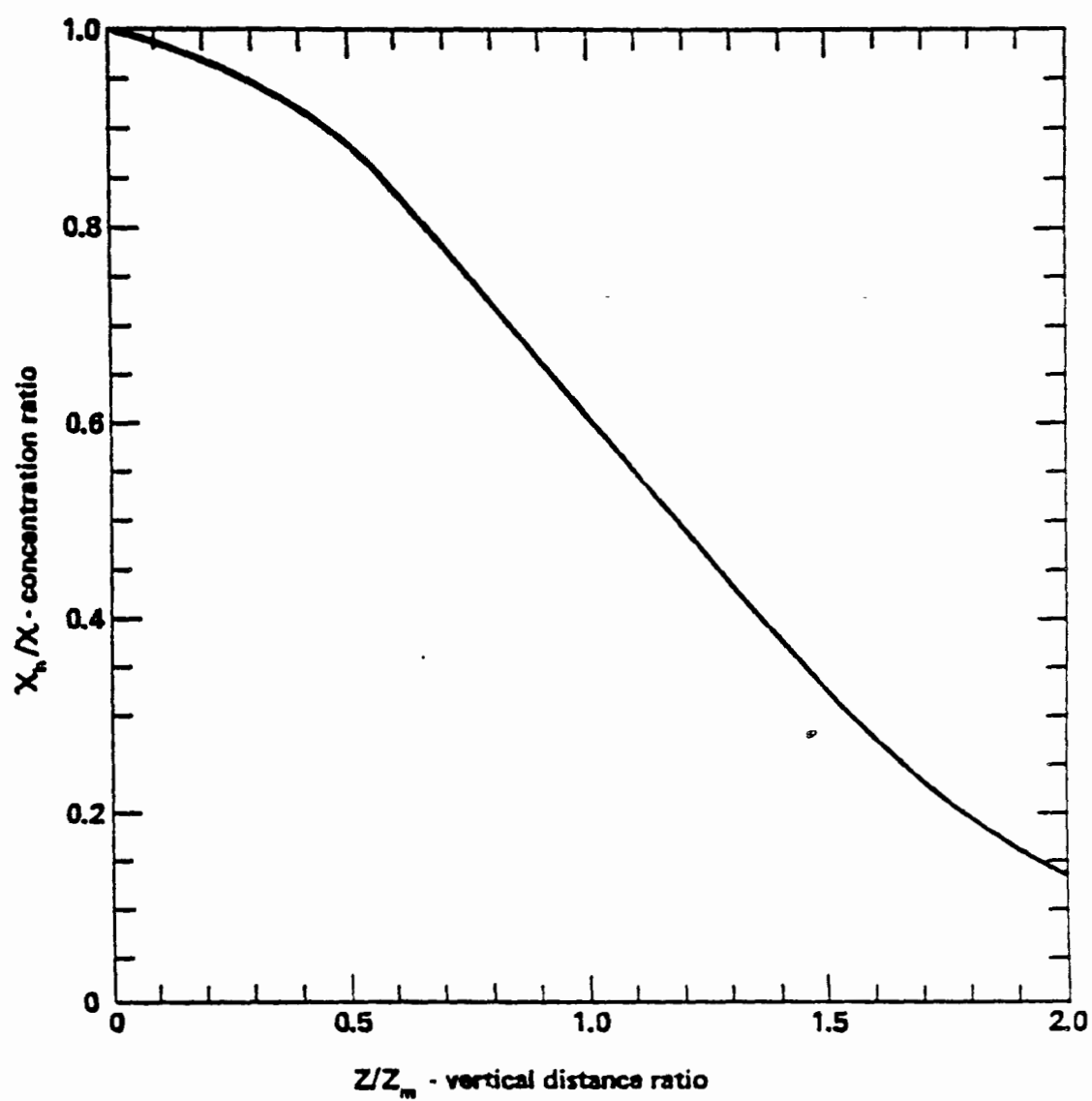


Fig. 3-5. Pollutant concentration ratios for vertical locations.

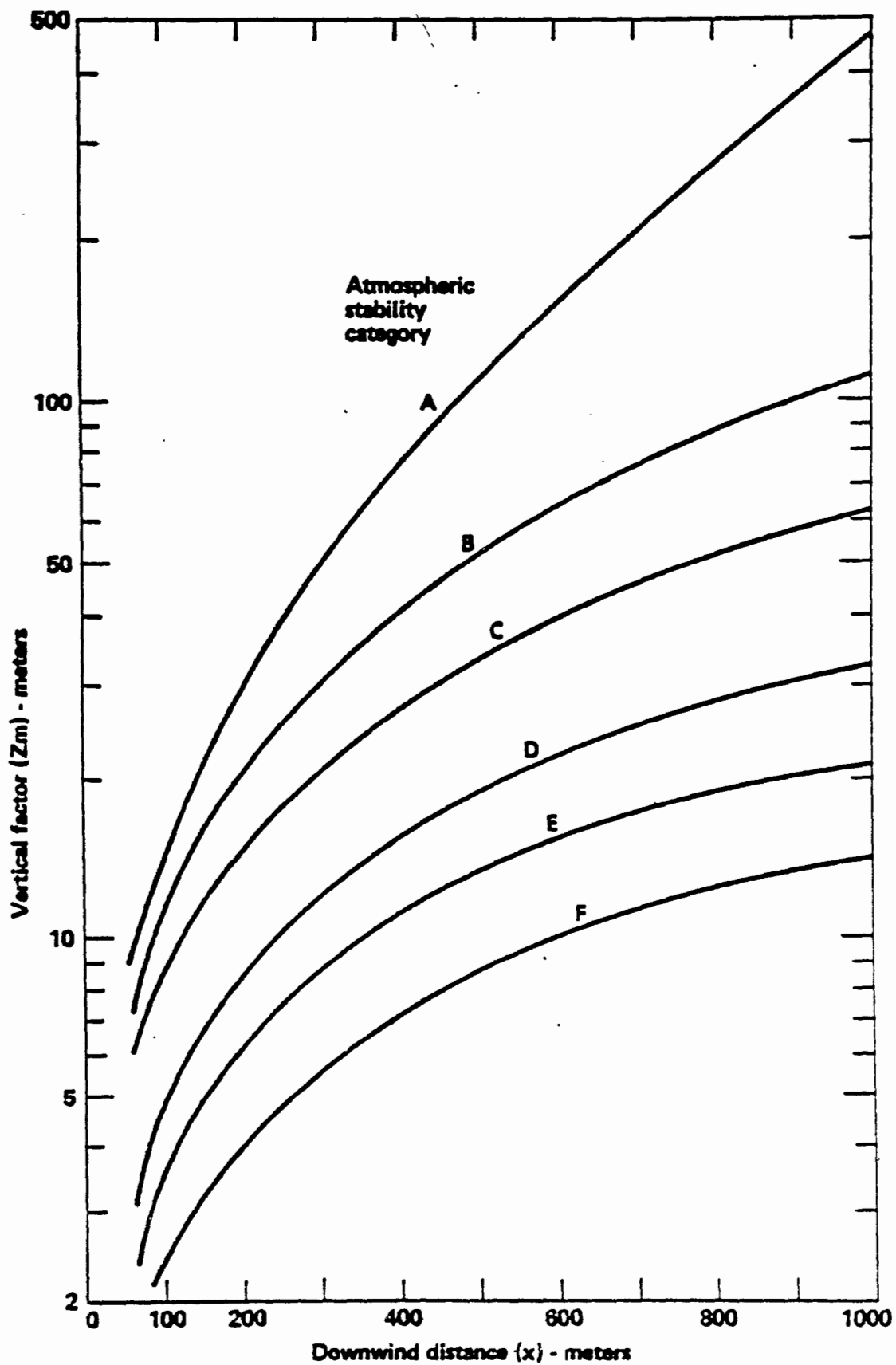


Fig. 3-8. Vertical concentration distribution factors.

design.

Wind speed and direction should be measured at each sampler or array location. Pretest survey observations should indicate whether stratification will occur to a degree which will require wind data at more than one level.

An example of the application of these guidelines to the design of survey and detailed systems for the measurement of pollutants at a Portland cement plant is presented as an appendix to this document.

3.5.4. Data Reduction

Samples are analyzed to yield concentrations of specific pollutants in such terms as micrograms per cubic meter at each sampling site. Measured upwind concentrations are substituted into appropriate diffusion equations to provide ambient air background concentrations at each downwind site and the background concentration subtracted from the measured downwind concentration at each site to yield the source contribution. These values are then substituted into diffusion equations to back-calculate source strengths in terms of grams per unit time, utilizing UNAMAP or other available computer programs.

3.6 Atmospheric Tracers

In some instances, prevailing process or meteorological conditions prohibit the collection of samples containing measurable, clearly defined amounts of a specific pollutant for the back-calculation of source strengths. In many such cases, the atmospheric tracer method may be employed to determine a typical distribution of a general class of pollu-

tant analogous to the pollutant of concern.

The use of tracers should be considered under any of the following circumstances:

When the pollutant background concentration is either excessively high or inhomogeneous. This can be caused by significant emissions from external upwind sources.

When the fugitive emissions are of such a complex nature that an excessive number of downwind vertical profiles are required to characterize the emissions.

When physical limitations prohibit the installation of adequate instrumentation for specific pollutant concentration measurement.

When the nature of the specific pollutant prohibits its measurement with acceptable instrumentation or indicates large probable errors in measurement.

When estimates of fugitive emissions are being made for non-operating processes or planned operations.

The atmospheric tracer method, which may be considered as a special detailed system, consists of the introduction into the atmosphere, at the source site under consideration, of a readily identifiable material similar in the character of its diffusion in the atmosphere to the pollutant of concern. The quantity released may be controlled to provide readily measurable concentrations. A detailed downwind measurement system, designed using the guidelines of Section 3.5, is used to collect samples of the tracer and to determine its dispersion for the known and controllable source strength. This dispersion will be analogous to the dispersion of the pollutant of concern and will permit the prediction of pollutant concentrations for a range of source strengths.

3.6.1 Tracers and Samplers

Both particulate and gaseous atmospheric tracers are in general use. The most commonly used particulate tracers are zinc-cadmium sulfide and sodium fluorescein (urinine dye). The primary gaseous tracer is sulfur hexafluoride (SF_6).

Zinc-cadmium sulfide is a particulate material which can be obtained in narrow size ranges to closely match the size of the pollutant of concern. The material is best introduced into the atmosphere in dry form by a blower type disseminator although it can also be accomplished by spraying from an aqueous or solvent slurry. The zinc-cadmium sulfide fluoresces a distinctive color under ultraviolet light which provides a specific and rapid means of identification and quantification of the tracer in the samples.

Sodium fluorescein is a soluble fluorescing particulate material. It is normally spray disseminated from an aqueous slurry solution to produce a particulate airborne plume, the size distribution of which can be predetermined by the spraying apparatus. Sodium fluorescein can be uniquely identified by colorimeter assessment.

Sulfur hexafluoride is a gas which can be readily obtained in ordinary gas cylinders. Sulfur hexafluoride can be disseminated by metering directly from the gas cylinder through a flow meter to the atmosphere. The amount disseminated can be determined by careful flow metering and/or weight differentiation of the gas cylinder.

Particulate tracers are usually sampled with filter impaction devices or, for particles over 10 microns in diameter, the more easily used and somewhat less accurate Rotorod sampler which collects particles

on an adhesive-coated U- or H-shaped rod which is rotated in the ambient air by a battery-driven electric motor.

Sulfur hexafluoride gaseous samples are collected for laboratory gas chromatograph analysis in non-reactive bags of such materials as Mylar.

3.6.2 Tracer Sampling System Design

All of the design guidelines presented in 3.4.2 and 3.5.2 may be applied to the design of a tracer sampling system as site conditions dictate. Their application is, in general, simplified since the source strength may be controlled to provide measurable tracer concentrations at readily accessible sampling locations.

A single upwind sampler will usually be sufficient to establish that no significant amount of the tracer material is present in the ambient atmosphere approaching the source.

3.6.3 Tracer Sampling and Data Analysis

The methods introduced in Section 3.4.3 and 3.5.3 for determining sampler design and location are fully applicable to tracer sampling. Like the design guidelines, they may be more easily applied because the source strength is easily controlled.

The analysis of the data is also simplified since the source strength is known and no back-calculation is required.

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

4. Procurement Document Control

Verify that all design specification 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 distrib-

uted 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 upwind-downwind fugitive emissions sampling programs using the methodology described in this document. Four programs are listed, representing minimum and more typical 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 upwind-downwind 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 1500 man-hours for a more complex survey program; and 2800 man-hours for a simple detailed program and 4500 man-hours for a more complex detailed program.

TABLE 4-1

**CONDITIONS ASSUMED FOR COST ESTIMATION
OF UPWIND - DOWNWIND SAMPLING PROGRAMS**

Parameter	Survey Program		Detailed Program	
	Simple	Complex	Simple	Complex
Site Location	Open Area- Accessible	Congested- Limited Access	Open Area- Accessible	Congested- Limited Access
Emission Source	Well Defined	Complex	Well Defined	Complex
Emission Character	Steady	Steady	Cyclic	Cyclic- Measured at Two Levels
Wind Measurement	External Source	Measured On Site	Measured On Site	Two Measure- ments On Site
Sample Sites	One Upwind Two Downwind	One Upwind Three Downwind	Vertical Arrays- One Upwind, Two Downwind	Grid Arrays- One Upwind, Two Downwind
Samplers	3	8	16	30
Towers	0	4 Low	4 High	4 High - Grids
Experiments	1	1	2	4
Estimated Basic Accuracy	± 500%	± 150%	± 125%	± 75%

TABLE 4-2

ESTIMATED MANPOWER REQUIREMENTS FOR UPWIND - DOWNWIND
SAMPLING PROGRAMS

Estimates in Man-Hours

Task	Survey Programs						Detailed 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 Preparation	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	8	12	12	16	48	64	80	140	100	120	280	240
Field Study	24	48	120	60	200	268	120	300	536	180	560	796
Sample Analysis	20	20	36	60	60	108	120	240	96	180	320	180
Data Analysis	20	20	36	60	60	108	120	240	96	180	320	180
Report Preparation	16	16	8	64	64	32	160	80	40	200	200	80
Totals	104	144	224	284	480	612	628	972	1028	900	1784	1556
Engineer/Scientist Total		472			1376			2628			4240	
Clerical		40			120			200			280	
Grand Total		512			1496			2828			4520	

4.2 Other Direct Costs

Table 4-3 presents estimates for equipment purchases, rentals, calibration, and repairs; on-site construction of towers and platforms; shipping and on-site communications for each of the listed programs. Total costs are approximately \$4500 for a simple survey program and \$17,000 for a more complex survey program; and \$34,000 for a simple detailed program and \$64,000 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 17 weeks for a more complex survey program; and 21 weeks for a simple detailed program and 41 weeks for a more complex detailed program.

4.4 Cost Effectiveness

Figure 4-2 presents curves of the estimated cost effectiveness of the upwind-downwind 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.

TABLE 4-3

**ESTIMATED COSTS FOR UPWIND.- DOWNWIND
SAMPLING PROGRAMS
(LABOR COSTS EXCLUDED)**

Cost Item	Survey Programs		Detailed Programs	
	Simple	Complex	Simple	Complex
Equipment				
Sampler Purchase	\$1800	\$4800	\$9600	\$18000
Sequencer Purchase	900	2400	4800	9000
Wind Measurement Purchase	0	3500	3500	5000
Calibration	150	250	400	600
Repairs	270	1000	1500	2500
Wiring Harnesses	0	0	400	800
Construction				
Towers	0	2000	8000	19000
Platforms, etc.	500	1000	1500	2000
Electrical Hook-ups	0	100	200	300
Shipping	200	400	800	1200
Trailer Rental	0	0	500	500
Vehicle Rentals	280	560	1400	2800
On-Site Communications	100	300	700	900
TOTAL	<u>\$4500</u>	<u>\$16810</u>	<u>\$34100</u>	<u>\$63900</u>

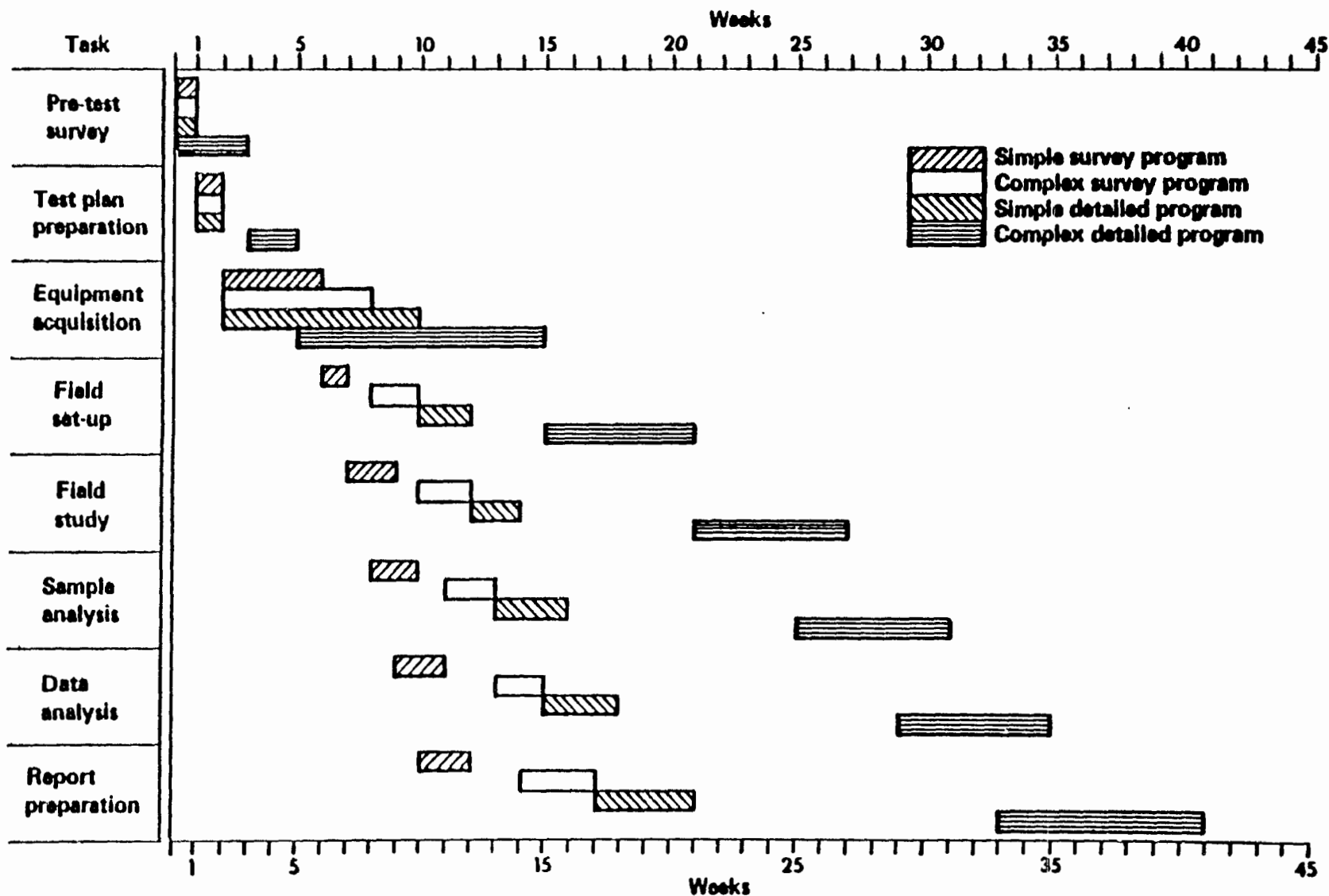


Fig. 4-1. Elapsed-time estimates for upwind-downwind sampling programs.

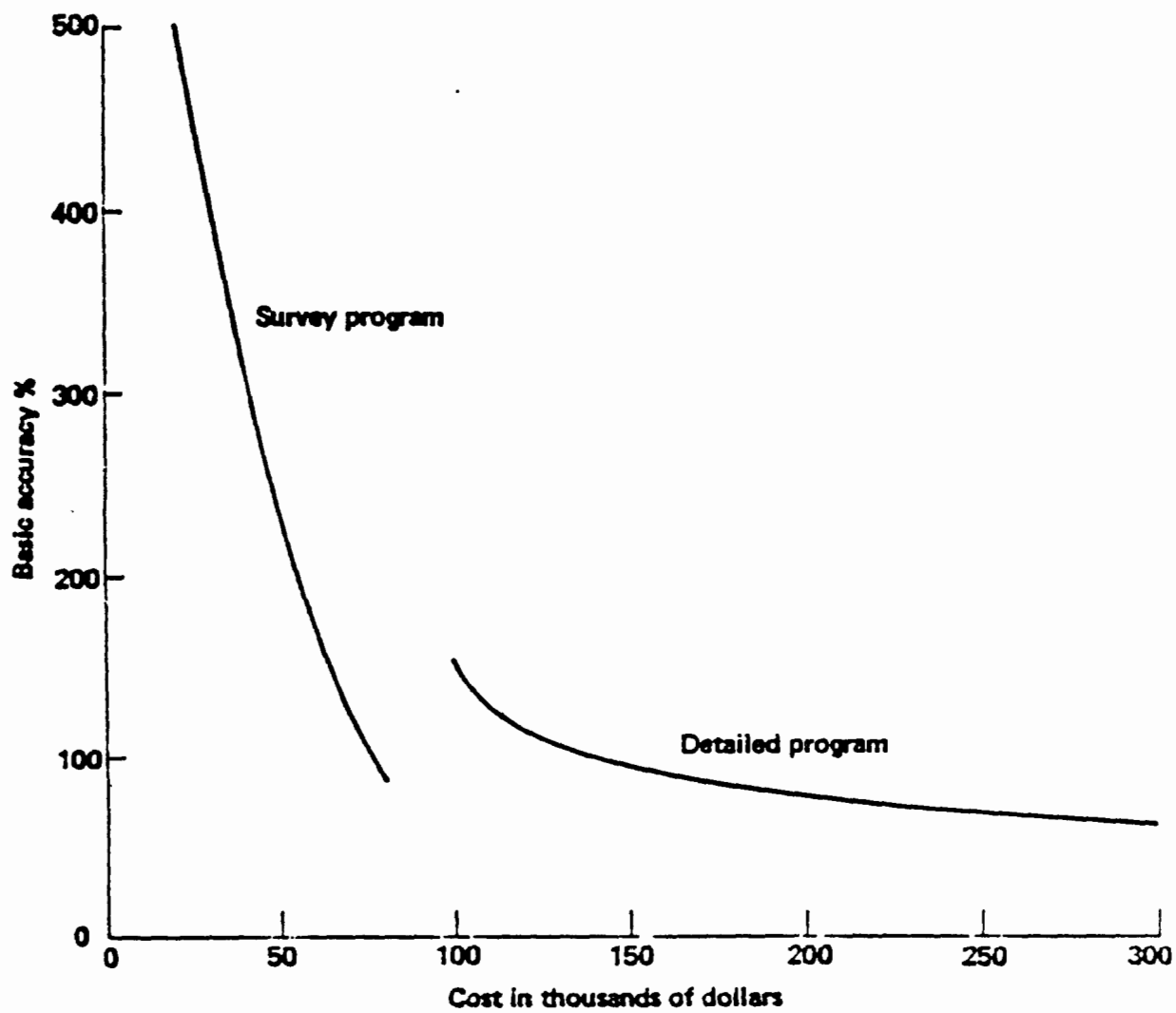


Fig. 4-2. Cost-effectiveness of upwind-downwind sampling programs.

APPENDIX A
TEST PROCEDURES APPLICATION

A.1.0 INTRODUCTION

This appendix presents an application of the upwind-downwind fugitive emissions measurement system selection and design criteria to a Portland cement manufacturing plant. 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 operation of the subject Portland cement manufacturing plant would ordinarily be gathered from interviews and observations during a visit to the plant for a pre-test survey.

Portland cement is made from a mixture of finely ground calcareous (lime component) and argillaceous (alumina component) materials. The four major steps for producing Portland cement are:

- (1) Obtaining raw materials and reducing their size,
- (2) Grinding, blending and homogenization of these materials to obtain desired composition and uniformity,
- (3) Heating to liberate carbon dioxide and burning to form clinker,
- (4) Grinding or fine pulverization of the clinker with addition of gypsum.

At this location, shown in Figure A-1, limestone is quarried at the site by dragline buckets, pulverized in a hammer mill, mixed with water and pumped to raw material storage. Other raw materials are delivered to storage by rail. Ball mills reduce first the limestone and then a limestone-clay mixture to a fine slurry which is stored in concrete tanks prior to its introduction to the rotary kilns. The slurry is dried and burned at about 2700°F to form clinker, which is cooled and stored in bins until needed for the finish grinding operation where it is pulverized and mixed with gypsum to produce the finished product. The cement is stored in silos prior to bagging or transfer to bulk container trucks and railroad cars for shipping.

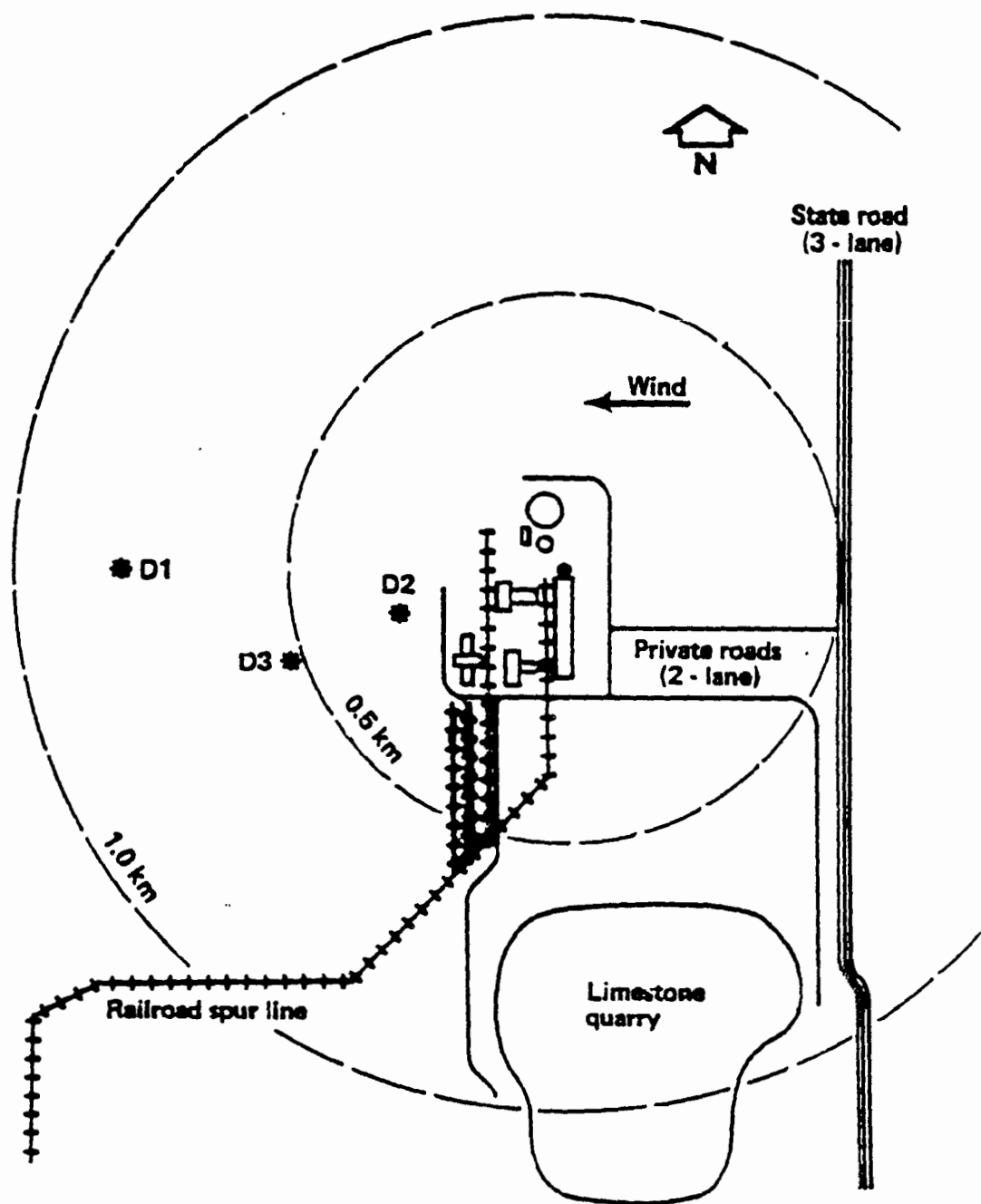


Fig. A-1. Portland cement plant site layout.

The plant operates on a three-shift, round-the-clock production schedule including all operations except shipping and unloading of rail-delivered raw materials, which are normally carried out only on the 8:00 a.m. to 4:00 p.m. shift. The plant produces about 300 barrels of finished product per hour, consuming about 600 pounds of raw materials for each 376 pound barrel produced.

The raw materials and the finished product are essentially dust; the principal emissions are also dust. The largest contributor is the kiln used to produce the clinker, where the dried mixture becomes suspended in the combustion gases as dust and is delivered through the stack to the atmosphere. A multi-cyclone/electrostatic precipitator combination removes about 95 percent of the dust before it is vented to the stack. Other sources of dust are the ball mills, materials transfer operations and packaging operations. Hoods at the ball mills and packing house are utilized to capture and transmit about 85 percent of their emissions to a bag house. The quarry operation at this plant contributes little or no dust since the entire process is conducted with the material in a wet condition.

The EPA estimates for uncontrolled emissions, as published in the Office of Air Programs Publication AP-42, Compilation of Air Pollutant Factors, are 15 to 55 pounds from the kiln and 2 to 10 pounds from all other sources for each barrel of cement produced. If the assumed 95 percent effectiveness of the stack controls is correct, 0.75 to 2.75 pounds per barrel could be transmitted to the atmosphere from the stack. Assuming that 80 percent of all other emissions are hooded, 0.5 to three pounds per barrel could be transmitted to the atmosphere as fugitive

emissions.

The prevailing daytime wind at the plant is from a general easterly direction and averages 10 miles per hour over open, flat, partly swampy terrain.

A.3.0 METHOD SELECTION

Selecting the most practical method to measure the amount of emitted pollutants reaching the ambient atmosphere involves evaluating the site, processes and pollutants concerned in terms of the criteria of Section 2.2 as follows:

Site Criteria - the various sources at the site are remote from one another, both indoors and outdoors, and are not small enough to be hooded or otherwise enclosed.

Process Criteria - emissions are essentially the same from all sources at the site with no interfering reactions between emissions or with other constituents in the ambient atmosphere. The process is continuous and does not entail any limitations as to the timing of sampling.

Pollutant Criteria - emissions to be measured are particulates whose generation rate and dilution in the ambient air will provide measurable concentrations within reasonable distances of the source.

The site criteria are, in this case, the determining factors in selecting the measurement method. Since the emissions cannot be contained or directed in any manner, only the upwind-downwind measurement method may be successfully utilized to determine the plant's contribution to the particulate concentration in the local atmosphere.

The basic question to be answered by the measurement program is "Does the rate of particulate emissions from the plant exceed the accepted regulatory agency standard?" This question can be answered by a survey program average measurement of the total particulate emissions from the plant, including emissions from the kiln stack. If the survey program indicates that the plant's emissions do exceed standards, the question to be answered will then be "What actions are neces-

sary to reduce emissions to an acceptable rate?" The answer to this question requires that the rates of the specific sources of the emissions be separately quantified. This will require the increased accuracy and extent of measurements of a detailed program. The design of both systems is described in the following sections.

A.4.0 SURVEY MEASUREMENT SYSTEM

To determine the total plant contribution of particulates to the atmosphere, measurement must be made of the approaching ambient air containing upwind and all background emissions. In this case, a single upwind sampler located between the kiln building and the road to the east will include the general ambient background particulates plus the particulates contributed by traffic on the road. A ground level sampler, located about 200 meters from the kiln, should provide an accurate measurement. The downwind measurement must include the contributions from all the sources at the site, which may be considered as emanating from a line source at ground level with an overlay of emission from the elevated stack, as illustrated in Figure A-2. To ensure that the stack emission contribution to the cloud is being measured, one downwind sampler is located within the estimated confines of the stack plume and others outside the stack plume as shown on Figure A-2.

A.4.1 Sampler Location

For a high volume sampler sampling 18 cubic feet per minute, a desired sample weight of 100 micrograms and a 60 minute sampling time, the particle concentration required at the sampling point is: (per Equation 3-1)

$$\chi = M/FT = 10^{-4} \text{ (gm)}/0.5 \text{ (m}^3\text{/min)} \times 60 \text{ (min)}$$

$$\chi = 3.3 \times 10^{-6} \text{ (gm/m}^3\text{)}$$

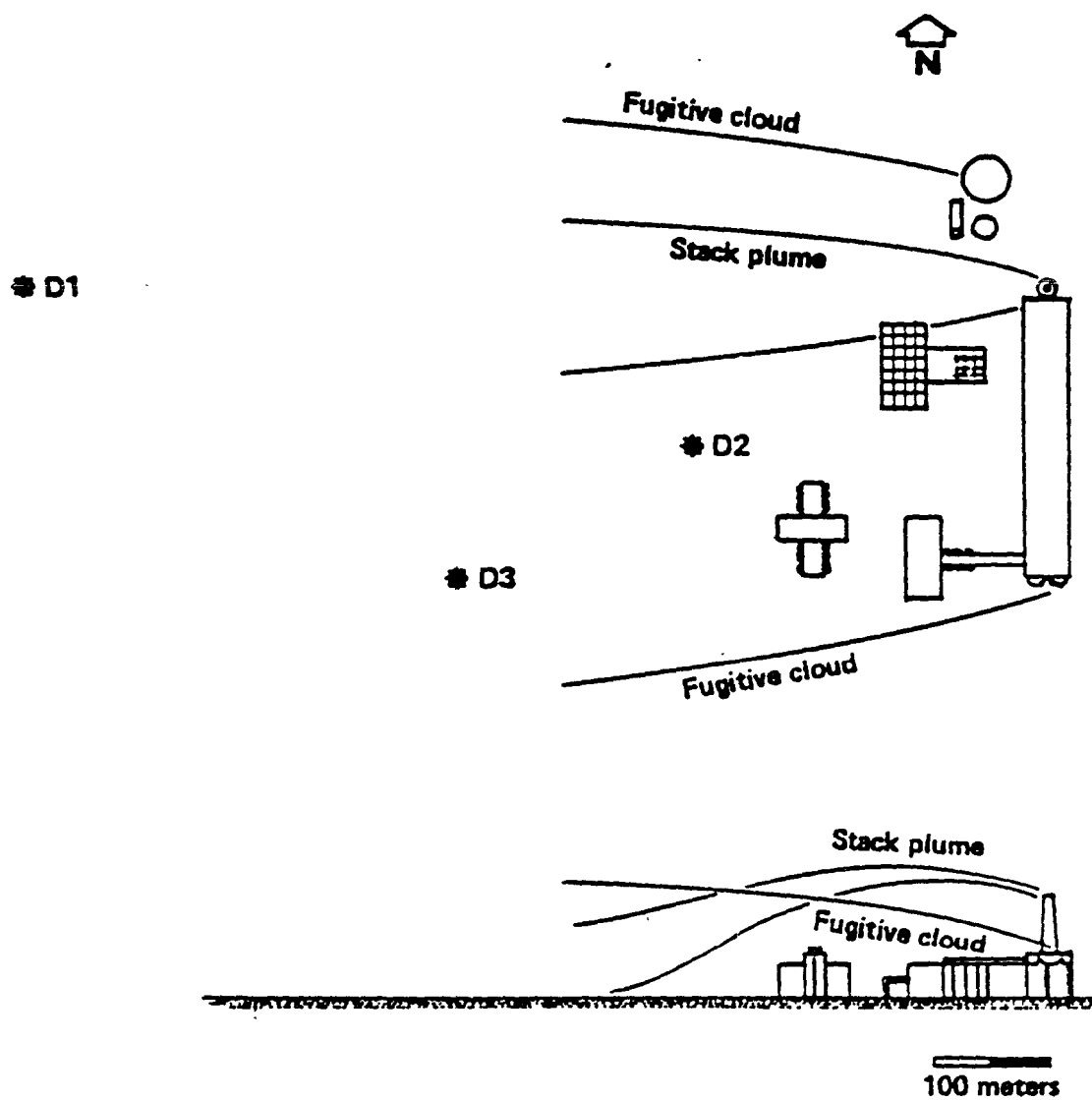


Fig. A-2. Portland cement plant emissions clouds.

Local emission limitations, promulgated on a process weight basis, permit 30 pounds per hour of particulate to be transmitted to the atmosphere from all sources. In order to measure this total emission rate in a 10 mile per hour (4.47 m/sec) wind with the proposed samplers, the product of the standard deviations used to determine the maximum distance from the source that samplers may be located is found using:

$$K = Q/\pi xu \quad (\text{Equation 3-2})$$

$$K = 30 \times 454 \times \frac{1}{3600} \left(\frac{\text{gm}}{\text{sec}} \right) / \pi \times 3.3 \times 10^{-6} \left(\frac{\text{gm}}{\text{m}^3} \right) \times 4.47 \left(\frac{\text{m}}{\text{sec}} \right) = 8 \times 10^4$$

Table 3-3 indicates the use of an atmospheric stability category B for clear midday conditions and the wind speed of 4.47 meters per second. Figure 3-2 indicates a maximum sampler downwind distance well in excess of one kilometer for $K = 8 \times 10^4$ and category B, so that any sampler location within one kilometer downwind of the plant will provide satisfactory measurements. To ensure that the stack emissions are also adequately measured, one sampler is located along the wind direction axis through the stack at a distance of 800 meters from the stack, at point D1 on Figure A-2. Two additional samplers are located within the fugitive emissions cloud outside the stack plume at points D2, 300 meters from the kiln structure on its wind direction centerline, and D3, 500 meters from the kiln at 100 meters to the south (cross-wind) of its centerline.

Samples are taken simultaneously at the upwind and three downwind locations for a one hour period chosen to include activities in all phases of the process- kiln operation, grinding, packaging and all phases

of material transfer including bulk product loading and raw material unloading. The samples are analyzed to determine particulate concentrations at the sampler locations, which are then used in computer programmed diffusion equations to determine the source strengths of the fugitive and stack emissions.

A.5.0 DETAILED MEASUREMENT SYSTEM

Assuming that the survey measurements indicate an emission rate in excess of the local regulations, say 40 pounds per hour, a detailed system must be designed to more accurately quantify the emissions from the separate sources at the plant.

The separate sources are identified as individual particulate clouds on Figure A-3. Their characteristics and schedules are as follows:

- (1) Flotation Tanks - continuous low level emissions. Cloud usually isolated.
- (2) Ball Mill and Slurry Tanks - continuous emissions. Cloud usually mixed with (3).
- (3) Raw Materials Storage - continuous low level emissions, higher emissions during day shift material unloading operations. Cloud always mixed with (2).
- (4) Packing and Shipping - emission level variable with activity, on day shift only. Cloud always partially mixed with (5).
- (5) Finish Grinding Mill - continuous emissions. Cloud partially mixed with (4).
- (6) Stack - continuous emissions.
- (7) Materials Transfer - continuous low level emissions as background to all except (1).

Assuming that the prevailing wind direction remains from the east:

Cloud (1) may be individually measured at any time.

Cloud (2) may be individually measured only when material unloading operations are shut down - measurement would be improved by wetting down raw materials.

Cloud (3) may not be individually measured. Emissions may be quantified by measuring total of clouds (2) and (3) and subtracting individual measurement of (2).

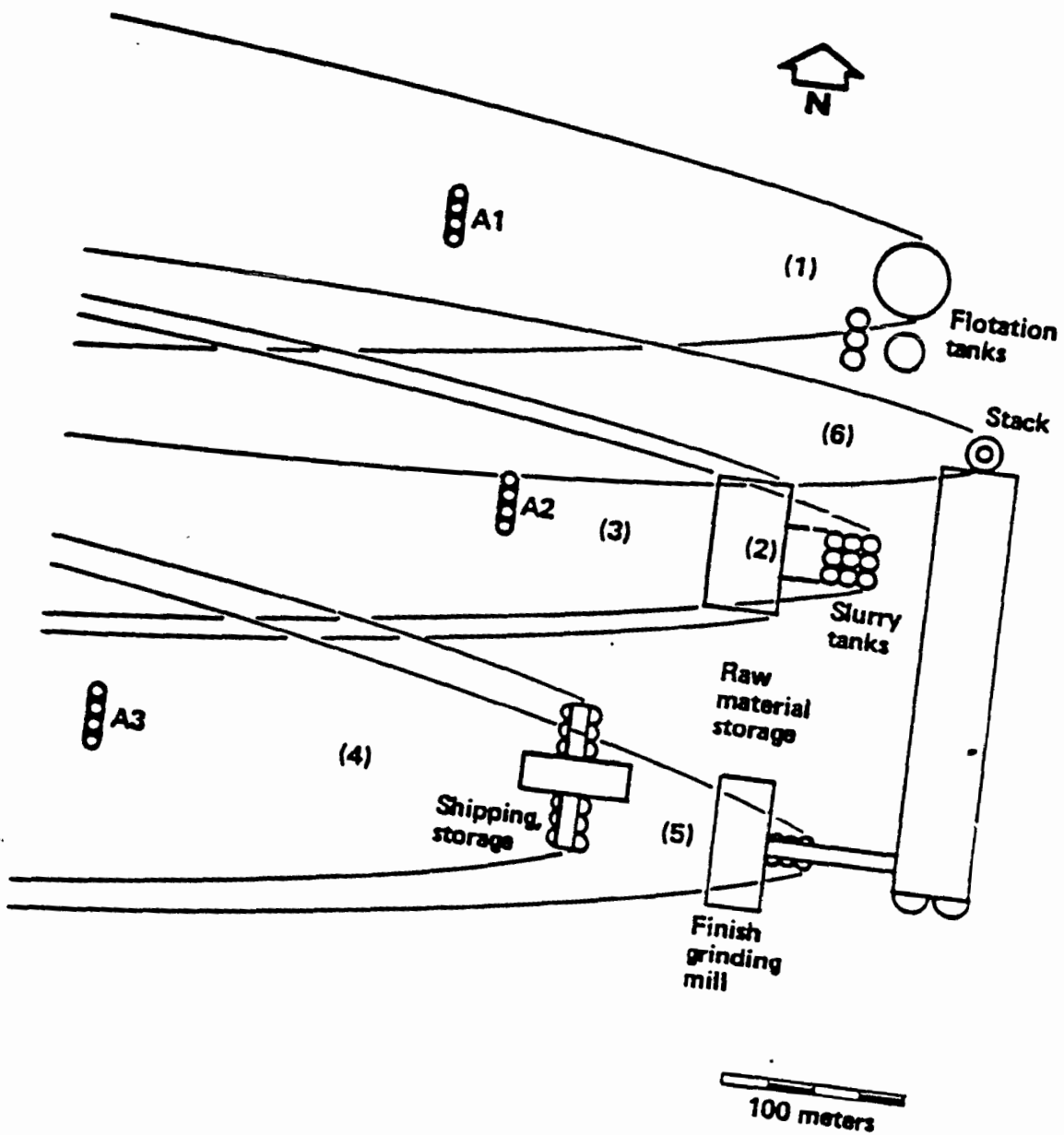


Fig. A-3. Portland cement plant separate source clouds.

Cloud (4) may not be individually measured. Emissions may be quantified by measuring total of clouds (4) and (5) and subtracting individual measurement of (2).

Cloud (5) may be individually measured when packing and shipping operations are shut down.

Cloud (6) emissions may be measured by stack sampling at any time.

Cloud (7) emissions may not be individually measured. Their low level background contribution is present in all clouds measured except (1).

To measure the source strengths associated with clouds (1) through (5), a network of individual arrays may be set up as follows:

Array [1] - in cloud (1)

Array [2] - in combined clouds (2) and (3)

Array [3] - in combined clouds (5) and (6)

Samples taken during first shift operations using all three arrays will provide measurements of the particulate concentrations in cloud (1), the combined concentrations of clouds (2) and (3) and the combined concentrations of clouds (4) and (5). Samples should be taken during materials unloading operations to provide measurements of the maximum concentrations of cloud (3) and during maximum activity level in the shipping area to provide measurements of the maximum concentrations of cloud (4).

Samples taken during second or third shift operations using arrays [2] and [3] will provide measurements of the particulate concentrations of clouds (2) and (5).

Stack samples may be taken at any convenient time.

Analyses of the samples will provide particulate concentrations at

the array locations for each source, which may then be back-calculated to provide equivalent source strengths, which, with appropriate subtractions described above, will give individual source strengths.

The flotation tanks are located very nearly at ground level and may reasonably be considered a ground level source. Array [1] may therefore be composed of only ground level samplers located across the cloud (1) generated by these tanks.

Raw material storage generates a ground level source cloud (3), while the ball mills and the slurry tanks generate an elevated cloud (2). The array [2] used to sample these clouds must then employ both ground level and elevated samplers located across the portion of the cloud combining the emissions of both sources.

Packing and shipping operations generate a cloud (4) of both ground level and elevated emissions, as do the finish grinding mill and clinker storage in cloud (5). Array [3] must then be composed of ground level and elevated samplers located across the portion of the cloud combining the emissions of both clouds.

Assumptions as to the approximate source strengths for each of the sources are made to provide the starting points for determining array locations and spacing. Based on the 40 pound per hour rate for the total emissions indicated by the survey measurements, a source strength of eight pounds per hour is assigned to each of the sources of clouds (2) through (5), and four pounds per hour for the sources of clouds (1) and (7). The conditions of the survey example of Section A.4.1; with a 10 mile per hour wind from the east, an atmospheric stability category B, a desired sample weight of 100 micrograms and a 60 minute sampling

time are assumed to apply to the detailed system.

The best locations for the arrays, each within the clouds they are designed to measure and away from the influences of other clouds, are shown at A1, A2 and A3 on Figure A-3.

For array [1], located about 250 meters downwind of the source of cloud (1) in order to avoid the influence of neighboring clouds, the approximate particle concentration on the wind direction axis at ground level is determined from Equation 3-2, rearranged as

$$\chi = Q/\pi Ku, \text{ where}$$

$$\begin{aligned}\chi &= \text{concentration (gm/m}^3\text{)} \\ Q &= \text{source strength} = 4 \text{ (lbs/hr)} = 0.5 \text{ (gm/sec)} \\ K &= 110 \text{ (m}^2\text{)} - \text{from Figure 3-7} \\ u &= 4.47 \text{ (m/sec), and}\end{aligned}$$

$$\chi = 3.2 \times 10^{-5} \text{ (gm/m}^3\text{)}$$

The required sampler flow rate is determined from Equation 3-1, rearranged as

$$F = M/\chi T, \text{ where}$$

$$\begin{aligned}F &= \text{flow rate (m}^3\text{/min)} \\ M &= \text{sample weight} = 10^{-4} \text{ (gm)} \\ \chi &= 3.2 \times 10^{-5} \text{ (gm/m}^3\text{)} \\ T &= \text{sampling time} = 60 \text{ (min), and}\end{aligned}$$

$$F = 5.2 \times 10^{-2} \text{ (m}^3\text{/min)}$$

The cross-wind spacing of the samplers in the array is determined by assigning a particle concentration desired to be measured at a sampler location of about 1/2 the concentration at the wind direc-

tion axis, or, $\chi = 1.6 \times 10^5$ (gm/m³), and calculating its ratio calculated concentration on the wind direction axis, χ_0 . In this $\chi/\chi_0 = 0.5$. Figure 3-4 indicates a value of 0.91 for the cross-wind distance ratio y/y_m , in which y is the desired cross-wind sampler distance and y_m is the maximum cross-wind distance determined from Figure 3-3. In this case, y_m for $x = 250$ meters and category B is 68 meters and $y = 62$ meters.

Array [1], then, would consist of three ground level samplers located 250 meters downwind of the flotation tanks with the central sampler on the wind axis and two samplers 62 meters away, one in each of the two cross-wind directions. This array will provide measurement of at least two particle concentrations within the cloud for use in the back calculation of the source strength at the flotation tanks.

Similar computations may be made for each of the other arrays, with the addition of a vertical spacing determination using Figures 3-5 and 3-6 in the same manner as Figures 3-3 and 3-4 for the determination of cross-wind spacing.

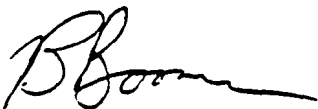
Appendix H

PREFACE

This report was prepared as part of Work Assignment No. II-44 of EPA Contract No. 68-DO-0123 as an example test protocol for line sources of fugitive emissions. Mr. Dennis Shipman of the EPA's Emission Inventory Branch served as the EPA technical monitor. Dr. Gregory E. Muleski served as Midwest Research Institute's (MRI's) project leader. Mr. Gary Garman and Dr. Muleski prepared this report.

Approved for:

MIDWEST RESEARCH INSTITUTE



For Richard V. Crume
Program Manager
Environmental Engineering Department



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April 28, 1993

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SECTION 1

INTRODUCTION

This report outlines the test plan to be followed during a field sampling program to determine fugitive emissions from a uniformly emitting line source. Sources of this type include (for example) off-highway vehicles, general earthmoving, and travel emissions at logging and associated industrial facilities. The report describes the sampling methodology, data analysis, and quality assurance procedures to be followed in the field study. The primary pollutant of concern is particulate matter (PM), especially PM no greater than 10 μm in aerodynamic diameter (PM_{10}). However, the basic sampling strategy and data analysis are equally applicable to other types of pollutants that might be emitted from the same types of sources.

The basic field sampling methodology uses the concept of "exposure profiling"¹ developed by MRI. The exposure profiling method calculates emission rates using a conservation of mass approach. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by the spatial integration of exposure (mass/area) measurements distributed over the effective cross section of the plume. Note that for a uniform line or "moving point" source such as an unpaved road, only a vertically distributed sampling array is required to characterize the plume's effective cross section.^{1,2} A companion report describes procedures to be followed to sample other types of fugitive sources.³

The remainder of this report provides a "skeleton" test protocol in that issues are discussed in general terms but can be readily expanded once a specific source and site have been selected for testing. Section 2 discusses quality assurance considerations, and Section 3 outlines the general sampling and analysis procedures to be followed. Section 4 describes an example test schedule.

SECTION 2

QUALITY ASSURANCE

The sampling and analysis procedures to be followed in this field testing program are subject to certain quality control (QC) guidelines. These guidelines will be discussed in conjunction with the activities to which they apply. These procedures meet or exceed the requirements specified in the reports entitled *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II—Ambient Air Specific Methods* (EPA 600/4-77-027a) and *Ambient Monitoring Guidelines for Prevention of Significant Deterioration* (EPA 4350/2-78-019).

As part of the QC program for this study, routine audits of sampling and analysis procedures will be performed. The purpose of the audits is to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items to be audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially-designed reporting forms for sampling and analysis of data obtained in the field and laboratory aids in the auditing procedure. Further details on specific sampling and analysis procedures are provided in the following section.

SECTION 3

SAMPLING AND ANALYSIS PROCEDURES

This section describes the general methodology used to characterize particulate emissions from uniformly emitting line sources.

GENERAL AIR SAMPLING EQUIPMENT AND TECHNIQUES

Exposure profiling, which is the primary air sampling technique in this study, is based on simultaneous multipoint sampling over the effective cross section of the open dust source plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model (as in the so-called "upwind/downwind" method).

The equipment deployment for a typical test is shown in Figure 1 and Table 1. The primary air sampling device in this example test plan is a standard high-volume air sampler fitted with a cyclone preseparator (Figure 2). The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 microns (μm) in aerodynamic diameter when operated at a flow rate of 40 cfm ($68 \text{ m}^3/\text{h}$).⁴

Besides the samplers fitted with the cyclone preseparator to sample PM_{10} emissions, two other types of samplers are used in the upwind and downwind arrays. Standard hi-vols are placed at two heights near one of the downwind arrays to sample TSP (total suspended particulate) emissions.

PM_{10} reference method samplers (Wedding and Associates' PM_{10} Critical Flow High-Volume Samplers) are also used, with one located alongside the upwind array and another next to a downwind array.

Throughout each test, wind speed is monitored at the downwind sampling site by directional warm wire anemometers (Kurz Model 465) at three heights. Horizontal wind direction is monitored by a wind vane at a single height. Wind speed and direction are scanned using a data logger, with 5-min averages stored in a computer file. The vertical profile of horizontal wind speed is determined by fitting the measurements to a logarithmic profile. The sampling intakes are adjusted for proper directional orientation based on the monitored average wind direction.

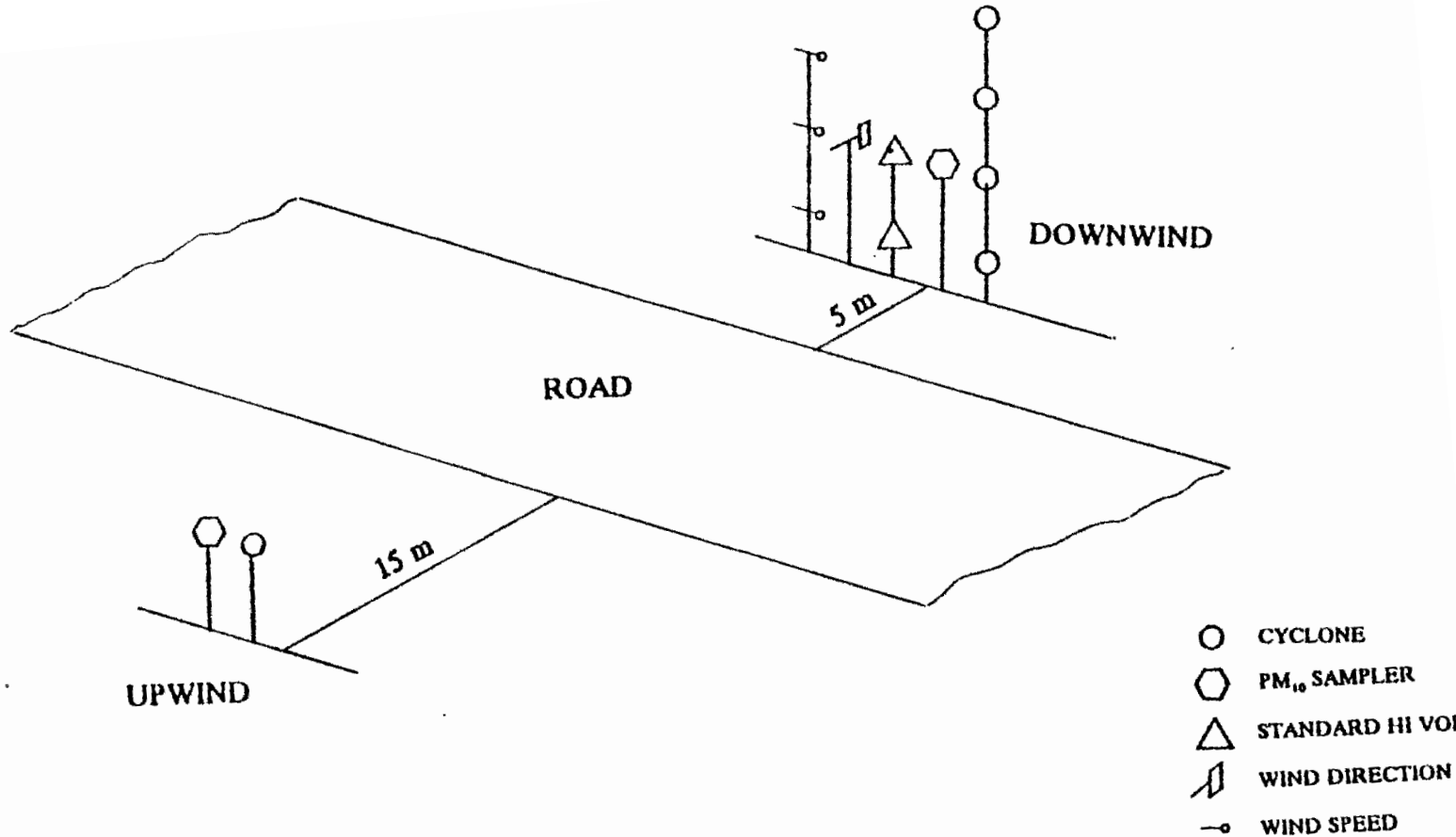


Figure 1. Sampler deployment.

TABLE 1. SAMPLER DEPLOYMENT

Upwind/ downwind	No. of instruments	Measurement height(s) ^a (m)	Type of sampler or instrument	Parameter measured
U	1	2	Cyclone	PM ₁₀
U	1	2	Wedding PM ₁₀ Sampler	PM ₁₀
D	4 per array	1.5, 3, 4.5, 6	Cyclone	PM ₁₀
D	2	1.5, 3	Hi-Vol	TSP
D	1	3	Wedding PM ₁₀ Sampler	PM ₁₀
D	1	3	Wind vane	Wind direction
D	3	1, 3, 5	Warm wire anemometer	Wind velocity

^a Selection of sampling heights depends upon various factors, including roadway width, travel speeds, range of wind speeds expected, etc. Values listed in the table represent heights commonly used.

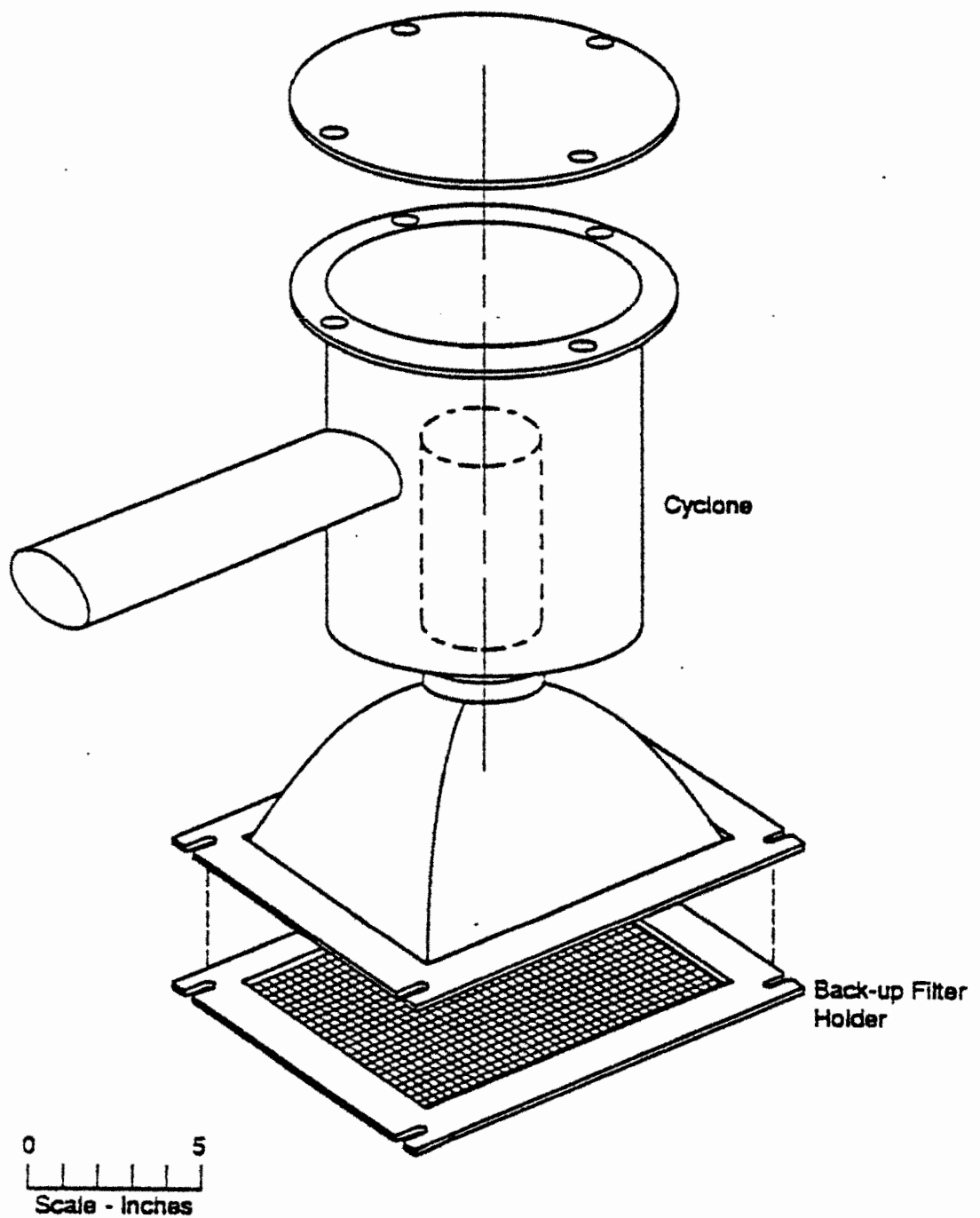


Figure 2. Cyclone preseparator.

For each source selected for testing, triplicate tests are recommended to quantify emissions under three different average travel speeds (spanning the range of common speeds on the road). Note that:

- "Captive" traffic is recommended in order to maintain constant average vehicle characteristics during the testing periods.
- The roads are tested in the "uncontrolled" condition.
- The primary pollutant of concern during the field exercise is particulate matter no greater than 10 μm in aerodynamic diameter (PM_{10}). However, at each test site, at least one set of total suspended particulate (TSP) emission measurements (using standard high-volume [hi-vol] air samplers) will be taken.

Each field testing program should begin with a visit to the candidate test site(s). Upon return, a site-specific test protocol is developed, which describes sampler deployment and spacing, test schedule, and any special provisions.

EMISSION TESTING PROCEDURE

Preparation of Sample Collection Media

Particulate samples are collected on glass fiber filters, with the exception of the PM_{10} reference samplers which require quartz filters. Prior to the initial weighing, the filters will be equilibrated for 24 h at constant temperature and humidity in a special weighing room. During weighing, the balance is checked at frequent intervals with standard (Class S) weights to ensure accuracy. The filters will remain in the same controlled environment for another 24 h, after which a second analyst reweighs them as a precision check. If a filter cannot pass audit limits, the entire lot is to be reweighed. Ten percent of the filters taken to the field are used as blanks. The quality assurance guidelines pertaining to preparation of sample collection media are presented in Table 2.

TABLE 2. QUALITY ASSURANCE PROCEDURES FOR SAMPLING MEDIA

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 h in a clean controlled room with relative humidity of 45% (variation of less than $\pm 5\%$ RH) and with temperature of 23°C (variation of less than $\pm 1^\circ\text{C}$).
Weighing	Weigh hi-vol filters to nearest 0.1 mg.
Auditing of weights	Independently verify final weights of 10% of filters (at least four from each batch). Reweigh batch if weights of any hi-vol filters deviate by more than ± 2.0 mg. For tare weights, conduct a 100% audit. Reweigh tare weight of any filters that deviate by more than ± 1.0 mg.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type for each test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

Pretest Procedures/Evaluation of Sampling Conditions

Prior to equipment deployment, a number of decisions are to be made as to the potential for acceptable source testing conditions. These decisions shall be based on forecast information obtained from the local U.S. Weather Service office. If conditions are considered acceptable, the sampling equipment deployment is initiated. At this time the sampling flow rates will be set for the various air sampling instruments. The quality control guidelines governing this activity are found in Table 3.

TABLE 3. QUALITY ASSURANCE PROCEDURES FOR SAMPLING FLOW RATES

Activity	QA check/requirement
<ul style="list-style-type: none"> High volume air samplers 	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter at each regional site prior to testing.
<ul style="list-style-type: none"> Orifice and electronic calibrator 	Calibrate against displaced volume test meter annually.

Once the source testing equipment is set up and the filters inserted, air sampling commences. Information is recorded on specially designed reporting forms and includes:

- a. Air samples—Start/stop times, wind speed profiles, flow rates, and wind direction relative to the roadway perpendicular (5- to 15-min average). See Table 4 for QA procedures.
- b. Traffic count by vehicle type and speed.
- c. General meteorology—Wind speed, wind direction, and temperature.

Sampling time must be long enough to provide sufficient particulate mass and to average over several cycles of the fluctuation in the emission rate (i.e., vehicle passes on the road). Occasionally sampling may be interrupted because of the occurrence of unacceptable meteorological conditions and then restarted when suitable conditions return. Table 5 presents the criteria used for suspending or terminating a source test.

Sample Handling and Analysis

To prevent particulate losses, the exposed media are carefully transferred at the end of each run to protective containers for transportation. In the field laboratory, exposed filters are placed in individual glassine envelopes and then into numbered file folders. When exposed filters and the associated blanks are returned to the MRI laboratory, they are equilibrated under the same conditions as the initial weighing. After reweighing, 10% of the filters are audited to check weighing accuracy.

TABLE 4. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA check/requirement ^a
Maintenance	
• All samplers	Check motors, gaskets, timers, and flow measuring devices at each plant prior to testing.
Operation	
• Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. This technique allocates no nozzle for wind speeds ranging from 0 to 10 mph, and unique nozzles for four wind speed ranges above 10 mph.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

^a All "means" refer to 5- to 15-min averages.

TABLE 5. CRITERIA FOR SUSPENDING OR TERMINATING A TEST

A test may be suspended or terminated if:^a

1. Rainfall ensues during equipment setup or when sampling is in progress.
2. Mean wind speed during sampling moves outside the 0.9- to 8.9 m/sec (2- to 20-mph) acceptable range for more than 20% of the sampling time.
3. The angle between mean wind direction and perpendicular to the path of the moving point source during sampling exceeds 45 degrees for two consecutive averaging periods.
4. Daylight or available artificial lighting is insufficient for safe equipment operation.
5. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill or accidental water splashing prior to uncontrolled testing).

^a "Mean" denotes a 5- to 15-min average.

EMISSION FACTOR CALCULATION PROCEDURES

To calculate emission rates, a conservation of mass approach is used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure for uniformly emitting line sources are described below.

Particulate Concentrations

The concentration of particulate matter measured by a sampler is given by:

$$C = 10^3 \frac{m}{Qt}$$

where: C = particulate concentration ($\mu\text{g}/\text{m}^3$)
m = particulate sample weight (mg)
Q = sampler flow rate (m^3/min)
t = duration of sampling (min)

To be consistent with the National Ambient Air Quality Standards, all concentrations and flow rates are expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 inHg).

The isokinetic flow ratio (IFR) is the ratio of a directional sampler's intake air speed to the mean wind speed approaching the sampler. It is given by:

$$\text{IFR} = \frac{Q}{aU}$$

where: Q = sampler flow rate (m^3/min)
a = intake area of sampler (m^2)
U = mean wind speed at height of sampler (m/min)

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. Note, however, that because the primary interest in this program is directed to PM_{10} emissions, sampling under moderately nonisokinetic conditions poses no difficulty. It is readily agreed that $10 \mu\text{m}$ (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.⁵

Exposure represents the net passage of mass through a unit area normal to the direction of plume transport (wind direction) and is calculated by:

$$E = 10^{-7} \times C U t$$

where: E = particulate exposure (mg/cm²)
C = net concentration (μg/m³)
U = approaching wind speed (m/s)
t = duration of sampling (s)

Exposure values vary over the spatial extent of the plume. If exposure is integrated over the plume effective cross section, then the quantity obtained represents the total passage of airborne particulate matter due to the source.

For a line source, a one-dimensional integration is used:

$$A1 = \int_0^H E \, dh$$

where: A1 = integrated exposure (m-mg/cm²)
E = particulate exposure (mg/cm²)
h = vertical distance coordinate (m)
H = effective extent of plume above ground (m)

The effective height of the plume is found by linear extrapolation of the uppermost net concentrations to a value of zero.

Because exposures are measured at discrete heights of the plume, a numerical integration is necessary to determine A1. The exposure must equal zero at the vertical extremes of the profile (i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentration equals zero). However, the maximum exposure usually occurs below a height of 1 m, so that there is a sharp decay in exposure near the ground. To account for this sharp decay, the value of exposure at the ground level is set equal to the value at a height of 1 m. The integration is then performed numerically.

Particulate Emission Factors

The emission factor for particulate generated by vehicular traffic on a straight road segment expressed in grams of emissions per vehicle-kilometer traveled (VKT) is given by:

$$e = 10^4 \frac{A1}{N}$$

where: e = particulate emission factor (g/VKT)
 A1 = integrated exposure (m-mg/cm²)
 N = number of vehicle passes (dimensionless)

SURFACE MATERIAL SAMPLES

Associated with each test site is a series of at least three samples of the surface material. The collection and analysis of these samples are important because the available emission factor and control performance models often make use of material parameters. Samples are to be analyzed (at a minimum) for silt (particles passing a 200-mesh screen) and moisture contents and to determine surface loading values. Detailed steps for collection and analysis of samples for silt and moisture are given in the Appendix. An abbreviated discussion is presented below.

Unpaved line source dust samples are to be collected by sweeping the loose layer of soil or crushed rock from the hardpan road base with a broom and dust pan. Sweeping is performed so that the road base is not abraded by the broom, and so that only the naturally occurring loose dust is collected. The sweeping will be performed slowly so that dust is not entrained into the atmosphere.

Once the field sample is obtained, it will be prepared for analysis. If necessary, the field sample will be split with a riffle to a sample size amenable to laboratory analysis. The basic procedure for moisture analysis is determination of weight loss on oven drying. Silt analysis procedures follow the ASTM-C-136 method. The Appendix details these procedures.

1

SECTION 4

TESTING SCHEDULE

The following describes a typical schedule of field activities involving captive traffic on a line source, starting with the arrival of the crew at each test site:

1. Unpack the transport truck and arrange field laboratory facilities. Provide at least 1 h of captive traffic prior to the start of air testing.
2. Erect the upwind and downwind sampling arrays.
3. Calibrate each sampler to the required volumetric flow rate (40 cfm for the cyclone preseparators described in Section 3).
4. Providing captive traffic at a constant vehicle speed, conduct air sampling following the procedures described in Section 3. At the end of this test period:
 - Cover sampler inlets.
 - Discontinue the captive traffic.
 - Remove and store the sampling media from the downwind samplers as specified in Section 3.
 - Repeat the sampling procedure so that three tests are conducted for the current vehicle speed.
 - Collect a road surface material sample following the procedures given in Section 3.
5. Repeat Step 4 until all three vehicle speeds of interest have been considered.
6. Pack equipment for transport to the next regional test site or for return to the main laboratories.

SECTION 5

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APPENDIX
MATERIAL SAMPLING AND ANALYSIS PROCEDURES

SAMPLES FROM UNPAVED ROADS

PROCEDURE

The following steps describe the collection method for samples (increments).

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one person to "spot" and route traffic safely around another person collecting the surface sample (increment).
2. Using string or other suitable markers, mark a 1 ft (0.3 m) width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.)
3. With a whisk broom and dustpan, remove the loose surface material from the hard road base. Do not abrade the base during sweeping. Sweeping should be performed slowly so that fine surface material is not injected into the air. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline).
4. Periodically deposit the swept material into a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Increments may be mixed within this container.
5. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

For uncontrolled unpaved road surfaces, a gross sample of 10 lb (5 kg) to 50 lb (23 kg) is desired. Samples of this size will require splitting to a size amenable for analysis. For unpaved roads that have been treated with chemical dust suppressants (such as petroleum resins, asphalt emulsions, etc.), the above goal may not be practical in well-defined study areas because a very large area would need to be swept. In general, a minimum of 1 lb (400 g) is required for silt and moisture analysis. Additional increments should be taken from heavily controlled unpaved surfaces, until the minimum sample mass has been achieved.

SAMPLES FROM PAVED ROADS

The following steps describe the collection method for samples (increments).

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one crew member to "spot" and route traffic safely around another person collecting the surface sample (increment).
2. Using string or other suitable markers, mark the sampling width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.) The widths may be varied between 0.3 m (1 ft) for visibly dirty roads and 3 m (10 ft) for clean roads. When using an industrial-type vacuum to sample lightly loaded roads, a width greater than 3 m (10 ft) may be necessary to meet sample specifications unless increments are being combined.
3. If large, loose material is present on the surface, it should be collected with a whisk broom and dustpan. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line." Store the swept material in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Increments for the same sample may be mixed within the container.
4. Vacuum sweep the collection area using a portable vacuum cleaner fitted with a tared filter bag. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line." The same filter bag may be used for different increments for one sample. For heavily loaded roads, more than one filter bag may be required for a sample (increment).
5. Carefully remove the bag from the vacuum sweeper and check for tears or leaks. If necessary, reduce samples from broom sweeping to a size amenable for analysis. Seal broom swept material in a clean, labeled plastic jar for transport (alternatively, the swept material may be placed in the vacuum filter bag). Fold the unused portion of the filter bag, wrap a rubber band around the folded bag, and store the bag for transport.
6. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

Broom swept samples (if collected) should be at least 400 g (1 lb) for silt and moisture analysis. The vacuum swept sample should be at least 200 g (0.5 lb); in addition, the exposed filter bag weight should be at least 5 to 10 times greater than the empty bag tare weight. Additional increments should be taken until these sample mass goals have been achieved.

SAMPLES FROM STORAGE PILES

The following steps describe the method for collecting samples from storage piles:

1. Sketch plan and elevation views of the pile. Indicate if any portion is inaccessible. Use the sketch to plan where the N increments will be taken by dividing the perimeter into N-1 roughly equivalent segments.
 - a. For a large pile, collect a minimum of 10 increments should as near to the mid-height of the pile as practical.
 - b. For a small pile, a sample should consist of a minimum of 6 increments evenly distributed among the top, middle, and bottom.

"Small" or "large" piles, for practical purposes, may be defined as those piles which can or cannot, respectively, be scaled by a person carrying a shovel and pail.

2. Collect material with a straight-point shovel or a small garden spade and store the increments in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Depending upon the ultimate goals of the sampling program, choose one of the following procedures:
 - a. To characterize emissions from material handling operations at an active pile, take increments from the portions of the pile which most recently had material added and removed. Collect the material with a shovel to a depth of 10 to 15 cm (4 to 6 inches). Do not deliberately avoid collecting larger pieces of aggregate present on the surface.
 - b. To characterize handling emissions from an inactive pile, obtain increments of the core material from a 1 m (3 ft) depth in the pile. A 2 m (6 ft) long sampling tube with a diameter at least 10 times the diameter of the largest particle being sampled is recommended for these samples. Note that, for piles containing large particles, the diameter recommendation may be impractical.
 - c. If characterization of wind erosion (rather than material handling) is the goal of the sampling program, collect the increments by skimming the surface in an upwards direction. The depth of the sample should be 2.5 cm (1 inch) or the the diameter of the largest particle, whichever is less. Do no deliberately avoid collecting larger pieces of aggregate present on the surface.

In most instances, collection method (a) should be selected.

3. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

For any of the procedures, the sample mass collected should be at least 5 kg (10 lb). When most materials are sampled with procedures 2.a or 2.b, ten increments normally result in a sample of at least 23 kg (50 lb). Note that storage pile samples usually require splitting to a size more amenable to laboratory analysis.

MOISTURE CONTENT DETERMINATION

1. Preheat the oven to approximately 110°C (230°F). Record oven temperature.
2. Tare the laboratory sample containers which will be placed in the oven. Tare the containers with the lids on if they have lids. Record the tare weight(s). Check zero before weighing.
3. Record the make, capacity, smallest division, and accuracy of the scale.
4. Weigh the laboratory sample in the container(s). Record the combined weight(s). Check zero before weighing.
5. Place sample in oven and dry overnight.^a
6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero before weighing.
7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.
8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

^a Dry materials composed of hydrated minerals or organic materials like coal and certain soils for only 1-1/2 hr. Because of this short drying time, material dried for only 1-1/2 hr must not be more than 2.5 cm (1 in.) deep in the container.

SILT CONTENT DETERMINATION

1. Select the appropriate 8-in. diameter, 2-in. deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8-in. No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particular sieve during sieving indicates that an intermediate sieve should be inserted.
2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap (without the tapping function).
3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.
4. Obtain a scale (capacity of at least 1,600 g) and record make, capacity, smallest division, date of last calibration, and accuracy.
5. Tare sieves and pan. Check the zero before every weighing. Record weights.
6. After nesting the sieves in decreasing order with the pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. The sample should weigh between 400 and 1,600 g (~ 0.9 to 3.5 lb).^a Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.
7. Place nested sieves into the mechanical device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10-min intervals until the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%. Do not sieve longer than 40 min.
8. Weigh each sieve and its contents and record the weight. Check the zero before every weighing.
9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.
10. Calculate the percent of mass less than the 200 mesh screen (75 μ m). This is the silt content.

^a This amount will vary for fine textured materials; 100 to 300 g may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve.

Appendix I

MRI REPORT

Example Test Plan for Point or Non-Uniform Line Sources

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

Attn: Mr. Dennis Shipman

EPA Contract No. 68-DO-0123
Work Assignment No. II-44
MRI Project No. 9712-M(44)

April 28, 1993

PREFACE

This report was prepared as part of Work Assignment No. II-44 of EPA Contract No. 68-DO-0123 as an example test protocol for point or non-uniform line sources of fugitive emissions. Mr. Dennis Shipman of the EPA's Emission Inventory Branch served as the EPA technical monitor. Dr. Gregory E. Muleski served as Midwest Research Institute's (MRI's) project leader. Mr. Gary Garman and Dr. Muleski prepared this report.

Approved for:

MIDWEST RESEARCH INSTITUTE



For Richard V. Crume
Program Manager
Environmental Engineering Department



Charles F. Holt, Ph.D., Director
Engineering and Environmental
Technology Department

April 28, 1993

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SECTION 1

INTRODUCTION

This report outlines the test plan to be followed during a field sampling program to determine particulate emissions from a point source, such as a batch material handling operation or a non-uniformly emitting line source, such as mud/dirt track-out onto paved roads. The report describes the sampling methodology, data analysis, and quality assurance procedures to be followed in the field study. The primary pollutant of concern is particulate matter (PM), especially PM no greater than 10 μm in aerodynamic diameter (PM_{10}). However, the basic sampling strategy and data analysis are equally applicable to other types of pollutants that might be emitted from the same types of sources.

The basic field sampling methodology uses the concept of "exposure profiling" developed by MRI.¹ The exposure profiling method calculates emission rates using a conservation of mass approach. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by the spatial integration of exposure (mass/area) measurements distributed over the effective cross section of the plume. Note that for a point source such as a material handling operation, a two-dimensional sampling array is required to characterize the plume's effective cross section. For a non-uniformly emitting line source, it is necessary to characterize emissions along the line. This, of course, also requires a two-dimensional sampling array. A companion report² describes sampling protocol for uniformly emitting line sources, which may be characterized using a one-dimensional vertical sampling array.

The remainder of this report provides a "skeleton" test protocol in that issues are discussed in general terms but can be readily expanded once a specific source and site have been selected for testing. Section 2 discusses quality assurance considerations, and Section 3 outlines the general sampling and analysis procedures to be followed. Section 4 describes an example test schedule.

SECTION 2

QUALITY ASSURANCE

The sampling and analysis procedures to be followed in this field testing program are subject to certain quality control (QC) guidelines. These guidelines will be discussed in conjunction with the activities to which they apply. These procedures meet or exceed the requirements specified in the reports entitled *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II—Ambient Air Specific Methods* (EPA 600/4-77-027a), and *Ambient Monitoring Guidelines for Prevention of Significant Deterioration* (EPA 4350/2-78-019).

As part of the QC program for this study, routine audits of sampling and analysis procedures will be performed. The purpose of the audits is to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items to be audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially-designed reporting forms for sampling and analysis of data obtained in the field and laboratory aids in the auditing procedure. Further details on specific sampling and analysis procedures are provided in the following section.

SECTION 3

SAMPLING AND ANALYSIS PROCEDURES

This section describes the general methodology used to characterize emissions from point or non-uniform line sources.

GENERAL AIR SAMPLING EQUIPMENT AND TECHNIQUES

Exposure profiling, which is the primary air sampling technique in this study, is based on simultaneous multipoint sampling over the effective cross section of the open dust source plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model (as in the so-called "upwind/downwind" method).

Example equipment deployments are shown in Figures 1 and 2 for a point source and a non-uniform line source, respectively. The exact spacing of samplers is highly dependent upon various factors including

- Source dimensions
- Emission release height
- Range of wind speeds expected

The primary air sampling device in this example test plan is a standard high-volume air sampler fitted with a cyclone preseparator (Figure 3). The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 microns (μm) in aerodynamic diameter when operated at a flow rate of 40 cfm ($68 \text{ m}^3/\text{h}$).³

Throughout each test, wind speed is monitored at the downwind sampling site(s) by directional warm wire anemometers (Kurz Model 465) at three heights. Horizontal wind direction is monitored by a wind vane at a single height. Wind speed and direction are scanned using a data logger, with 5-min averages stored in a computer file. The vertical profile of horizontal wind speed is determined by fitting the measurements to a logarithmic profile.

The remainder of this report provides a "skeleton" test protocol in that items are discussed in general terms but can be readily expanded once a specific source and site have been selected for testing.

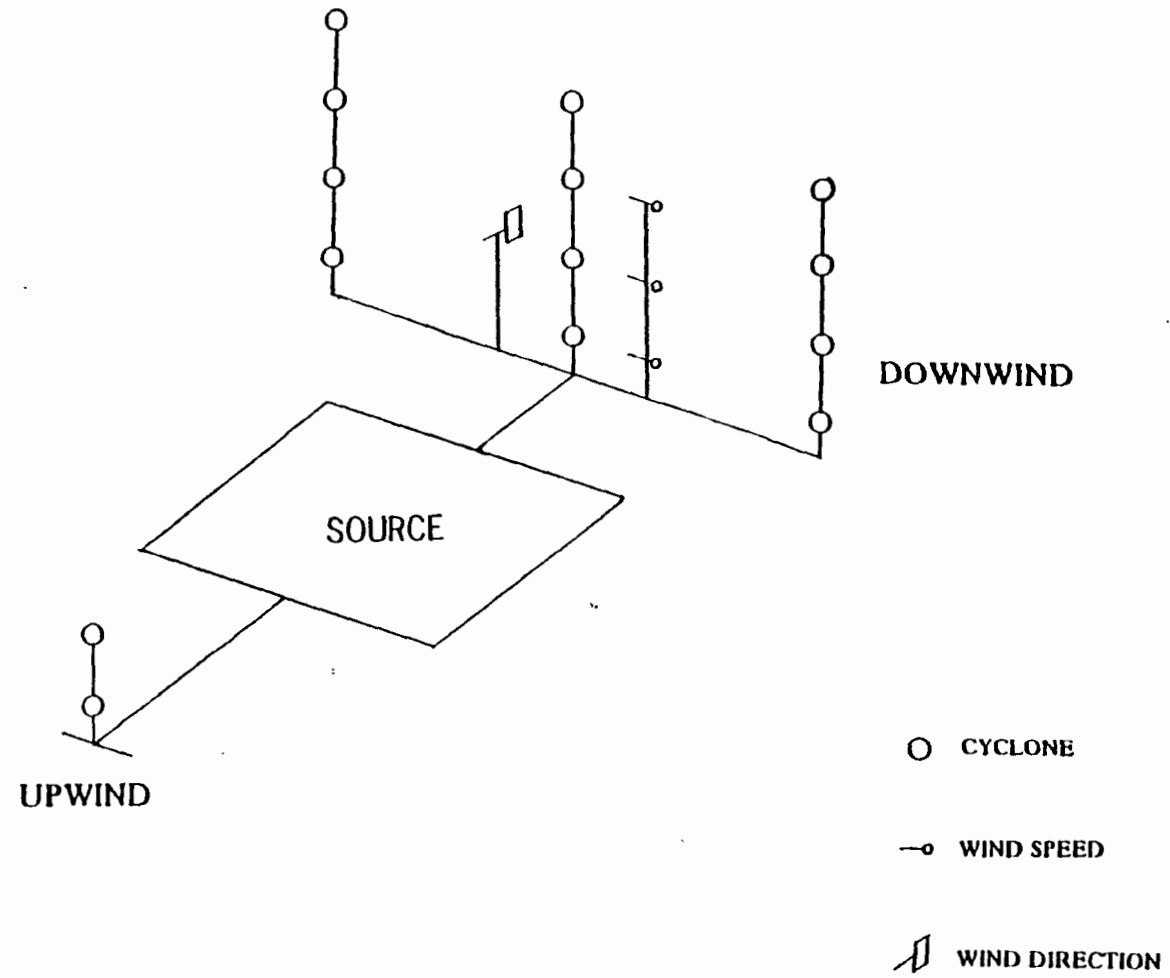


Figure 1. Example sampler deployment for a point source.

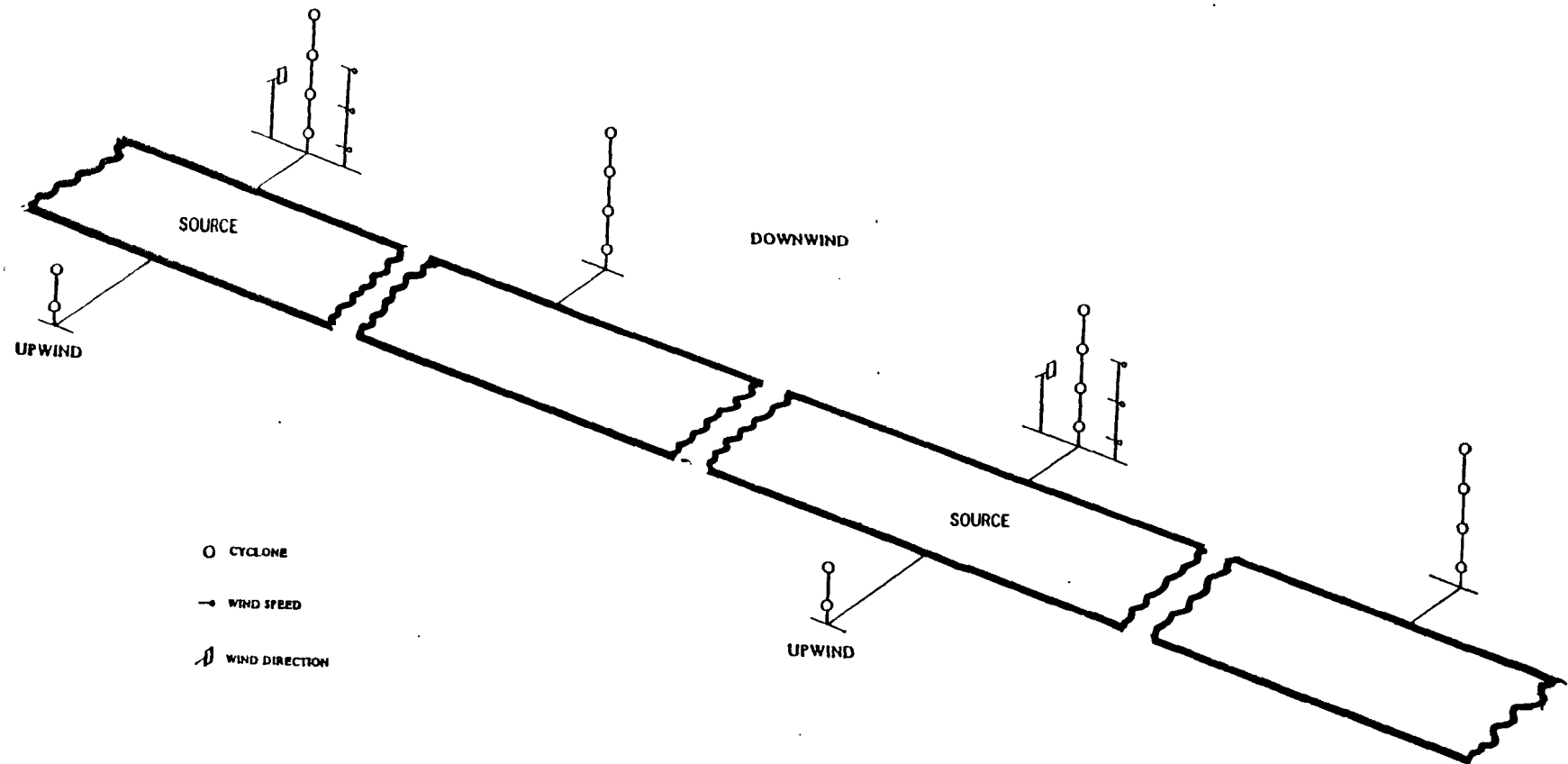


Figure 2. Example deployment for a non-uniformly emitting source.

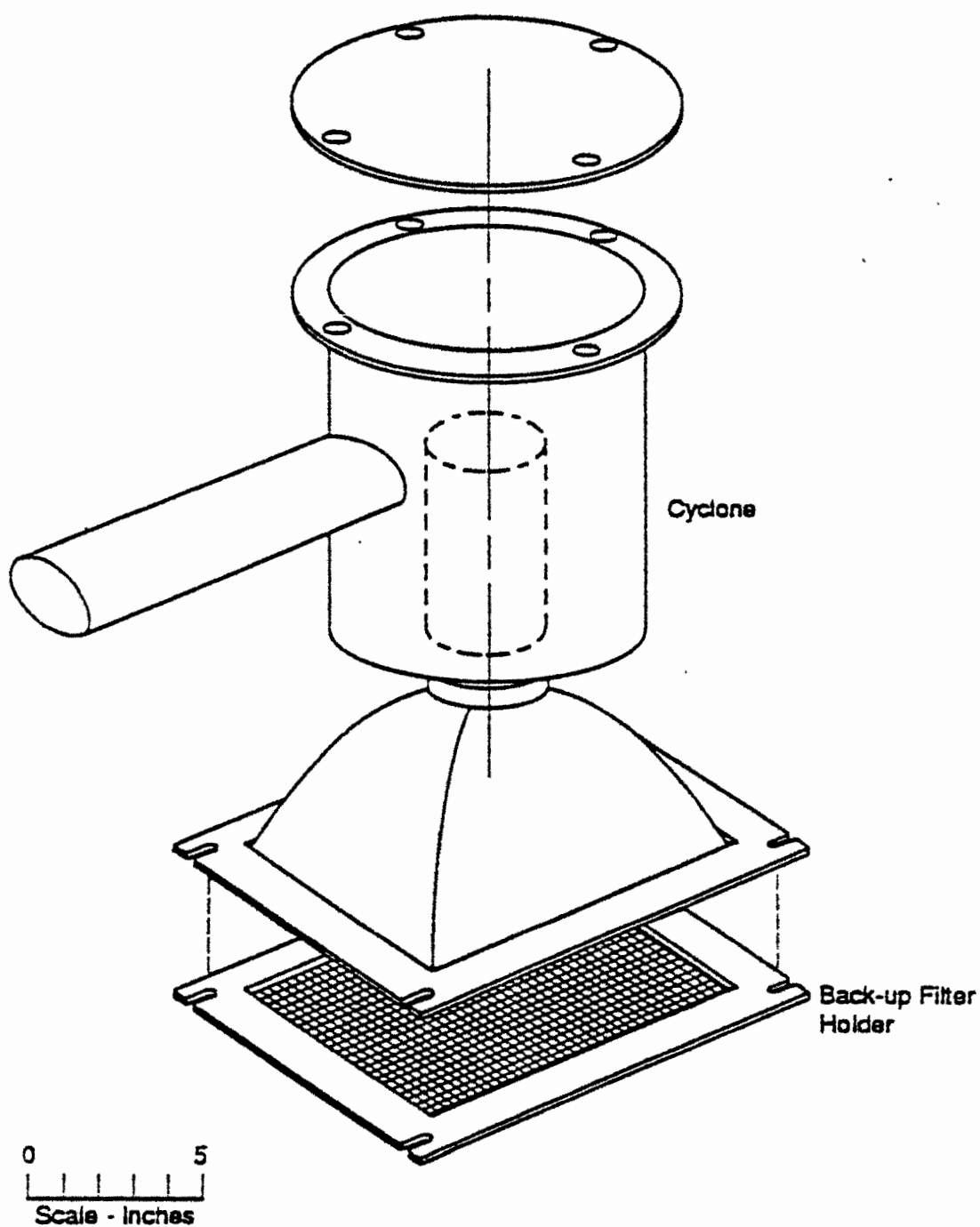


Figure 3. Cyclone preseparator.

Each field testing program should begin with a visit to the candidate test site(s). Upon return, a site-specific test protocol is developed, which describes sampler deployment and spacing, test schedule, and any special provisions, such as different source conditions (i.e., test matrix).

EMISSION TESTING PROCEDURE

Preparation of Sample Collection Media

Particulate samples are collected on glass fiber filters. Prior to the initial weighing, the filters are equilibrated for 24 h at constant temperature and humidity in a special weighing room. During weighing, the balance is checked at frequent intervals with standard (Class S) weights to ensure accuracy. The filters remain in the same controlled environment for another 24 h, after which a second analyst reweighs them as a precision check. If a filter cannot pass audit limits, the entire lot is to be reweighed. Ten percent of the filters taken to the field are used as blanks.

The quality assurance guidelines pertaining to preparation of sample collection media are presented in Table 1.

TABLE 1. QUALITY ASSURANCE PROCEDURES FOR SAMPLING MEDIA

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 h in a clean controlled room with relative humidity of 45% (variation of less than $\pm 5\%$ RH) and with temperature of 23°C (variation of less than $\pm 1^\circ\text{C}$).
Weighing	Weigh hi-vol filters to nearest 0.1 mg.
Auditing of weights	Independently verify final weights of 10% of filters (at least four from each batch). Reweigh batch if weights of any hi-vol filter deviates by more than ± 2.0 mg. For tare weights, conduct a 100% audit. Reweigh tare weight of any filter that deviates by more than ± 1.0 mg.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type for each test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

Pretest Procedures/Evaluation of Sampling Conditions

Prior to equipment deployment, a number of decisions are to be made as to the potential for acceptable source testing conditions. These decisions are based on forecast information obtained from the local U.S. Weather Service office. If conditions are considered acceptable, the sampling equipment deployment is initiated. At this time the sampling flow rates are set for the various air sampling instruments. The quality control guidelines governing this activity are found in Table 2.

TABLE 2. QUALITY ASSURANCE PROCEDURES FOR SAMPLING FLOW RATES

Activity	QA check/requirement
High volume air samplers	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter at each regional site prior to testing.
Orifice and electronic calibrator	Calibrate against displaced volume test meter annually.

Once the source testing equipment is set up and the filters inserted, air sampling commences. Information is recorded on specially-designed reporting forms and includes:

- a. Air samples—Start/stop times, wind speed profiles, flow rates, and wind direction (5- to 15-min average). See Table 3 for QA procedures.
- b. Measures of source activity—such as number of material batch drops and number of vehicles passing over a track-out site.
- c. General meteorology—Wind speed, wind direction, and temperature.

Sampling time must be long enough to provide sufficient sample and to average over several cycles of the fluctuation in the emission rate (i.e., batch drops). Occasionally sampling may be interrupted because of the occurrence of unacceptable meteorological conditions and then restarted when suitable conditions return. Table 4 presents the criteria used for suspending or terminating a source test.

TABLE 3. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA check/requirement ^a
Maintenance	
• All samplers	Check motors, gaskets, timers, and flow-measuring devices at each plant prior to testing.
Operation	
• Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. This technique allocates no nozzle for wind speeds ranging from 0 to 10 mph, and unique nozzles for four wind speed ranges above 10 mph.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

^a All "means" refer to 5- to 15-min averages.

TABLE 4. CRITERIA FOR SUSPENDING OR TERMINATING A TEST

A test may be suspended or terminated if:^a

1. Rainfall ensues during equipment setup or when sampling is in progress.
2. Mean wind speed during sampling moves outside the 0.9- to 8.9-m/sec (2- to 20-mph) acceptable range for more than 20% of the sampling time.
3. The angle between mean wind direction and perpendicular to the plane of the sampling array during sampling exceeds 45 degrees for two consecutive averaging periods.
4. Daylight or available artificial lighting is insufficient for safe equipment operation.
5. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill or accidental water splashing prior to uncontrolled testing).

^a "Mean" denotes a 5- to 15-min average.

Sample Handling and Analysis

To prevent particulate losses, the exposed media are carefully transferred at the end of each run to protective containers for transportation. In the field laboratory, exposed filters are placed in individual glassine envelopes and then into numbered file folders. When exposed filters and the associated blanks are returned to the MRI laboratory, they are equilibrated under the same conditions as the initial weighing. After reweighing, 10% of the filters are audited to check weighing accuracy.

EMISSION FACTOR CALCULATION PROCEDURES

To calculate emission rates, a conservation of mass approach is used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure for line sources are described below.

Particulate Concentrations

The concentration of particulate matter measured by a sampler is given by:

$$C = 10^3 \frac{m}{Qt}$$

where: C = particulate concentration ($\mu\text{g}/\text{m}^3$)
m = particulate sample weight (mg)
Q = sampler flow rate (m^3/min)
t = duration of sampling (min)

To be consistent with the National Ambient Air Quality Standards, all concentrations and flow rates are expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 inHg).

The isokinetic flow ratio (IFR) is the ratio of a directional sampler's intake air speed to the mean wind speed approaching the sampler. It is given by:

$$\text{IFR} = \frac{Q}{aU}$$

where: Q = sampler flow rate (m^3/min)
a = intake area of sampler (m^2)
U = mean wind speed at height of sampler (m/min)

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. Note, however, that because the primary interest in this program is directed to PM₁₀ emissions, sampling under moderately nonisokinetic conditions poses no difficulty. It is readily agreed that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.⁴

Exposure represents the net passage of mass through a unit area normal to the direction of plume transport (wind direction) and is calculated by:

$$E = 10^{-7} \times C U t$$

where: E = particulate exposure (mg/cm²)
 C = net concentration (µg/m³)
 U = approaching wind speed (m/s)
 t = duration of sampling (s)

Exposure values vary over the spatial extent of the plume. If exposure is integrated over the plume effective cross section, then the quantity obtained represents the total passage of airborne particulate matter due to the source.

For point sources, a two-dimensional integration is used:

$$A_2 = \int_{-\frac{W}{2}}^{\frac{W}{2}} \int_0^H E \, dh \, dy$$

where: A₂ = integrated mass (m²-mg/cm²)
 W = effective plume width (m)
 H = effective extent of plume above ground (m)
 E = particulate exposure (mg/cm²)
 h = vertical distance coordinate (m)
 y = horizontal crosswind coordinate (m)

An analogous expression applies to non-uniform line sources.

Particulate Emission Factors

The emission factor for particulate generated by material handling expressed in grams of emissions per megagram of material handled is found as:

$$e = 10 \frac{A2}{S}$$

where:

- e = particulate emission factor (g/Mg)
- A2 = integrated mass (m²-mg/cm²)
- S = measure of source activity appropriate for the source of interest (e.g., mass of material handled or number of vehicles traveling over a track-out surface)

SURFACE AND OTHER MATERIAL SAMPLES

A sample that is characteristic of the emitting material or surface is taken in conjunction with each test. The collection and analysis of these samples are important because the available emission factor and control performance models often make use of material parameters. Samples are to be analyzed (at a minimum) for silt (particles passing a 200-mesh screen) and moisture contents. Detailed steps for collection and analysis of samples for silt and moisture are given in the Appendix. An abbreviated discussion is presented below.

Sample collection procedures depend on the type of material under consideration. For example, mud and dirt trackout onto a paved surface is sampled by broom sweeping (if necessary) followed by vacuum cleaning of the surface. When the emission source depends upon a bulk material being handled, samples are to be composited of increments taken from the material being transferred. The Appendix presents a series of specific procedures for the collection of samples.

Once the field sample is obtained, it will be prepared for analysis. If necessary, the field sample will be split with a riffle to a sample size amenable to laboratory analysis. The basic procedure for moisture analysis is determination of weight loss on oven drying. Silt analysis procedures follow the ASTM-C-136 method. The Appendix details these procedures.

SECTION 4

TESTING SCHEDULE

The following describes a typical schedule of field activities, starting with the arrival of the crew at the test site.

1. Unpack the transport truck and arrange field laboratory facilities. Provide captive activities or monitor actual operations for at least 1 hr prior to the start of air testing.
2. Erect upwind and downwind sampling arrays.
3. Calibrate each sampler to the required volumetric flow rate (40 cfm for the cyclone preseparators described in Section 3).
4. Conduct air sampling following the procedures described in Section 3. At the end of this test period:
 - Cover sampler inlets
 - Discontinue any captive activity
 - Remove and store the sampling media from the downwind samples as specified in Section 3
 - Repeat the sampling procedure so that at least replicate tests are conducted under essentially unchanged conditions
 - Collect a surface or other material sample following the procedures given in Section 3
5. Repeat Step 4 until all elements of the test matrix have been considered.
6. Pack equipment for transport to the next regional test site or for return to the main laboratories.

SECTION 5

REFERENCES

1. Muleski, G. E. Critical Review of Open Source Particulate Emissions Measurements: Field Comparison. MRI Final Report Prepared for Southern Research Institute, MRI Project No. 7993-L(2) (August 1984).
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3. Baxter, T. E., D. D. Lane, C. Cowherd, Jr., and F. Pendleton. Calibration of a Cyclone for Monitoring Inhalable Particles. *Journal of Environmental Engineering*, 112:3 (1986).
4. Davies, C. N. The Entry of Aerosols in Sampling Heads and Tubes. *British Journal of Applied Physics*, 2:921 (1968).

APPENDIX

MATERIAL SAMPLING AND ANALYSIS PROCEDURES

SAMPLES FROM UNPAVED ROADS

PROCEDURE

The following steps describe the collection method for samples (increments).

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one person to "spot" and route traffic safely around another person collecting the surface sample (increment).
2. Using string or other suitable markers, mark a 1 ft (0.3 m) width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.)
3. With a whisk broom and dustpan, remove the loose surface material from the hard road base. Do not abrade the base during sweeping. Sweeping should be performed slowly so that fine surface material is not injected into the air. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline).
4. Periodically deposit the swept material into a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Increments may be mixed within this container.
5. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

For uncontrolled unpaved road surfaces, a gross sample of 10 lb (5 kg) to 50 lb (23 kg) is desired. Samples of this size will require splitting to a size amenable for analysis. For unpaved roads that have been treated with chemical dust suppressants (such as petroleum resins, asphalt emulsions, etc.), the above goal may not be practical in well-defined study areas because a very large area would need to be swept. In general, a minimum of 1 lb (400 g) is required for silt and moisture analysis. Additional increments should be taken from heavily controlled unpaved surfaces, until the minimum sample mass has been achieved.

SAMPLES FROM PAVED ROADS

The following steps describe the collection method for samples (increments).

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one crew member to "spot" and route traffic safely around another person collecting the surface sample (increment).
2. Using string or other suitable markers, mark the sampling width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.) The widths may be varied between 0.3 m (1 ft) for visibly dirty roads and 3 m (10 ft) for clean roads. When using an industrial-type vacuum to sample lightly loaded roads, a width greater than 3 m (10 ft) may be necessary to meet sample specifications unless increments are being combined.
3. If large, loose material is present on the surface, it should be collected with a whisk broom and dustpan. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line." Store the swept material in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Increments for the same sample may be mixed within the container.
4. Vacuum sweep the collection area using a portable vacuum cleaner fitted with a tared filter bag. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line." The same filter bag may be used for different increments for one sample. For heavily loaded roads, more than one filter bag may be required for a sample (increment).
5. Carefully remove the bag from the vacuum sweeper and check for tears or leaks. If necessary, reduce samples from broom sweeping to a size amenable for analysis. Seal broom swept material in a clean, labeled plastic jar for transport (alternatively, the swept material may be placed in the vacuum filter bag). Fold the unused portion of the filter bag, wrap a rubber band around the folded bag, and store the bag for transport.
6. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

Broom swept samples (if collected) should be at least 400 g (1 lb) for silt and moisture analysis. The vacuum swept sample should be at least 200 g (0.5 lb); in addition, the exposed filter bag weight should be at least 5 to 10 times greater than the empty bag tare weight. Additional increments should be taken until these sample mass goals have been achieved.

SAMPLES FROM STORAGE PILES

The following steps describe the method for collecting samples from storage piles:

1. Sketch plan and elevation views of the pile. Indicate if any portion is inaccessible. Use the sketch to plan where the N increments will be taken by dividing the perimeter into N-1 roughly equivalent segments.
 - a. For a large pile, collect a minimum of 10 increments should as near to the mid-height of the pile as practical.
 - b. For a small pile, a sample should consist of a minimum of 6 increments evenly distributed among the top, middle, and bottom.

"Small" or "large" piles, for practical purposes, may be defined as those piles which can or cannot, respectively, be scaled by a person carrying a shovel and pail.

2. Collect material with a straight-point shovel or a small garden spade and store the increments in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Depending upon the ultimate goals of the sampling program, choose one of the following procedures:
 - a. To characterize emissions from material handling operations at an active pile, take increments from the portions of the pile which most recently had material added and removed. Collect the material with a shovel to a depth of 10 to 15 cm (4 to 6 inches). Do not deliberately avoid collecting larger pieces of aggregate present on the surface.
 - b. To characterize handling emissions from an inactive pile, obtain increments of the core material from a 1 m (3 ft) depth in the pile. A 2 m (6 ft) long sampling tube with a diameter at least 10 times the diameter of the largest particle being sampled is recommended for these samples. Note that, for piles containing large particles, the diameter recommendation may be impractical.
 - c. If characterization of wind erosion (rather than material handling) is the goal of the sampling program, collect the increments by skimming the surface in an upwards direction. The depth of the sample should be 2.5 cm (1 inch) or the the diameter of the largest particle, whichever is less. Do no deliberately avoid collecting larger pieces of aggregate present on the surface.

In most instances, collection method (a) should be selected.

3. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

For any of the procedures, the sample mass collected should be at least 5 kg (10 lb). When most materials are sampled with procedures 2.a or 2.b, ten increments normally result in a sample of at least 23 kg (50 lb). Note that storage pile samples usually require splitting to a size more amenable to laboratory analysis.

MOISTURE CONTENT DETERMINATION

1. Preheat the oven to approximately 110°C (230°F). Record oven temperature.
2. Tare the laboratory sample containers which will be placed in the oven. Tare the containers with the lids on if they have lids. Record the tare weight(s). Check zero before weighing.
3. Record the make, capacity, smallest division, and accuracy of the scale.
4. Weigh the laboratory sample in the container(s). Record the combined weight(s). Check zero before weighing.
5. Place sample in oven and dry overnight.^a
6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero before weighing.
7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.
8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

^a Dry materials composed of hydrated minerals or organic materials like coal and certain soils for only 1-1/2 hr. Because of this short drying time, material dried for only 1-1/2 hr must not be more than 2.5 cm (1 in.) deep in the container.

SILT CONTENT DETERMINATION

1. Select the appropriate 8-in. diameter, 2-in. deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8-in. No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particular sieve during sieving indicates that an intermediate sieve should be inserted.
2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap (without the tapping function).
3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.
4. Obtain a scale (capacity of at least 1,600 g) and record make, capacity, smallest division, date of last calibration, and accuracy.
5. Tare sieves and pan. Check the zero before every weighing. Record weights.
6. After nesting the sieves in decreasing order with the pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. The sample should weigh between 400 and 1,600 g (~ 0.9 to 3.5 lb).^a Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.
7. Place nested sieves into the mechanical device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10-min intervals until the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%. Do not sieve longer than 40 min.
8. Weigh each sieve and its contents and record the weight. Check the zero before every weighing.
9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.
10. Calculate the percent of mass less than the 200 mesh screen (75 μ m). This is the silt content.

^a This amount will vary for fine textured materials; 100 to 300 g may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve.

Example Test Plan for Point or Non-Uniform Line Sources

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

Attn: Mr. Dennis Shipman

EPA Contract No. 68-DO-0123
Work Assignment No. II-44
MRI Project No. 9712-M(44)

April 28, 1993

PREFACE

This report was prepared as part of Work Assignment No. II-44 of EPA Contract No. 68-DO-0123 as an example test protocol for point or non-uniform line sources of fugitive emissions. Mr. Dennis Shipman of the EPA's Emission Inventory Branch served as the EPA technical monitor. Dr. Gregory E. Muleski served as Midwest Research Institute's (MRI's) project leader. Mr. Gary Garman and Dr. Muleski prepared this report.

Approved for:

MIDWEST RESEARCH INSTITUTE



For Richard V. Crume
Program Manager
Environmental Engineering Department



Charles F. Holt, Ph.D., Director
Engineering and Environmental
Technology Department

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SECTION 1

INTRODUCTION

This report outlines the test plan to be followed during a field sampling program to determine particulate emissions from a point source, such as a batch material handling operation or a non-uniformly emitting line source, such as mud/dirt track-out onto paved roads. The report describes the sampling methodology, data analysis, and quality assurance procedures to be followed in the field study. The primary pollutant of concern is particulate matter (PM), especially PM no greater than 10 μm in aerodynamic diameter (PM_{10}). However, the basic sampling strategy and data analysis are equally applicable to other types of pollutants that might be emitted from the same types of sources.

The basic field sampling methodology uses the concept of "exposure profiling" developed by MRI.¹ The exposure profiling method calculates emission rates using a conservation of mass approach. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by the spatial integration of exposure (mass/area) measurements distributed over the effective cross section of the plume. Note that for a point source such as a material handling operation, a two-dimensional sampling array is required to characterize the plume's effective cross section. For a non-uniformly emitting line source, it is necessary to characterize emissions along the line. This, of course, also requires a two-dimensional sampling array. A companion report² describes sampling protocol for uniformly emitting line sources, which may be characterized using a one-dimensional vertical sampling array.

The remainder of this report provides a "skeleton" test protocol in that issues are discussed in general terms but can be readily expanded once a specific source and site have been selected for testing. Section 2 discusses quality assurance considerations, and Section 3 outlines the general sampling and analysis procedures to be followed. Section 4 describes an example test schedule.

SECTION 2

QUALITY ASSURANCE

The sampling and analysis procedures to be followed in this field testing program are subject to certain quality control (QC) guidelines. These guidelines will be discussed in conjunction with the activities to which they apply. These procedures meet or exceed the requirements specified in the reports entitled *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II—Ambient Air Specific Methods* (EPA 600/4-77-027a), and *Ambient Monitoring Guidelines for Prevention of Significant Deterioration* (EPA 4350/2-78-019).

As part of the QC program for this study, routine audits of sampling and analysis procedures will be performed. The purpose of the audits is to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items to be audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially-designed reporting forms for sampling and analysis of data obtained in the field and laboratory aids in the auditing procedure. Further details on specific sampling and analysis procedures are provided in the following section.

SECTION 3

SAMPLING AND ANALYSIS PROCEDURES

This section describes the general methodology used to characterize emissions from point or non-uniform line sources.

GENERAL AIR SAMPLING EQUIPMENT AND TECHNIQUES

Exposure profiling, which is the primary air sampling technique in this study, is based on simultaneous multipoint sampling over the effective cross section of the open dust source plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model (as in the so-called "upwind/downwind" method).

Example equipment deployments are shown in Figures 1 and 2 for a point source and a non-uniform line source, respectively. The exact spacing of samplers is highly dependent upon various factors including

- Source dimensions
- Emission release height
- Range of wind speeds expected

The primary air sampling device in this example test plan is a standard high-volume air sampler fitted with a cyclone preseparator (Figure 3). The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 microns (μm) in aerodynamic diameter when operated at a flow rate of 40 cfm ($68 \text{ m}^3/\text{h}$).³

Throughout each test, wind speed is monitored at the downwind sampling site(s) by directional warm wire anemometers (Kurz Model 465) at three heights. Horizontal wind direction is monitored by a wind vane at a single height. Wind speed and direction are scanned using a data logger, with 5-min averages stored in a computer file. The vertical profile of horizontal wind speed is determined by fitting the measurements to a logarithmic profile.

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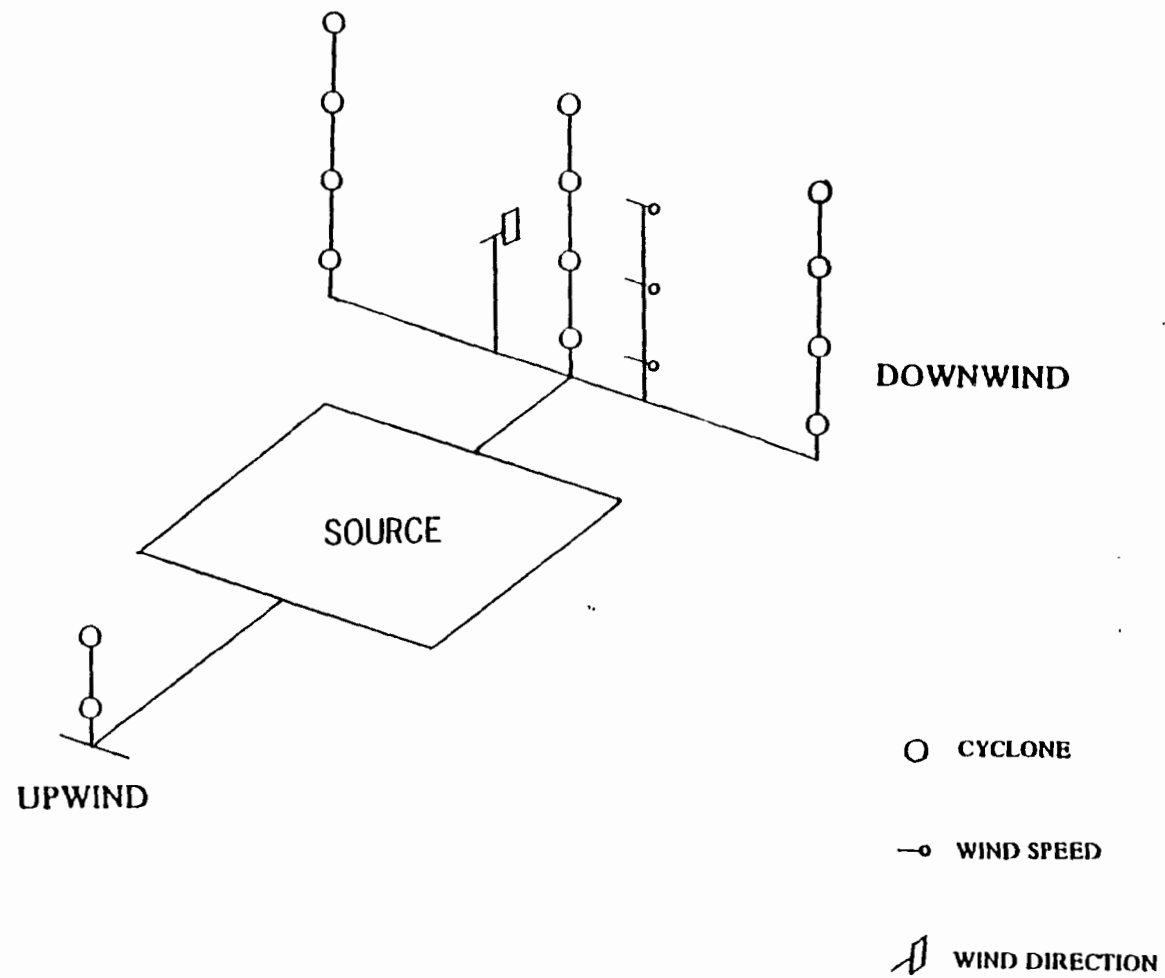


Figure 1. Example sampler deployment for a point source.

3-3

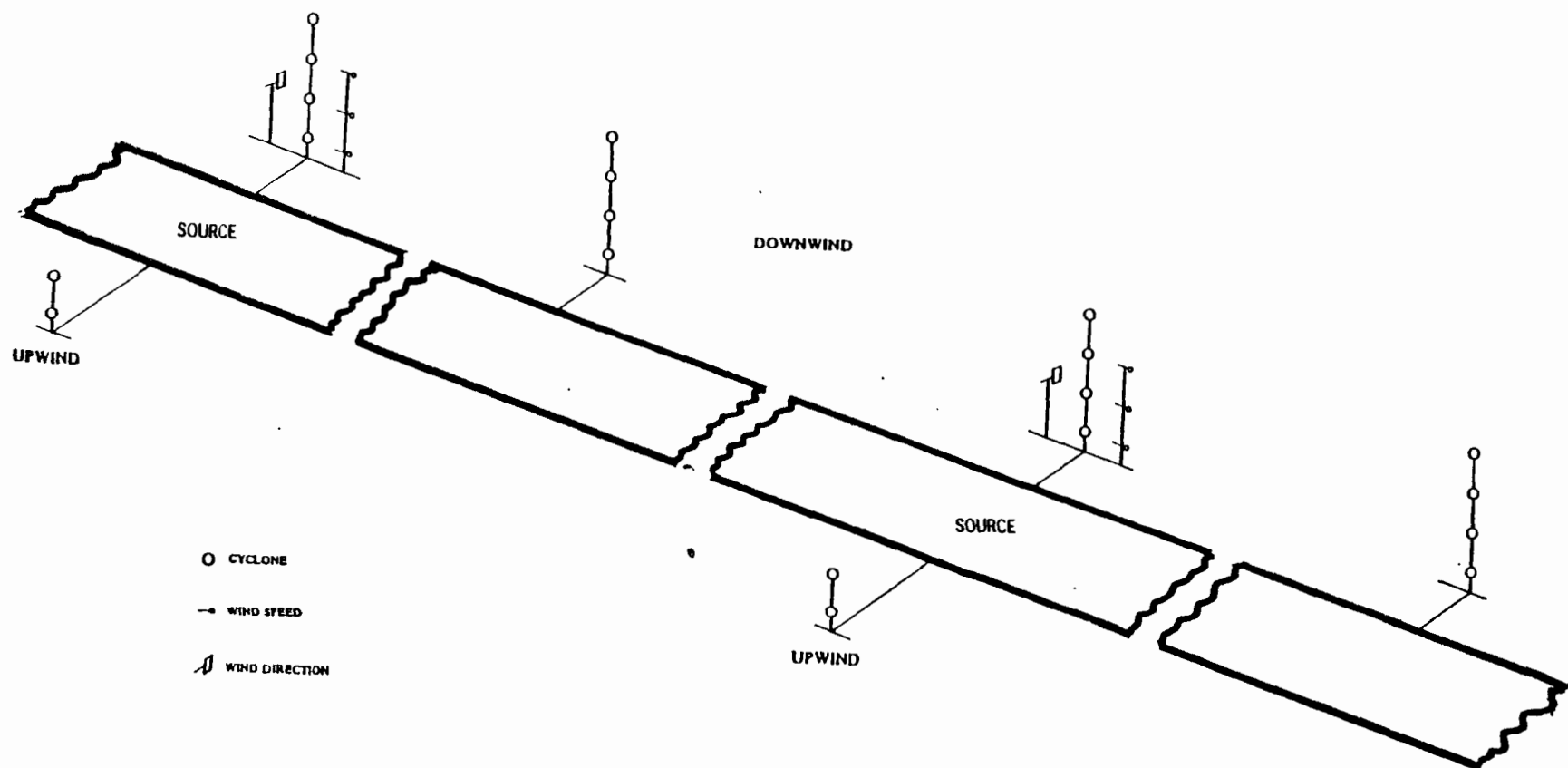


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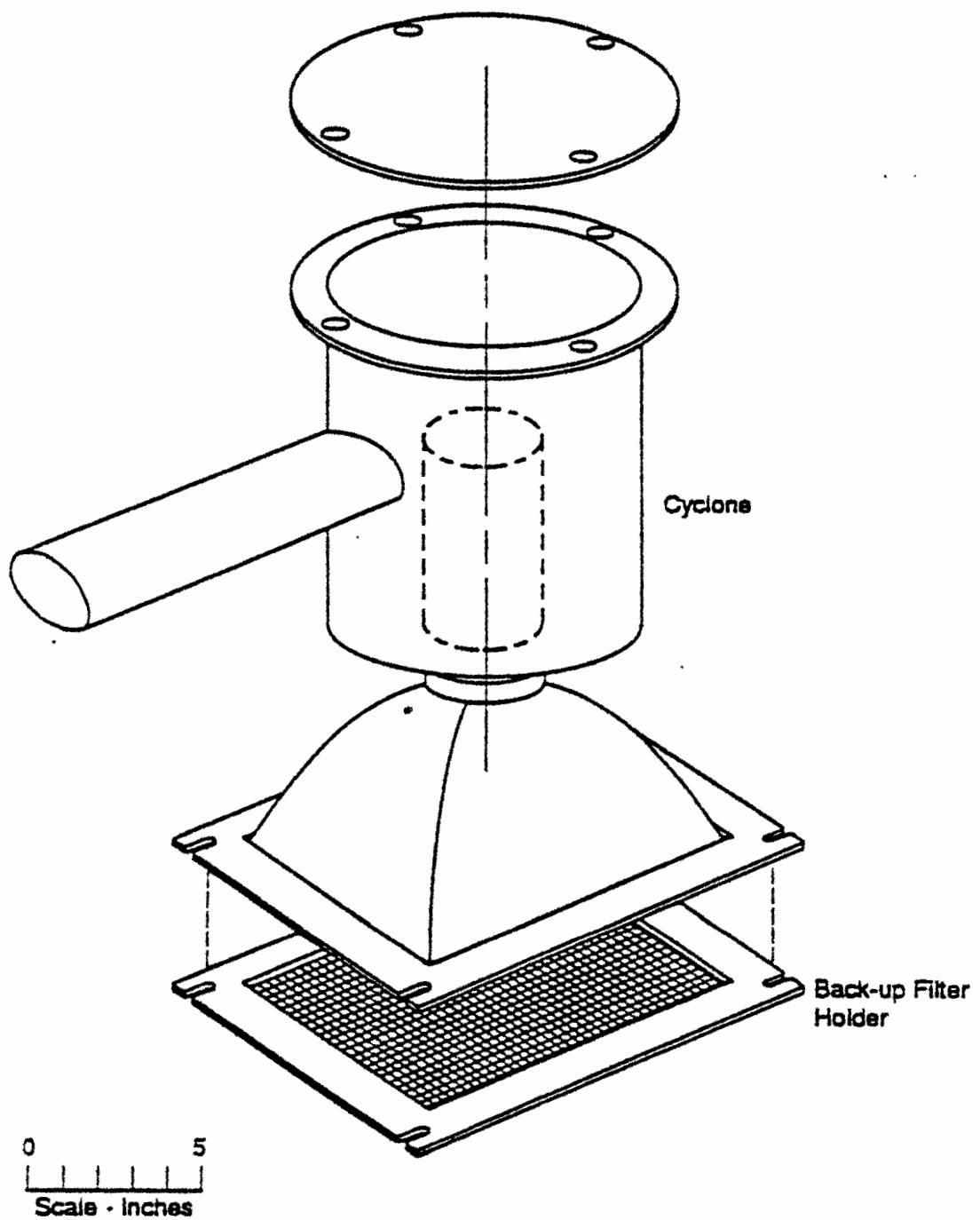


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Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

Pretest Procedures/Evaluation of Sampling Conditions

Prior to equipment deployment, a number of decisions are to be made as to the potential for acceptable source testing conditions. These decisions are based on forecast information obtained from the local U.S. Weather Service office. If conditions are considered acceptable, the sampling equipment deployment is initiated. At this time the sampling flow rates are set for the various air sampling instruments. The quality control guidelines governing this activity are found in Table 2.

TABLE 2. QUALITY ASSURANCE PROCEDURES FOR SAMPLING FLOW RATES

Activity	QA check/requirement
High volume air samplers	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter at each regional site prior to testing.
Orifice and electronic calibrator	Calibrate against displaced volume test meter annually.

Once the source testing equipment is set up and the filters inserted, air sampling commences. Information is recorded on specially-designed reporting forms and includes:

- a. Air samples—Start/stop times, wind speed profiles, flow rates, and wind direction (5- to 15-min average). See Table 3 for QA procedures.
- b. Measures of source activity—such as number of material batch drops and number of vehicles passing over a track-out site.
- c. General meteorology—Wind speed, wind direction, and temperature.

Sampling time must be long enough to provide sufficient sample and to average over several cycles of the fluctuation in the emission rate (i.e., batch drops). Occasionally sampling may be interrupted because of the occurrence of unacceptable meteorological conditions and then restarted when suitable conditions return. Table 4 presents the criteria used for suspending or terminating a source test.

TABLE 3. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA check/requirement ^a
Maintenance	
• All samplers	Check motors, gaskets, timers, and flow-measuring devices at each plant prior to testing.
Operation	
• Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. This technique allocates no nozzle for wind speeds ranging from 0 to 10 mph, and unique nozzles for four wind speed ranges above 10 mph.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

^a All "means" refer to 5- to 15-min averages.

TABLE 4. CRITERIA FOR SUSPENDING OR TERMINATING A TEST

A test may be suspended or terminated if:^a

1. Rainfall ensues during equipment setup or when sampling is in progress.
2. Mean wind speed during sampling moves outside the 0.9- to 8.9-m/sec (2- to 20-mph) acceptable range for more than 20% of the sampling time.
3. The angle between mean wind direction and perpendicular to the plane of the sampling array during sampling exceeds 45 degrees for two consecutive averaging periods.
4. Daylight or available artificial lighting is insufficient for safe equipment operation.
5. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill or accidental water splashing prior to uncontrolled testing).

^a "Mean" denotes a 5- to 15-min average.

Sample Handling and Analysis

To prevent particulate losses, the exposed media are carefully transferred at the end of each run to protective containers for transportation. In the field laboratory, exposed filters are placed in individual glassine envelopes and then into numbered file folders. When exposed filters and the associated blanks are returned to the MRI laboratory, they are equilibrated under the same conditions as the initial weighing. After reweighing, 10% of the filters are audited to check weighing accuracy.

EMISSION FACTOR CALCULATION PROCEDURES

To calculate emission rates, a conservation of mass approach is used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure for line sources are described below.

Particulate Concentrations

The concentration of particulate matter measured by a sampler is given by:

$$C = 10^3 \frac{m}{Qt}$$

where: C = particulate concentration ($\mu\text{g}/\text{m}^3$)
m = particulate sample weight (mg)
Q = sampler flow rate (m^3/min)
t = duration of sampling (min)

To be consistent with the National Ambient Air Quality Standards, all concentrations and flow rates are expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 inHg).

The isokinetic flow ratio (IFR) is the ratio of a directional sampler's intake air speed to the mean wind speed approaching the sampler. It is given by:

$$\text{IFR} = \frac{Q}{aU}$$

where: Q = sampler flow rate (m^3/min)
a = intake area of sampler (m^2)
U = mean wind speed at height of sampler (m/min)

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. Note, however, that because the primary interest in this program is directed to PM₁₀ emissions, sampling under moderately nonisokinetic conditions poses no difficulty. It is readily agreed that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.⁴

Exposure represents the net passage of mass through a unit area normal to the direction of plume transport (wind direction) and is calculated by:

$$E = 10^{-7} \times C U t$$

where: E = particulate exposure (mg/cm²)
 C = net concentration (µg/m³)
 U = approaching wind speed (m/s)
 t = duration of sampling (s)

Exposure values vary over the spatial extent of the plume. If exposure is integrated over the plume effective cross section, then the quantity obtained represents the total passage of airborne particulate matter due to the source.

For point sources, a two-dimensional integration is used:

$$A_2 = \int_{-\frac{W}{2}}^{\frac{W}{2}} \int_0^H E \, dh \, dy$$

where: A₂ = integrated mass (m²-mg/cm²)
 W = effective plume width (m)
 H = effective extent of plume above ground (m)
 E = particulate exposure (mg/cm²)
 h = vertical distance coordinate (m)
 y = horizontal crosswind coordinate (m)

An analogous expression applies to non-uniform line sources.

Particulate Emission Factors

The emission factor for particulate generated by material handling expressed in grams of emissions per megagram of material handled is found as:

$$e = 10 \frac{A2}{S}$$

where:

- e = particulate emission factor (g/Mg)
- A2 = integrated mass (m²-mg/cm²)
- S = measure of source activity appropriate for the source of interest (e.g., mass of material handled or number of vehicles traveling over a track-out surface)

SURFACE AND OTHER MATERIAL SAMPLES

A sample that is characteristic of the emitting material or surface is taken in conjunction with each test. The collection and analysis of these samples are important because the available emission factor and control performance models often make use of material parameters. Samples are to be analyzed (at a minimum) for silt (particles passing a 200-mesh screen) and moisture contents. Detailed steps for collection and analysis of samples for silt and moisture are given in the Appendix. An abbreviated discussion is presented below.

Sample collection procedures depend on the type of material under consideration. For example, mud and dirt trackout onto a paved surface is sampled by broom sweeping (if necessary) followed by vacuum cleaning of the surface. When the emission source depends upon a bulk material being handled, samples are to be composited of increments taken from the material being transferred. The Appendix presents a series of specific procedures for the collection of samples.

Once the field sample is obtained, it will be prepared for analysis. If necessary, the field sample will be split with a riffle to a sample size amenable to laboratory analysis. The basic procedure for moisture analysis is determination of weight loss on oven drying. Silt analysis procedures follow the ASTM-C-136 method. The Appendix details these procedures.

SECTION 4

TESTING SCHEDULE

The following describes a typical schedule of field activities, starting with the arrival of the crew at the test site.

1. Unpack the transport truck and arrange field laboratory facilities. Provide captive activities or monitor actual operations for at least 1 hr prior to the start of air testing.
2. Erect upwind and downwind sampling arrays.
3. Calibrate each sampler to the required volumetric flow rate (40 cfm for the cyclone preseparators described in Section 3).
4. Conduct air sampling following the procedures described in Section 3. At the end of this test period:
 - Cover sampler inlets
 - Discontinue any captive activity
 - Remove and store the sampling media from the downwind samples as specified in Section 3
 - Repeat the sampling procedure so that at least replicate tests are conducted under essentially unchanged conditions
 - Collect a surface or other material sample following the procedures given in Section 3
5. Repeat Step 4 until all elements of the test matrix have been considered.
6. Pack equipment for transport to the next regional test site or for return to the main laboratories.

SECTION 5

REFERENCES

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APPENDIX

MATERIAL SAMPLING AND ANALYSIS PROCEDURES

SAMPLES FROM UNPAVED ROADS

PROCEDURE

The following steps describe the collection method for samples (increments).

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one person to "spot" and route traffic safely around another person collecting the surface sample (increment).
2. Using string or other suitable markers, mark a 1 ft (0.3 m) width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.)
3. With a whisk broom and dustpan, remove the loose surface material from the hard road base. Do not abrade the base during sweeping. Sweeping should be performed slowly so that fine surface material is not injected into the air. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline).
4. Periodically deposit the swept material into a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Increments may be mixed within this container.
5. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

For uncontrolled unpaved road surfaces, a gross sample of 10 lb (5 kg) to 50 lb (23 kg) is desired. Samples of this size will require splitting to a size amenable for analysis. For unpaved roads that have been treated with chemical dust suppressants (such as petroleum resins, asphalt emulsions, etc.), the above goal may not be practical in well-defined study areas because a very large area would need to be swept. In general, a minimum of 1 lb (400 g) is required for silt and moisture analysis. Additional increments should be taken from heavily controlled unpaved surfaces, until the minimum sample mass has been achieved.

SAMPLES FROM PAVED ROADS

The following steps describe the collection method for samples (increments).

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one crew member to "spot" and route traffic safely around another person collecting the surface sample (increment).
2. Using string or other suitable markers, mark the sampling width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.) The widths may be varied between 0.3 m (1 ft) for visibly dirty roads and 3 m (10 ft) for clean roads. When using an industrial-type vacuum to sample lightly loaded roads, a width greater than 3 m (10 ft) may be necessary to meet sample specifications unless increments are being combined.
3. If large, loose material is present on the surface, it should be collected with a whisk broom and dustpan. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line." Store the swept material in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Increments for the same sample may be mixed within the container.
4. Vacuum sweep the collection area using a portable vacuum cleaner fitted with a tared filter bag. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line." The same filter bag may be used for different increments for one sample. For heavily loaded roads, more than one filter bag may be required for a sample (increment).
5. Carefully remove the bag from the vacuum sweeper and check for tears or leaks. If necessary, reduce samples from broom sweeping to a size amenable for analysis. Seal broom swept material in a clean, labeled plastic jar for transport (alternatively, the swept material may be placed in the vacuum filter bag). Fold the unused portion of the filter bag, wrap a rubber band around the folded bag, and store the bag for transport.
6. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

Broom swept samples (if collected) should be at least 400 g (1 lb) for silt and moisture analysis. The vacuum swept sample should be at least 200 g (0.5 lb); in addition, the exposed filter bag weight should be at least 5 to 10 times greater than the empty bag tare weight. Additional increments should be taken until these sample mass goals have been achieved.

SAMPLES FROM STORAGE PILES

The following steps describe the method for collecting samples from storage piles:

1. Sketch plan and elevation views of the pile. Indicate if any portion is inaccessible. Use the sketch to plan where the N increments will be taken by dividing the perimeter into N-1 roughly equivalent segments.
 - a. For a large pile, collect a minimum of 10 increments should as near to the mid-height of the pile as practical.
 - b. For a small pile, a sample should consist of a minimum of 6 increments evenly distributed among the top, middle, and bottom.

"Small" or "large" piles, for practical purposes, may be defined as those piles which can or cannot, respectively, be scaled by a person carrying a shovel and pail.

2. Collect material with a straight-point shovel or a small garden spade and store the increments in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gallon] bucket) with a sealable polyethylene liner. Depending upon the ultimate goals of the sampling program, choose one of the following procedures:
 - a. To characterize emissions from material handling operations at an active pile, take increments from the portions of the pile which most recently had material added and removed. Collect the material with a shovel to a depth of 10 to 15 cm (4 to 6 inches). Do not deliberately avoid collecting larger pieces of aggregate present on the surface.
 - b. To characterize handling emissions from an inactive pile, obtain increments of the core material from a 1 m (3 ft) depth in the pile. A 2 m (6 ft) long sampling tube with a diameter at least 10 times the diameter of the largest particle being sampled is recommended for these samples. Note that, for piles containing large particles, the diameter recommendation may be impractical.
 - c. If characterization of wind erosion (rather than material handling) is the goal of the sampling program, collect the increments by skimming the surface in an upwards direction. The depth of the sample should be 2.5 cm (1 inch) or the the diameter of the largest particle, whichever is less. Do no deliberately avoid collecting larger pieces of aggregate present on the surface.

In most instances, collection method (a) should be selected.

3. Record the required information on the sample collection sheet.

SAMPLE SPECIFICATIONS

For any of the procedures, the sample mass collected should be at least 5 kg (10 lb). When most materials are sampled with procedures 2.a or 2.b, ten increments normally result in a sample of at least 23 kg (50 lb). Note that storage pile samples usually require splitting to a size more amenable to laboratory analysis.

MOISTURE CONTENT DETERMINATION

1. Preheat the oven to approximately 110°C (230°F). Record oven temperature.
2. Tare the laboratory sample containers which will be placed in the oven. Tare the containers with the lids on if they have lids. Record the tare weight(s). Check zero before weighing.
3. Record the make, capacity, smallest division, and accuracy of the scale.
4. Weigh the laboratory sample in the container(s). Record the combined weight(s). Check zero before weighing.
5. Place sample in oven and dry overnight.^a
6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero before weighing.
7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.
8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

^a Dry materials composed of hydrated minerals or organic materials like coal and certain soils for only 1-1/2 hr. Because of this short drying time, material dried for only 1-1/2 hr must not be more than 2.5 cm (1 in.) deep in the container.

SILT CONTENT DETERMINATION

1. Select the appropriate 8-in. diameter, 2-in. deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8-in. No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particular sieve during sieving indicates that an intermediate sieve should be inserted.
2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap (without the tapping function).
3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.
4. Obtain a scale (capacity of at least 1,600 g) and record make, capacity, smallest division, date of last calibration, and accuracy.
5. Tare sieves and pan. Check the zero before every weighing. Record weights.
6. After nesting the sieves in decreasing order with the pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. The sample should weigh between 400 and 1,600 g (~ 0.9 to 3.5 lb).^a Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.
7. Place nested sieves into the mechanical device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10-min intervals until the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%. Do not sieve longer than 40 min.
8. Weigh each sieve and its contents and record the weight. Check the zero before every weighing.
9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.
10. Calculate the percent of mass less than the 200 mesh screen (75 μm). This is the silt content.

^a This amount will vary for fine textured materials; 100 to 300 g may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve.

Appendix J

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11.2.7 INDUSTRIAL WIND EROSION

11.2.7.1 General¹⁻³

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 centimeter (cm) in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 meters per second (11 miles per hour) at 15 centimeters above the surface or 10 meters per second (22 miles per hour) at 7 meters above the surface, and (b) particulate emission rates tend to decay rapidly (half life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential.

11.2.7.2 Emissions And Correction Parameters

If typical values for threshold wind speed at 15 centimeters are corrected to typical wind sensor height (7-10 meters), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1 mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 minutes (for a fastest mile of 30 miles per hour), matches well with the half life of the erosion process, which ranges between 1 and 4 minutes. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \quad (1)$$

where u = wind speed, centimeters per second
 u^* = friction velocity, centimeters per second
 z = height above test surface, cm
 z_0 = roughness height, cm
 0.4 = von Karman's constant, dimensionless

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the y intercept of the velocity profile, i. e., the height at which the wind speed is zero. These parameters are illustrated in Figure 11.2.7-1 for a roughness height of 0.1 centimeters.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

11.2.7.3 Predictive Emission Factor Equation⁴

The emission factor for wind generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of grams per square meter per year as follows:

$$\text{Emission factor} = k \sum_{i=1}^N P_i \quad (2)$$

where k = particle size multiplier
 N = number of disturbances per year
 P_i = erosion potential corresponding to the observed (or probable) fastest mile of wind for the i th period between disturbances, g/m^2

The particle size multiplier (k) for Equation 2 varies with aerodynamic particle size, as follows:

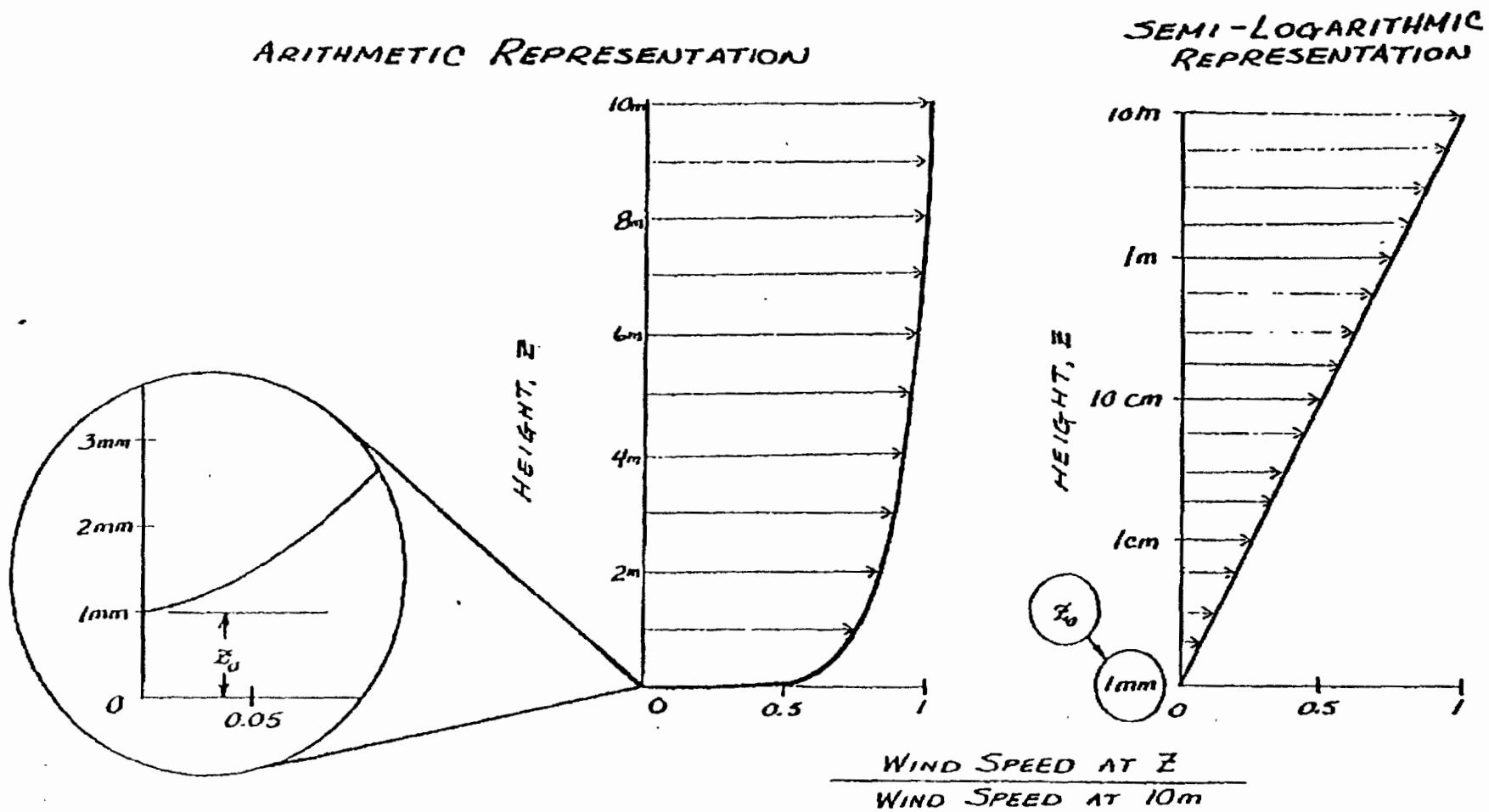
AERODYNAMIC PARTICLE SIZE MULTIPLIERS FOR EQUATION 2

30 μm	<15 μm	<10 μm	<2.5 μm
1.0	0.6	0.5	0.2

This distribution of particle size within the under 30 micron fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see Section 11.2.3).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, $N = 365$ per year, and for a surface disturbance once every 6 months, $N = 2$ per year.

Figure 11.2.7-1. Illustration of logarithmic velocity profile.



The erosion potential function for a dry, exposed surface is:

$$P = 58 (u^* - u_t^*)^2 + 25 (u^* - u_t^*) \quad (3)$$

$$P = 0 \text{ for } u^* \leq u_t^*$$

where u^* = friction velocity (m/s)

u_t^* = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady state emission rates.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below in Table 11.2.7-1. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, as described by Gillette.⁵⁻⁶

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 11.2.7-2.

TABLE 11.2.7-1. FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY

Tyler sieve no.	Opening (mm)	Midpoint (mm)	u_t^* (cm/sec)
5	4	3	100
9	2	1.5	72
16	1	0.75	58
32	0.5	0.375	43
60	0.25		

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY
(from a 1952 laboratory procedure published by W. S. Chepil):

1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. Place a collector pan below the bottom (0.25 mm) sieve.
2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm.
3. Pour the sample into the top sieve (4 mm opening), and place a lid on the top.
4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.
5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i. e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.
6. Determine the threshold friction velocity from Figure 1.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.⁷ These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10 meter reference height using Equation 1.

To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 meters to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053 u_{10}^+ \quad (4)$$

where u^* = friction velocity (meters per second)

u_{10}^+ = fastest mile of reference anemometer for period
between disturbances (meters per second)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat piles or exposed areas with little penetration into the surface wind layer.

TABLE 11.2.7-2. THRESHOLD FRICTION VELOCITIES

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)	
			$z_0 = \text{Act}$	$z_0 = 0.5 \text{ cm}$
Overburden ^a	1.02	0.3	21	19
Scoria (roadbed material) ^a	1.33	0.3	27	25
Ground coal ^a (surrounding coal pile)	0.55	0.01	16	10
Uncrusted coal pile ^a	1.12	0.3	23	21
Scraper tracks on coal pile ^{a, b}	0.62	0.06	15	12
Fine coal dust on concrete pad ^c	0.54	0.2	11	10

^aWestern surface coal mine. Reference 2.

^bLightly crusted.

^cEastern power plant. Reference 3.

If the pile significantly penetrates the surface wind layer (i. e., with a height-to-base ratio exceeding 0.2), it is necessary to divide the pile area into subareas representing different degrees of exposure to wind. The results of physical modeling show that the frontal face of an elevated pile is exposed to wind speeds of the same order as the approach wind speed at the top of the pile.

For two representative pile shapes (conical and oval with flattop, 37 degree side slope), the ratios of surface wind speed (u_s) to approach wind speed (u_r) have been derived from wind tunnel studies.⁹ The results are shown in Figure 11.2.7-2 corresponding to an actual pile height of 11 meters, a reference (upwind) anemometer height of 10 meters, and a pile surface roughness height (z_0) of 0.5 centimeters. The measured surface winds correspond to a height of 25 centimeters above the surface. The area fraction within each contour pair is specified in Table 11.2.7-3.

The profiles of u_s/u_r in Figure 11.2.7-2 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

1. Correct the fastest mile value (u^+) for the period of interest from the anemometer height (z) to a reference height of 10 m (u_{10}^+) using a variation of Equation 1:

$$u_{10}^+ = u^+ \frac{\ln (10/0.005)}{\ln (z/0.005)} \quad (5)$$

where a typical roughness height of 0.5 cm (0.005 meters) has been assumed. If a site specific roughness height is available, it should be used.

2. Use the appropriate part of Figure 11.2.7-2 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u_s^+):

$$u_s^+ = \frac{(u_s)}{u_r} u_{10}^+ \quad (6)$$

3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 1 to calculate the equivalent friction velocity (u^*):

$$u^* = \frac{0.4 u_s^+}{\frac{25}{\ln 0.5}} = 0.10 u_s^+$$

From this point on, the procedure is identical to that used for a flat pile, as described above.

Implementation of the above procedure is carried out in the following steps:

1. Determine threshold friction velocity for erodible material of interest (see Table 11.2.7-2 or determine from mode of aggregate size distribution).
2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).
3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u_{10}^+) using Equation 5.
4. Convert fastest mile values (u_{10}^+) to equivalent friction velocities (u^*), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 4, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 6 and 7.
5. For elevated surfaces (piles), subdivide areas of constant N into subareas of constant u^* (i. e., within the isopleth values of u_s/u_r in Figure 11.2.7-2 and Table 11.2.7-3) and determine the size of each subarea.
6. Treating each subarea (of constant N and u^*) as a separate source, calculate the erosion potential (P_1) for each period between disturbances using Equation 3 and the emission factor using Equation 2.
7. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-hr emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

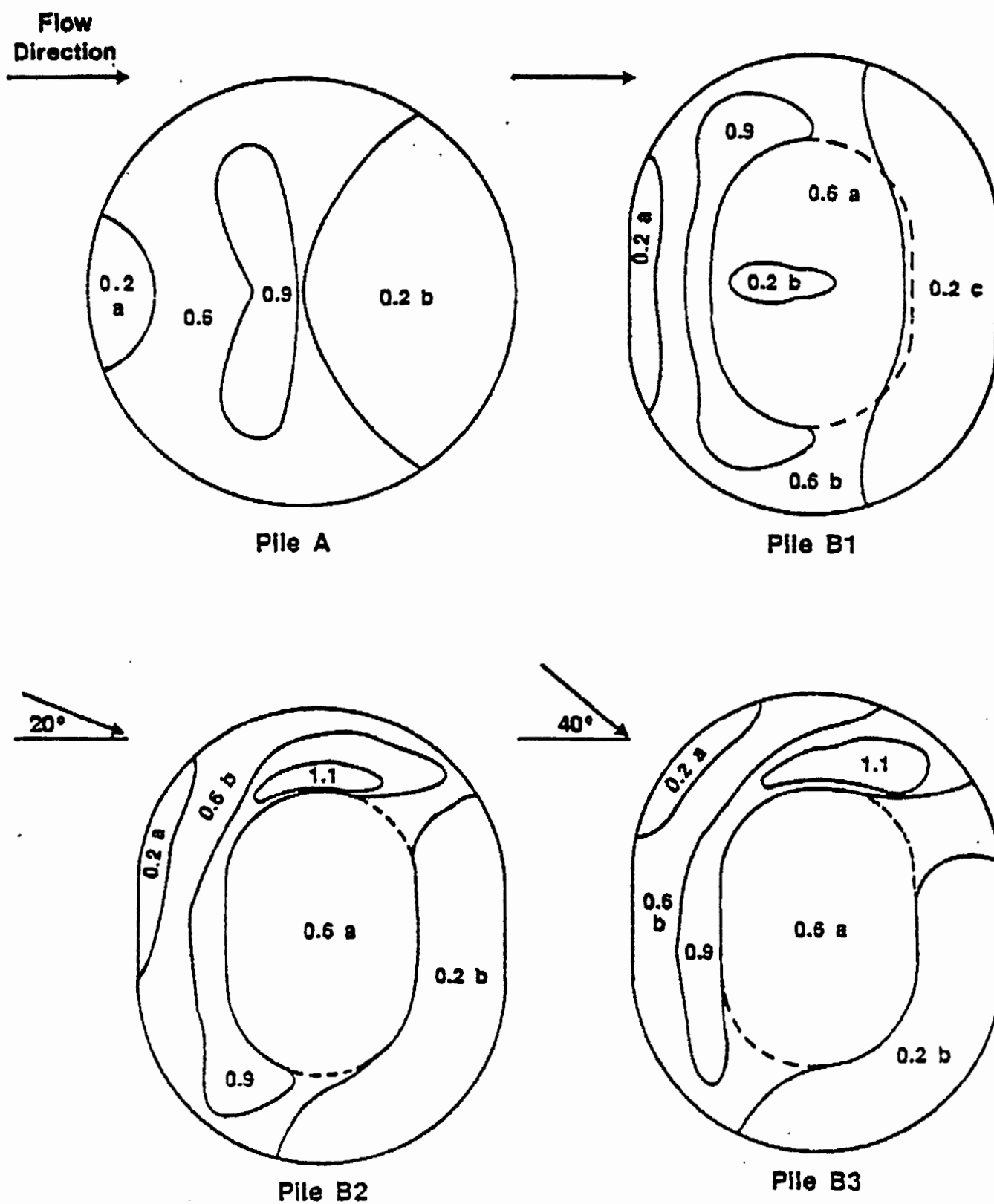


Figure 11.2.7-2. Contours of normalized surface wind speeds, u_s/u_r .

TABLE 11.2.7-3. SUBAREA DISTRIBUTION FOR REGIMES OF u_s/u_r

Pile Subarea	Percent of pile surface area			
	Pile A	Pile B1	Pile B2	Pile B3
0.2a	5	5	3	3
0.2b	35	2	28	25
0.2c	-	29	-	-
0.6a	48	26	29	28
0.6b	-	24	22	26
0.9	12	14	15	14
1.1	-	-	3	4

The recommended emission factor equation presented above assumes that all of the erosion potential corresponding to the fastest mile of wind is lost during the period between disturbances. Because the fastest mile event typically lasts only about 2 minutes, which corresponds roughly to the halflife for the decay of actual erosion potential, it could be argued that the emission factor overestimates particulate emissions. However, there are other aspects of the wind erosion process which offset this apparent conservatism:

1. The fastest mile event contains peak winds which substantially exceed the mean value for the event.
2. Whenever the fastest mile event occurs, there are usually a number of periods of slightly lower mean wind speed which contain peak gusts of the same order as the fastest mile wind speed.

Of greater concern is the likelihood of overprediction of wind erosion emissions in the case of surfaces disturbed infrequently in comparison to the rate of crust formation.

11.2.7.4 Example 1: Calculation for wind erosion emissions from conically shaped coal pile

A coal burning facility maintains a conically shaped surge pile 11 meters in height and 29.2 meters in base diameter, containing about 2000 megagrams of coal, with a bulk density of 800 kg/m^3 (50 lb/ft^3). The total exposed surface area of the pile is calculated as follows:

$$\begin{aligned}
 S &= \pi r (r^2 + h^2) \\
 &= 3.14(14.6) (14.6)^2 + (11.0)^2 \\
 &= 838 \text{ m}^2
 \end{aligned}$$

Coal is added to the pile by means of a fixed stacker and reclaimed by front-end loaders operating at the base of the pile on the downwind side. In addition, every 3 days 250 megagrams (12.5 percent of the stored capacity of coal) is added back to the pile by a topping off operation, thereby restoring

the full capacity of the pile. It is assumed that (a) the reclaiming operation disturbs only a limited portion of the surface area where the daily activity is occurring, such that the remainder of the pile surface remains intact, and (b) the topping off operation creates a fresh surface on the entire pile while restoring its original shape in the area depleted by daily reclaiming activity.

Because of the high frequency of disturbance of the pile, a large number of calculations must be made to determine each contribution to the total annual wind erosion emissions. This illustration will use a single month as an example.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 1.12 meters per second is obtained from Table 11.2.7-2.

Step 2: Except for a small area near the base of the pile (see Figure 11.2.7-3), the entire pile surface is disturbed every 3 days, corresponding to a value of $N = 120$ per year. It will be shown that the contribution of the area where daily activity occurs is negligible so that it does not need to be treated separately in the calculations.

Step 3: The calculation procedure involves determination of the fastest mile for each period of disturbance. Figure 11.2.7-4 shows a representative set of values (for a 1-month period) that are assumed to be applicable to the geographic area of the pile location. The values have been separated into 3-day periods, and the highest value in each period is indicated. In this example, the anemometer height is 7 meters, so that a height correction to 10 meters is needed for the fastest mile values. From Equation 5,

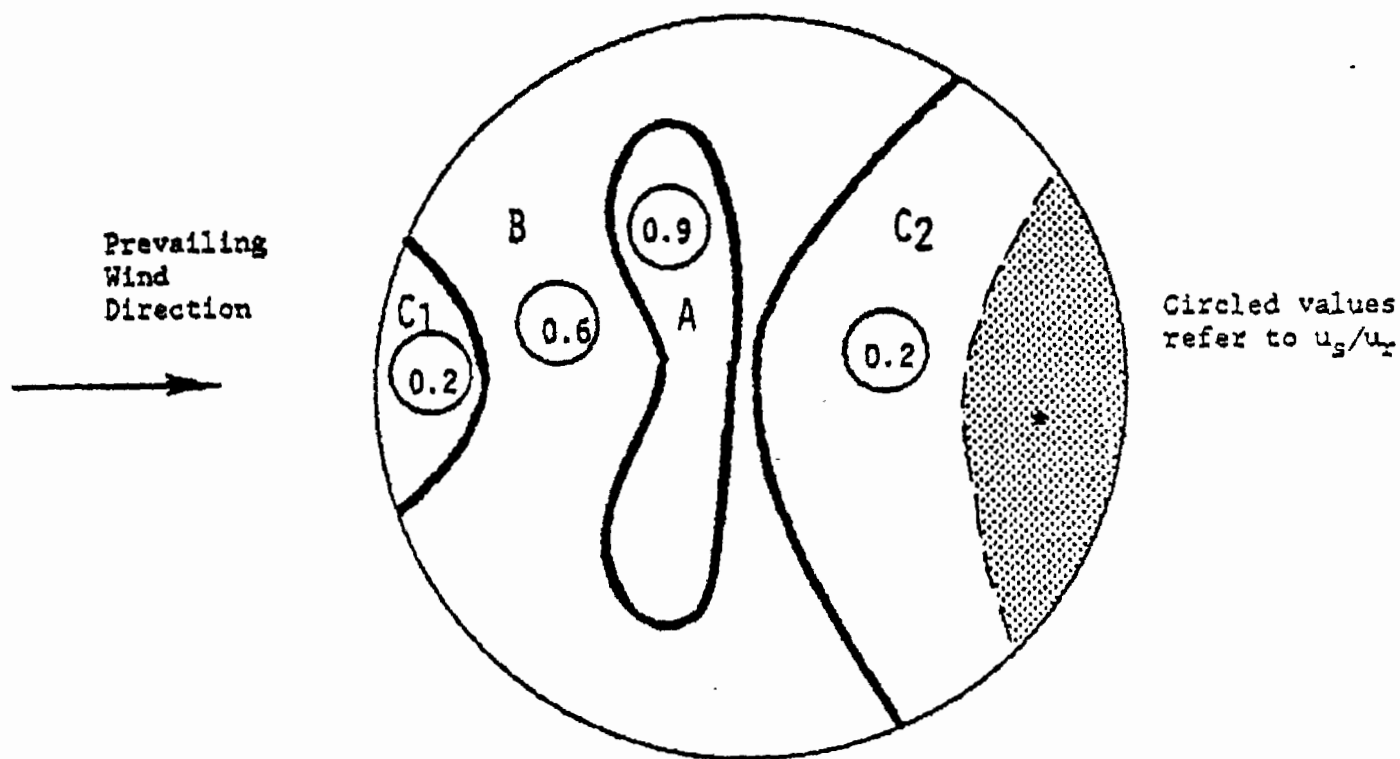
$$u_{10}^+ = u_7^+ \left(\frac{\ln (10/0.005)}{\ln (7/0.005)} \right)$$

$$u_{10}^+ = 1.05 u_7^+$$

Step 4: The next step is to convert the fastest mile value for each 3 day period into the equivalent friction velocities for each surface wind regime (i. e., u_s/u_T ratio) of the pile, using Equations 6 and 7. Figure 11.2.7-3 shows the surface wind speed pattern (expressed as a fraction of the approach wind speed at a height of 10 meters). The surface areas lying within each wind speed regime are tabulated below the figure.

The calculated friction velocities are presented in Table 11.2.7-4. As indicated, only three of the periods contain a friction velocity which exceeds the threshold value of 1.12 meters per second for an uncrusted coal pile. These three values all occur within the $u_s/u_T = 0.9$ regime of the pile surface.

Step 5: This step is not necessary because there is only one frequency of disturbance used in the calculations. It is clear that the small area of daily disturbance (which lies entirely within the $u_s/u_T = 0.2$ regime) is never subject to wind speeds exceeding the threshold value.



* A portion of C_2 is disturbed daily by reclaiming activities.

Area ID	$\frac{u_s}{u_T}$	Pile Surface	
		%	Area (m^2)
A	0.9	12	101
B	0.6	48	402
$C_1 + C_2$	0.2	40	335
Total			838

Figure 11.2.7-3. Example 1: Pile surface areas within each wind speed regime.

TABLE 11.2.7-4. EXAMPLE 1: CALCULATION OF FRICTION VELOCITIES

3-day period	u_7^+		u_{10}^+		$u^* = 0.1 u_s^+ \text{ (m/s)}$		
	(mph)	(m/s)	(mph)	(m/s)	$u_s/u_T: 0.2$	0.6	0.9
1	14	6.3	15	6.6	0.13	0.40	0.59
2	29	13.0	31	13.7	0.27	0.82	1.23
3	30	13.4	32	14.1	0.28	0.84	1.27
4	31	13.9	33	14.6	0.29	0.88	1.31
5	22	9.8	23	10.3	0.21	0.62	0.93
6	21	9.4	22	9.9	0.20	0.59	0.89
7	16	7.2	17	7.6	0.15	0.46	0.68
8	25	11.2	26	11.8	0.24	0.71	1.06
9	17	7.6	18	8.0	0.16	0.48	0.72
10	13	5.8	14	6.1	0.12	0.37	0.55

Steps 6 and 7: The final set of calculations (shown in Table 11.2.7-5) involves the tabulation and summation of emissions for each disturbance period and for the affected subarea. The erosion potential (P) is calculated from Equation 3.

TABLE 11.2.7-5. EXAMPLE 1: CALCULATION OF PM₁₀ EMISSIONS^a

3-day period	$u^* \text{ (m/s)}$	$u^* - u_T^* \text{ (m/s)}$	$P \text{ (g/m}^2\text{)}$	ID	File	kPA (g)
					Surface Area (m ²)	
2	1.23	0.11	3.45	A	101	170
3	1.27	0.15	5.06	A	101	260
4	1.31	0.19	6.84	A	101	350
Total:						780

^awhere $u_T^* = 1.12$ meters per second for uncrusted coal and $k = 0.5$ for PM₁₀.

For example, the calculation for the second 3 day period is:

$$\begin{aligned}
 P &= 58(u^* - u_T^*)^2 + 25(u^* - u_T^*) \\
 P_2 &= 58(1.23 - 1.12)^2 + 25(1.23 - 1.12) \\
 &= 0.70 + 2.75 = 3.45 \text{ g/m}^2
 \end{aligned}$$

The PM₁₀ emissions generated by each event are found as the product of the PM₁₀ multiplier ($k = 0.5$), the erosion potential (P), and the affected area of the pile (A).

Local Climatological Data

MONTHLY SUMMARY



WIND					DATE
RESULTANT DIR.	RESULTANT SPEED M.P.H.	AVERAGE SPEED M.P.H.	FASTEST MILE		
			SPEED M.P.H.	DIRECTION	
13	14	15	16	17	22
30	5.3	6.9	9	36	1
01	10.5	10.6	14	01	2
10	2.4	6.0	10	02	3
13	11.0	11.4	16	13	4
12	11.3	11.9	15	11	5
20	11.1	19.0	23	30	6
29	19.6	19.8	20	30	7
29	10.9	11.2	17	30	8
22	3.0	8.1	15	13	9
14	12.6	15.1	23	12	10
29	22.3	23.3	31	29	11
17	7.9	13.5	23	17	12
21	7.7	15.5	18	18	13
10	4.5	9.6	22	13	14
10	6.7	8.8	13	11	15
01	13.7	13.8	23	36	16
33	11.2	11.5	15	34	17
27	4.3	5.8	12	31	18
32	9.3	10.2	14	35	19
24	7.5	7.8	15	24	20
22	10.3	10.6	16	20	21
32	17.1	17.3	29	32	22
29	2.4	8.5	14	13	23
07	5.9	8.8	15	02	24
34	11.3	11.7	17	32	25
31	12.1	12.2	16	32	26
30	8.3	8.5	16	26	27
30	8.2	8.3	13	32	28
33	5.0	6.6	10	32	29
34	3.1	5.2	9	31	30
29	4.9	5.5	8	25	31
FOR THE MONTH:					
30	3.3	11.1	31	29	
DATE: 11					

Figure 11.2.7-4. Example daily fastest miles of wind for periods of interest.

As shown in Table 11.2.7-5, the results of these calculations indicate a monthly PM₁₀ emission total of 780 grams.

11.2.7.5 Example 2: Calculation for wind erosion from flat area covered with coal dust

A flat circular area of 29.2 meters in diameter is covered with coal dust left over from the total reclaiming of a conical coal pile described in the example above. The total exposed surface area is calculated as follows:

$$S = \frac{\pi}{4} d^2 = 0.785 (29.2)^2 = 670 \text{ m}^2$$

This area will remain exposed for a period of 1 month when a new pile will be formed.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 0.54 m/s is obtained from Table 11.2.7-2.

Step 2: The entire surface area is exposed for a period of 1 month after removal of a pile and $N = 1/\text{yr}$.

Step 3: From Figure 11.2.7-4, the highest value of fastest mile for the 30-day period (31 mph) occurs on the 11th day of the period. In this example, the reference anemometer height is 7 m, so that a height correction is needed for the fastest mile value. From Step 3 of the previous example, $u_{10}^+ = 1.05 u_7^+$, so that $u_{10}^+ = 33 \text{ mph}$.

Step 4: Equation 4 is used to convert the fastest mile value of 33 mph (14.6 mps) to an equivalent friction velocity of 0.77 mps. This value exceeds the threshold friction velocity from Step 1 so that erosion does occur.

Step 5: This step is not necessary, because there is only one frequency of disturbance for the entire source area.

Steps 6 and 7: The PM₁₀ emissions generated by the erosion event are calculated as the product of the PM₁₀ multiplier ($k = 0.5$), the erosion potential (P) and the source area (A). The erosion potential is calculated from Equation 3 as follows:

$$\begin{aligned} P &= 58(u^* - u_t^*)^2 + 25(u^* - u_t^*) \\ P &= 58(0.77 - 0.54)^2 + 25(0.77 - 0.54) \\ &= 3.07 + 5.75 \\ &= 8.82 \text{ g/m}^2 \end{aligned}$$

Thus the PM₁₀ emissions for the 1 month period are found to be:

$$\begin{aligned} E &= (0.5)(8.82 \text{ g/m}^2)(670 \text{ m}^2) \\ &= 3.0 \text{ kg} \end{aligned}$$

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Appendix K

PROTOCOL FOR THE MEASUREMENT
OF INHALABLE PARTICULATE
FUGITIVE EMISSIONS FROM
STATIONARY INDUSTRIAL SOURCES

DRAFT



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SECTION 1

INTRODUCTION

This document is intended as a guideline protocol for the measurement of inhalable particulate fugitive emissions (IPFE), defined as particles having aerodynamic diameters 15 micrometers or less. The data gathered by the personnel utilizing this protocol will be used to develop emission factors for inhalable particulate matter from fugitive industrial sources. Since the actual testing will be performed by a number of different organizations, the instructions contained in this document have been designed to provide a degree of uniformity in the testing procedures that will result in emission factors of consistent accuracy and reliability.

Four measurement techniques are dealt with in this protocol: quasi-stack, roof monitor, upwind-downwind and exposure profiling sampling. A step-by-step guide for choosing the most appropriate measurement technique for a given source type is outlined in terms of selection criteria. The application of the criteria to each of the methods is illustrated. The site-specific information required to plan the sampling program and design the sampling system is defined, and the preparation of a test plan utilizing the information described. Detailed calculation methods for designing quasi-stack method capture hoods and locating roof monitor and upwind-downwind method samplers are included, along with descriptions of recommended sampling devices and associated equipment. A general description of the conduct of a program for each sampling method is followed by a description of the procedures to be used in

calculating emissions concentrations, source emission rates, and process-related emission factors.

The protocol does not discuss measurement accuracy or emission factor reliability in a quantitative sense. Fugitive emissions measurements are generally about an order of magnitude more costly than conventional point source stack testing, and usual budgetary limits preclude the completion of enough measurements to satisfy the requirements of statistical experiment design. The fugitive emission factors determined from measurements made in accordance with the procedures can be expected to exhibit a relatively wide range of variation. Discussion of emission factor accuracy, which goes beyond the reliability rating scheme given in AP-42, is not warranted.

The procedures described can, with a reasonable amount of engineering or scientific judgment, be effectively applied to almost any industrial LPFE source. Adjustments to the procedures will usually be required to meet the extensive variety of site and source-specific characteristics that will be encountered. A guideline of typical adjustments to accommodate the most common of such characteristics has been included in the text. An effort has been made to make this manual as much a "cookbook" type reference as possible while assuming the user has a working knowledge of general sampling theory, procedures and instruments.

SECTION 2

MEASUREMENT TECHNIQUES

The selection of the most appropriate measurement technique for particulate matter fugitive emissions involves the consideration of a number of parameters. These relate to the type of emissions generated, their rate of generation, the physical characteristics and location of their source, plant operating schedules, meteorological conditions and plant or site geometry and topography. The number of different operations of the same type which will be tested and the proposed budget for the program are also of paramount concern. This section describes each of the basic measurement techniques, defines the criteria to be considered in the selection of a technique and outlines a method for applying the criteria.

TECHNIQUE DESCRIPTIONS

There are four basic methodologies recognized as being effective in the quantification of particulate matter fugitive emissions. Each method is associated with different accuracy and precision limitations, instrumentation requirements and sources to which this method can be properly applied. These basic methodologies are:

- o Quasi-Stack Sampling
- o Rooftop Monitor Sampling
- o Upwind-Downwind Sampling
- o Exposure Profiling

Each technique is described in general terms in the following text.

Quasi-Stack Sampling

In this method the fugitive emissions are captured in a temporarily installed hood or enclosure and then transported by the conveying air to an exhaust duct or stack of regular cross-sectional area. The emissions are measured in this ductwork using the stack sampling procedures described in Section 3 of this document.

The precision and accuracy limits of the quasi-stack method are the best of the noted sampling techniques and are also the best defined. The accuracy of the quasi-stack method is only slightly less than that of a normal stack test in that fewer points in the stack are sampled and a constant bias may be introduced by a failure to capture all of the emissions from the source being tested. Care in the design of the capturing system would reduce the latter error to virtually zero. Also, the allowable isokinetic range is ± 20 percent rather than ± 10 percent is usually adhered to.

Quasi-stack sampling is necessarily limited to sources that can be isolated from other sources and effectively enclosed or hooded to capture their emissions. Careful consideration must be given to the design of the enclosure or hood and to providing a volume of emission - transporting air sufficient to carry the emissions intact to the sampling equipment. The procedures for choosing these velocities are explained in the hood and duct design sections. The hooded enclosure design should not interfere with normal plant operations, and the capturing air flow across the process should not be so large as to alter the nature of the process or affect the amount or character of the emissions.

Typical generic fugitive emissions source types measurable by the quasi-stack method are:

1. Material transfer operations-conveyor belts, loading
2. Process leaks-pressurized ducts
3. Fabricating operations-grinding and polishing

Specific examples of industrial sources whose fugitive emissions have been measured by this technique are given in Table 1.

Roof Monitor Sampling

This method is used to measure the emissions generated by sources located within a building or similar structure as they are transmitted into the atmosphere through a roof monitor or other opening. The total emission rate for all sources within the structure is determined as the product of the emissions concentration measured in the air at the opening and the air flow rate through the opening. Most roof monitor sampling programs require the collection of samples and the measurement of air velocities simultaneously at a number of points in the plane of the opening to ensure that representative average values of concentration and flow rate are obtained.

Roof monitor sampling is most effectively employed for larger sources located within structures with only a few openings, where essentially all of the emissions are transported through a single opening. It requires sampling and measurement devices capable of making accurate determinations of relatively small masses of emissions and very low air velocities. It may be utilized for the characterization of specific sources within an enclosure if operating schedules include or permit the arrangement of emissions generation by only that specific source. Tracer measurements may also be utilized with roof monitor sampling to identify specific source emissions.

The accuracy and precision of this technique vary with characteristics of the source and are definable only in general terms for each source tested.

Typical industrial sources whose fugitive emissions may be measured using the roof monitor technique are listed in Table 2.

TABLE 1. QUASI-STACK SAMPLING METHOD APPLICATION TO
TYPICAL INDUSTRIAL FUGITIVE EMISSION SOURCES

INDUSTRY	SOURCE	EMISSIONS
Iron & Steel Foundries	Mold Preparation	Dust
	Mold Pouring	Dust, Fumes
	Product Finishing	Dust
Primary Metals	Furnace Charging	Dust
	Furnace Tapping	Fume
Non-Metallic Minerals	Crushing	Dust
	Conveying	Dust
Coal	Crushing & Screening	Dust
Asphalt Batching	Reactor Charging	Dust
	Reactor Tapping	Dust, Tars
Graphite and Carbide	Arc Furnace	Carbon Dust, Silica, Fumes

TABLE 2. ROOF MONITOR SAMPLING METHOD APPLICATION TO
TO TYPICAL INDUSTRIAL FUGITIVE EMISSION SOURCES

INDUSTRY	SOURCE	EMISSIONS
Iron & Steel Foundries	Furnace or Cupola Charging	Fume, Carbon Dust, Smoke (Oil)
	Melting Mold Pouring	Fume, Dust Dust
Electric Furnace Steel	Charging	Metallic Fumes, Carbon Dust
	General Operations	Metallic Fumes, Dust
Primary Aluminum	Carbon Plant Potroom	Tars, Carbon Dust Tars, Carbon & Alum- inum Dust, Fluorides
	Alumina Calcining Cryolite Recovery	Alumina Dust Carbon & Alumina Dust, Fluorides
Primary Copper	Converter House Reverberatory Furnace	Fume, Silica Fume
	Roaster Operations	Fume
Tires & Rubber	Curing Press Room	Organic Particulate
	Cement House	Dust
Phosphate Fertilizer	General Ventilation	Dust, Fluorides
Lime	General Ventilation	Dust
Primary Steel	Blast Furnace Cast House BOF Operations	Metallic Fumes Metallic Fumes, Carbon Dust
	Open Hearth Operations	Metallic Fumes
Graphite and Carbide Production	Arc Furnace Operation	Carbon Dust, Silica Fume

Upwind-Downwind Sampling

This method is utilized in the measurement of emissions after they have entered the ambient atmosphere from open or area sources, or from enclosed sources not amenable to quasi-stack or roof monitor sampling. The emission rate for such sources is determined by measuring the concentration of the emissions in the ambient air downwind of the source, subtracting the portion of the concentration attributable to other sources and that measured as background upwind of the source, and using the thus-determined concentration from the source in proven diffusion equations or mathematical models to back-calculate the source's rate of emission. Measurements of other contributing parameters, such as wind speed and direction during the emission sampling, location of samplers relative to the source, and atmospheric and topographic conditions, are also required.

Careful design of the sampling network, especially in the location of the sampling devices, is required to ensure representative sampling of the source being investigated and to ensure that the accuracy of the resulting emission factors approaches as nearly as possible the accuracy of the equations or models used in calculating the emission rate.

Upwind-downwind sampling is probably the most universally applicable of the fugitive emissions measurement techniques, since it is not usually limited by source location or geometry. Some typical industrial sources whose fugitive emissions may be measured using the upwind-downwind technique are listed in Table 3.

Exposure Profiling

The exposure profiling method utilizes the isokinetic profiling concept which is the basis for conventional source testing. For measurement of inhalable particulate

TABLE 3. UPWIND-DOWNWIND SAMPLING METHOD APPLICATION
TO TYPICAL INDUSTRIAL FUGITIVE EMISSION SOURCES

INDUSTRY	SOURCE	EMISSIONS
Coke Making	Coal Handling & Storage	Coal Dust
	Charging Ovens	Coal Dust, Tars
	Coking, Door & Oven Leaks	Coke Dust, Tars
	Coke Pushing	Coke Dust, Tars
	Quenching	Coke Dust, Tars
	Coke Handling & Storage	Coke Dust
Primary Aluminum	Bauxite Handling & Storage	Ore Dust
	Alumina Calcining & Preparation	Alumina Dust
	Alumina Storage	Alumina Dust
Primary Copper	Mining	Dust
	Hauling	Dust
	Tailings Pond	Dust
Sand & Gravel	Quarrying & Truck Hauling	Dust
	Rock Transfer	Dust
	Crushing & Screening	Dust
	Product Storage & Handling	Dust
Electric Furnace Steel	Scrap & Sinter Delivery	Iron & Steel Dust
	Lime & Silica Delivery	Dust
	Furnace Tapping	Fume
Iron & Steel Foundries	Coke, Silica, Sinter Storage	Dust
Coal	Mining	Coal Dust
	Storage & Transfer	Coal Dust
	Screening & Crushing	Coal Dust
	Drying	Coal Dust
	Storage Piles	Coal Dust
	Waste Transfer	Dust
Asphalt	Gravel Delivery	Dust
	Asphalt Storage	Tars
	Storage Piles	Dust
	Asphalt Batching	Dust, Tars
	Drier & Blower	Dust, Tars
	Reactor Charge & Discharge	Dust, Tars
	Product Transfer	Dust, Tars

TABLE 3 (Cont.). UPWIND-DOWNWIND SAMPLING METHOD APPLICATION
TO TYPICAL INDUSTRIAL FUGITIVE EMISSION SOURCES

INDUSTRY	SOURCE	EMISSIONS
Coal Gasification	Coal Delivery, Storage & Transfer	Coal Dust
	Waste Transfer	Dust
	Scrubber Solids	Dust
Petroleum Refining	Waste Storage & Transfer	Dust
	Process Leaks	Tars
Phosphate Fertilizer	Mining	Dust
	Storage Piles	Dust
	Rock Transfer	Dust
	Settling Pond	Fluorides
	Gypsum Pile	Dust
	Product Storage & Transfer	

fugitive emissions, sampling heads are distributed over a vertical network positioned just downwind (usually about 5m) from the source. Sampling intakes are pointed into the wind and sampling velocity is adjusted to match the local mean wind speed, as monitored by distributed anemometers. A vertical line grid of samplers is sufficient for measurement of emissions from line or moving point sources (e.g., vehicular traffic on paved or unpaved roads), while a two-dimensional array of samplers is required for quantification of virtual point or area source emissions.

Sampling heads are distributed over a sufficiently large portion of the plume so that vertical and lateral plume boundaries may be located by spatial extrapolation of exposure measurements. The size limit of area sources for which exposure profiling is practical is determined by the feasibility of erecting sampling towers of sufficient height and number to characterize the plume. This problem can be minimized by sampling only when the wind direction is parallel to the direction of the minimum dimension of the area source.

The size of the sampling grid needed for exposure profiling of a particular source may be estimated by observing the size of a visible plume or by calculation of plume dispersion. Grid size adjustments may be required based on the results of preliminary testing.

Sampling heads should be symmetrically distributed over the concentrated portion of the plume containing about 90% of the total mass flux (exposure). For example, if the exposure from a point source is normally distributed, the exposure values measured by the samplers at the edge of the grid should be about 25% of the centerline exposure.

Sampling time should be long enough to provide sufficient particulate mass per sample and to average over several units of cyclic fluctuation in the emission rate (for

example, vehicle passes on an unpaved road). The first condition is usually easily met because of the proximity of the sampling grid to the source.

Assuming that sample collection media do not overload, the upper limit on sampling time is dictated by the need to sample under conditions of relatively constant wind direction and speed. In the absence of passage of weather fronts through the area, acceptable wind conditions might be anticipated to persist for a period of 1 to 6 hours.

TECHNIQUE SELECTION

The most appropriate measurement technique to apply to a given source is the one which can be most accurately applied. In general order of preference the techniques are quasi-stack, exposure profiling, roof monitor and upwind-downwind methods since precision and accuracy estimates follow this sequence in terms of rank ordering. This ordering follows from the fact that the quasi-stack method captures virtually all of the emitted particulate from a source and measures the flux using established procedures. This is not true of the exposure profiling and roof monitor measurement methods which use assumptions or estimates to relate the volume of air sampled to the total mass flux. In the case of the upwind-downwind scheme, a mathematical model with a generally accepted inaccuracy factor of two must be used to determine the source strength. This inaccuracy makes this method the least acceptable.

For a situation where the suitability of a given technique to a source is not immediately apparent (such as upwind-downwind to area sources), then the criteria for using the quasi-stack, exposure profiling, roof monitor and upwind-downwind methods should be applied to the situation in the order stated. For example, if for one reason or another the quasi-stack method cannot be applied to an operation, then it should be

determined if exposure profiling can be. If exposure profiling cannot be applied, then the roof monitor method should be considered.

Some of the individual criteria to be used in evaluating the utility of each method are:

Source Size - Is the source small enough to be enclosed or hooded? Can sufficient transport air flow be induced to capture the emissions?

Source Location - Is the source inside an enclosure? Where is an external source located in relation to buildings, roads, bodies of water? Will emissions be masked by emissions from other sources?

Source Accessibility - What are the limits of access to the source for hooding, ducting, location of samplers? Is there a platform or catwalk at a roof monitor?

Source Isolability - Can the emissions from the source be isolated from those of other sources? Can measurements be made of a combination of sources?

Site Topography - Will the terrain or buildings on or around the site affect the transport of the emissions or limit the location of samplers?

Site Meteorology - Will the emissions be affected by unusual wind speeds or directions? What is the likelihood of their occurrence? Will precipitation affect the emissions or measurements?

Process Continuity - Will the emissions be generated continuously? What are periods of generation of cyclic emissions? How many cycles must be sampled to obtain adequate data?

Process Variations - Are emission rates affected by variations in process parameters? What parameters are involved? Can variations during the sampling procedure be determined?

Measurement Effects - Will the measurement procedures affect the emissions or their generating process?

Application of Criteria

In evaluating which measurement scheme is most applicable for a given situation, preference first should be given to the quasi-stack method, followed by exposure profiling, roof monitor, and finally the upwind-downwind method. For each method,

those factors which count the methods' use are listed in terms of importance in the text:

Quasi-Stack Method

The following is use of the quasi-stack method.

- o Cannot be due to size, plant layout, OSHA or labor union requiring requirements, etc.
- o Space requiring method requires that a certain length of ductwork sec. The plant layout or process equipment arrangement be suitable to such.
- o Non-isolated source being tested has a low emission rate, and concentration in the area is relatively high, it may not be give precise results even if the background concentration measured.
- o Adverse conditions - if the source being tested is located out of downwind wind speeds could cause testing difficulty. Should it such conditions would greatly interfere with the conduct of, then this method should not be used.
- o Process induction of a significant flow of air over the process either the character or rate of the emissions by changing nature or flow rate.

Exposure Profiling

This technique is to line sources of fugitive emissions, but also has limited use with such as truck unloading. Sampling of haul roads has shown that the type with other factors such as silt content of the road, speed, and moisture have a pronounced effect upon amount of the emissions for line source tending to preclude the use of this method is the degree of difficulty of data in a field situation. These difficulties can be overcome through with plant personnel. The results obtained

with this method are usually much more accurate than those which would be obtained by an upwind-downwind measurement of a line or small area source.

In applying this measurement method to material transfer operations and the like the factors noted below would have to be overcome or the method could not be applied.

- o Proximity to the source - important since multi-point mass concentrations must be made in the fugitive cloud. The farther from the source the larger the cloud becomes due to diffusion, and as a result, more points need to be sampled. Should the samplers be placed too far from the source, then too many sampling points would be needed to make this technique usable.
- o Size - as noted above, too large a cloud would require too many samplers.

Non-isolatable emissions and adverse meteorological factors may also be reasons to reject the use of this technique.

Roof Monitor

Those factors which would preclude the use of this measurement method are:

- o Lack of specificity - by definition, the roof monitor technique measures emissions emanating from an enclosure. Ideally, the sources of those emissions are of a single unit operation or series of operations which are the focus of the testing program. This, however, is not always the case and, for the most part, any lack of specificity with regard to sources would tend to discount this method.
- o Unmeasurable Air Flow - the air flow from enclosures is governed by natural draft and influenced by related meteorological conditions. Should either the size of the openings be too large or the driving force of the draft too low, then accurate velocity measurements may not be possible.
- o Size of the area - roof monitors can extend for considerable distances and be of a large cross-sectional area. The number of points which need to be monitored for velocity or from which particulate samples are to be extracted may be too many to be practical.
- o Access - access to the opening of the monitor for the installation, monitoring and servicing of the measurement equipment by means of a platform, catwalk or reasonably flat roof surface must be available.

Upwind-Downwind Method

The use of the upwind-downwind sampling method is not usually restricted by considerations of source size, location or isolability. The method may be effectively employed with any size source as long as a measurable concentration of emissions is produced by the diffusion of the emissions into the atmosphere. Source location is not a factor, since all emissions are measured after their transport into the atmosphere. Access to the source is not generally required, but a non-obstructed area must be available to locate samplers within the emissions cloud downwind of the source.

The method permits sampling a combination of fugitive and stack sources as long as the other source's contributions to the measured concentrations can be separately and simultaneously identified. This eliminates the need for source isolation. The method is strongly influenced by site, topography and meteorological conditions, both in the location of sampling points and in the calculations of emission rates. Careful measurements of sampler locations and of wind speed and direction during the sampling are required. Since most upwind-downwind samplings are made as relatively long-term averages, the effects of cyclic emission generation or variations in the process will be diminished and need not be of primary concern. The measurement program has no effect on the process.

It is possible that at a given site a combination of topography and local meteorological conditions may combine to make a site unsuitable for upwind-downwind sampling. In this case, the site should be rejected for application of the method and a more suitable location found.

SECTION 3

SAMPLING EQUIPMENT

This section of the protocol describes the equipment to be used for the measurement of inhalable particulates from fugitive sources. The equipment is being dealt with separately from the methods description in order to avoid repetition and to place proper emphasis on the equipment itself. The sampling equipment can be divided into categories associated with each of the four measurement methodologies. There is also a description of the device to be used for determining inhalable particulate mass concentrations during the pre-test survey of the source.

Each of the sampling methodologies requires both velocity and mass concentration measurements. The equipment associated with each methodology is described for each method below.

QUASI-STACK SAMPLING EQUIPMENT

The techniques used for this methodology are identical to those used for the measurements of inhalable particulate matter in normal gas streams. For more detailed information than is presented here, the reader is referred to "Procedures Manual for Inhalable Particulate Sampler Operation" (Reference 1). For some of the sources tested (e.g., combustion-related) molecular weight determinations and water vapor concentrations may have to be known for sampling rate calculations. EPA Methods 3 (Reference 2) and 4 (Reference 3) should be used for these determinations when required.

Velocity Measurements for Quasi-Stack Application

Since for the most part the air flow rate in the duct will be determined by an averaging of point velocity determinations and since these point velocities will be in excess of ten feet per second, the most appropriate instrument is the Type S pitot tube (Reference 4).

Other point velocity sensors can be used for air flow determinations in quasi-stack applications as long as the accuracy of the instrument is known. Multiple point sampling probes are also workable alternatives for flow measurement, especially in those instances when the process cycle time is of such a limited duration as to make manual traversing impractical.

The number and the locations of the points in a velocity traverse are usually the same as those from which a sample is extracted (e.g., EPA Method 5). Since the sampling devices used in this program require a constant flow rate to insure a consistent collection efficiency, the number of sampling points must be restricted (see subsection Mass Concentration Measurements for Quasi-Stack Applications for details). These sampling points will not necessarily be the same as those specified for the velocity traverse, so that additional data must be taken. It is important that the velocity fluctuations at these sampling points be determined and that, based upon these fluctuations, the variation in percent isokinetic is calculated. If this variation is more than ± 20 percent, then another sampling point must be used.

Mass Concentration Measurements for Quasi-Stack Application

The Process Measurements Branch (PMB) of EPA's Industrial Environmental Research Laboratory of Research Triangle Park, North Carolina funded the development by Southern Research Institute of an inhalable particulate (IP) sampler to measure

the inhalable and fine particle fractions in industrial process streams. A complete description of this device can be found in Reference 1. Basically, the unit is designed to be compatible with a standard EPA Method 5 (Reference 5) or Method 17 (Reference 6) sampling train and consists of two series cyclones and a backup filter. The first cyclone (SK1-X) has a D_{50}^* of 15 micrometers while the second (SP1 III) one of 2.5 micrometers. The backup filter can be either a trimble or flat type depending upon the expected fine particulate concentrations. The cyclones are operated at a nominal flow of 25 l/min. (0.8 ft.³/min.) at 150°C (300°F). The flow through the cyclone must be kept constant to insure proper operation. Therefore, selecting a location in the ductwork which has the least velocity fluctuation is the most preferable since the number of nozzle changes is minimized. To determine the sampling flowrate for the cyclone SK1-X at D_{50} of 15 micrometers, Figure 1 can be used. This requires that a molecular weight analysis be made by EPA Method 3 (Reference 2). Viscosity can also be approximated by:

$$\mu = (1174.4 + 0.406 T) \times 10^{-6} \text{ poise} \quad (1)$$

where T is the gas stream temperature in degrees Celsius. The flow rate can then be used in conjunction with Figure 2 to determine the required nozzle size. The D_{50} of cyclone SK1-III can then be determined from Figure 3. As an example, assume that a gas stream to be sampled has a temperature of 50°C at a point whose velocity is 20 meters/sec. From Equation 1 the gas viscosity is 194.7×10^{-6} poise. From the figure,

*The D_{50} of a particulate collector is the aerodynamic particle diameter at which the collector achieves 50% collection efficiency; one-half of the particles are captured and one-half are not.

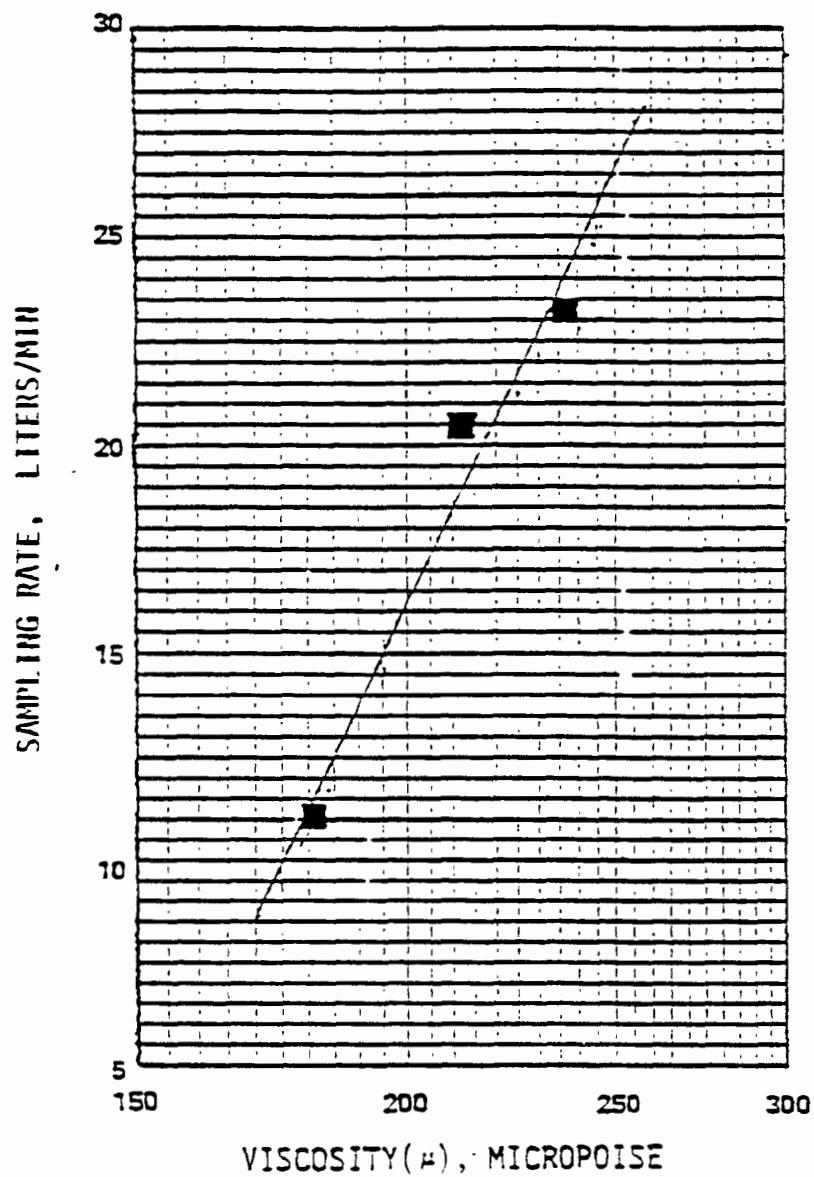


FIGURE 1: SAMPLING RATE VERSUS VISCOSITY AT $D_{50} = 15$ MICROMETERS AERODYNAMIC DIAMETER FOR IP CYCLONE SRI-X. (REF 1)

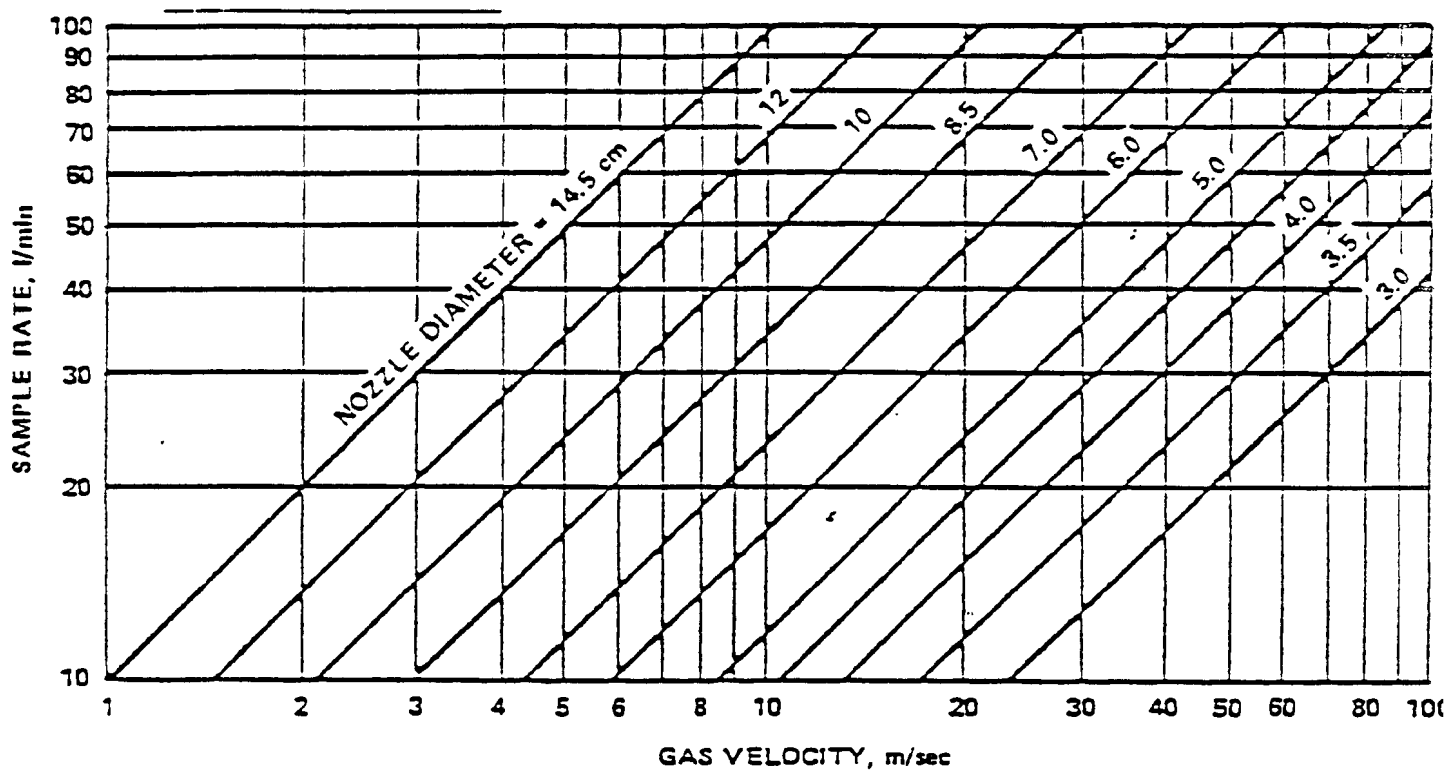


FIGURE 2: NOMOGRAPH FOR SELECTING NOZZLES FOR ISOKINETIC SAMPLING. (REF. 1)

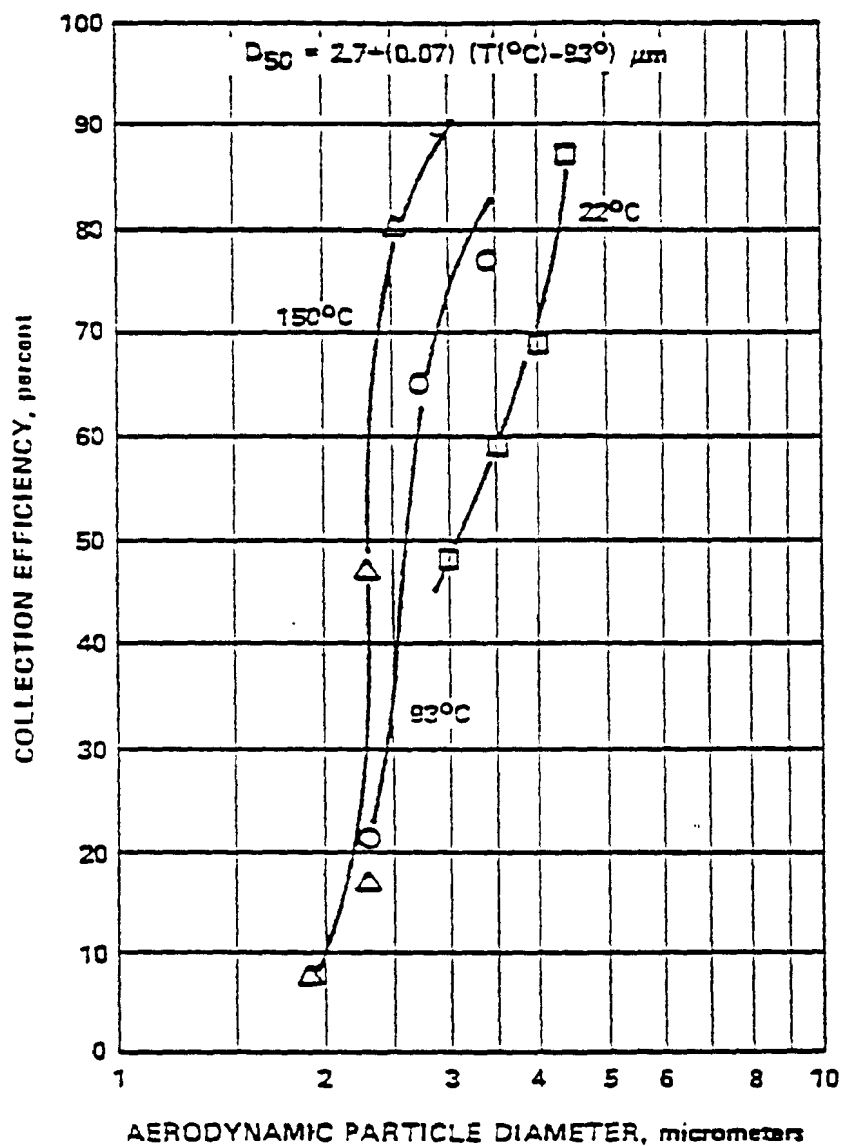


FIGURE 3: COLLECTION EFFICIENCY VERSUS AERODYNAMIC PARTICLE DIAMETER FOR CYCLONE SRI III AT 22°C AND 11.3 1/MIN (□), 93°C AND 19.8 1/MIN (○), AND 150°C AND 22.7 1/MIN (△). (REF 1)

the required sampling rate in liters/min. is about 15. From Figure 2, the nozzle diameter required for a sample flow rate of 15 and a velocity of 20 m/sec. is 4 cm.

An important point with respect to the LP sampling technique in quasi-stack applications is that the number of sampling point and samples taken is not the same as that for EPA Method 5. Four sampling points have been established for this technique, as per Reference 1.

A sample and at least one replicate is to be taken at each point. Any measurement of total mass concentration which deviates from the mean by more than 20% should be discarded and the sample repeated.

ROOF MONITOR SAMPLING EQUIPMENT

Most roof monitor systems rely on natural drafts caused by thermal gradients or very low volume fans as the prime movers of emissions-carrying air through the vent opening. Air velocities are usually quite low, in the order of a few feet per second, and require especially sensitive instruments for their measurement. Particulate concentrations in this air flowing through the monitor may be expected to be considerably higher than ambient levels, and can usually be effectively sampled with filter devices in the standard high volume sampler (40 cfm) flow rate range.

Velocity Measurements for Roof Monitor Applications

Since emissions from roof monitor type systems are transmitted by natural or low-volume induced drafts through relatively large openings, the air flow, while large, occurs at low velocity. The S-type pitot tube, which is the most commonly used point velocity sensor, has a lower limit of about 10 feet/second and is not applicable to this type of sampling. Table 4 lists some instruments which have lower velocity limits from

TABLE 4. LOW RANGE VELOCITY INSTRUMENTATION (Reference 7)

Instrument and manufacturer	Lower velocity limit, ft/min	Temperature range	Resistance to particulate	Applications
Inclined Manometer* Model 125-A1 Dwyer Instruments, Inc.	700	Same as primary sensor	Same as primary sensor	Industrial stacks, ducts, vents; also lab applications; air or non-air streams
Micromanometer* Model 10133 Thermo-systems, Inc.	700 in field 400 in lab	Same as primary sensor	Same as primary sensor	Lab applications; limited use in industrial stacks, ducts, vents; air or non-air streams
Microtector* Hook Gauge Dwyer Instruments, Inc.	700 in field 100 in lab	Same as primary sensor	Same as primary sensor	Lab applications; limited use in industrial stacks, ducts, vents; air or non-air streams
Electronic Manometer* Model 1023 Datametrics, Inc.	700 in field 100 in lab	Same as primary sensor	Same as primary sensor	Lab applications; limited use in industrial stacks, ducts, vents; air or non-air streams
Mechanical Vane Anemometer Davis Instrument Co.	70	To 250°F (est.)	Fair	Industrial vents and grilles; special calibration needed for non-air streams
Extended Range Propeller Anemometer Ruh. Young Co.	75	To 180°F for continuous duty	Fair	Roof monitors and vents; special calibration needed for non-air streams
Hot-wire Anemometer Model VT-1610 Thermo-systems, Inc.	30	To 212°F	Fair to good	Industrial stacks, vents, ducts; lab applications; special calibration needed for non-air streams
Hot-wire wedge sensor Model 1434-n Thermo-systems, Inc.	60	To 570°F	Good	Industrial stacks, vents, ducts; lab applications; special calibration needed for non-air streams
Fluidic Velocity Sensor Model 306K Fluidynamic Devices, Ltd.	200	To 450°F	Fair to good	Industrial stacks, vents, ducts; air or non-air streams
Stack Velocity Sampler* Model GSm-100K Teledyne Hastings-Raydist	100	Same as primary sensor	Excellent	Industrial stacks, vents, ducts; air or non-air streams
Differential Pressure* Transmitter brandt industries, Inc.	150	Same as primary sensor	Excellent	Industrial stacks, vents, ducts; air or non-air streams

*must be used in conjunction with a Type-S pitot tube or other appropriate primary sensing element.

- 1 to about 10 feet/second. The table also describes their resistance to particulates and gives application areas for each. While accuracy is the most important parameter associated with this type of instrumentation, the ability or ease of matching the sensor to an automatic data logger is of equal importance in roof monitor applications since the physical arrangements at the monitor will most often require remote operation of the instrumentation.

Mass Concentration Measurements for Roof Monitor Applications

The standard high volume sampler (as described in subsection High Volume Air Samplers), modified by the addition of a "horizontal elutriator" is to be used to determine mass concentrations for roof monitor applications. The elutriator is shown in Figure 4. The elutriator has been specifically designed to provide a D_{50} of 15 micrometers at a flow rate of 40 cfm with the collection diameter plates in a perfectly horizontal position. The air vent configuration thus requires that the high volume sampler be turned on its side with its filter in a vertical plume parallel to the roof monitor surface opening. The inlet velocity of about 0.14 m/sec., fixed by the constant flow rate and the bell mouth geometry of the inlet, will preclude isokinetic sampling in most instances. Corrections for an isokinetic sampling rate can be made in the concentration calculation procedure.

UPWIND-DOWNWIND SAMPLING EQUIPMENT

The equipment used in upwind-downwind sampling is basically the same as that used in standard ambient air monitoring work; namely, meteorological wind systems (anemometers and wind direction indicators) and high volume air samplers. While the

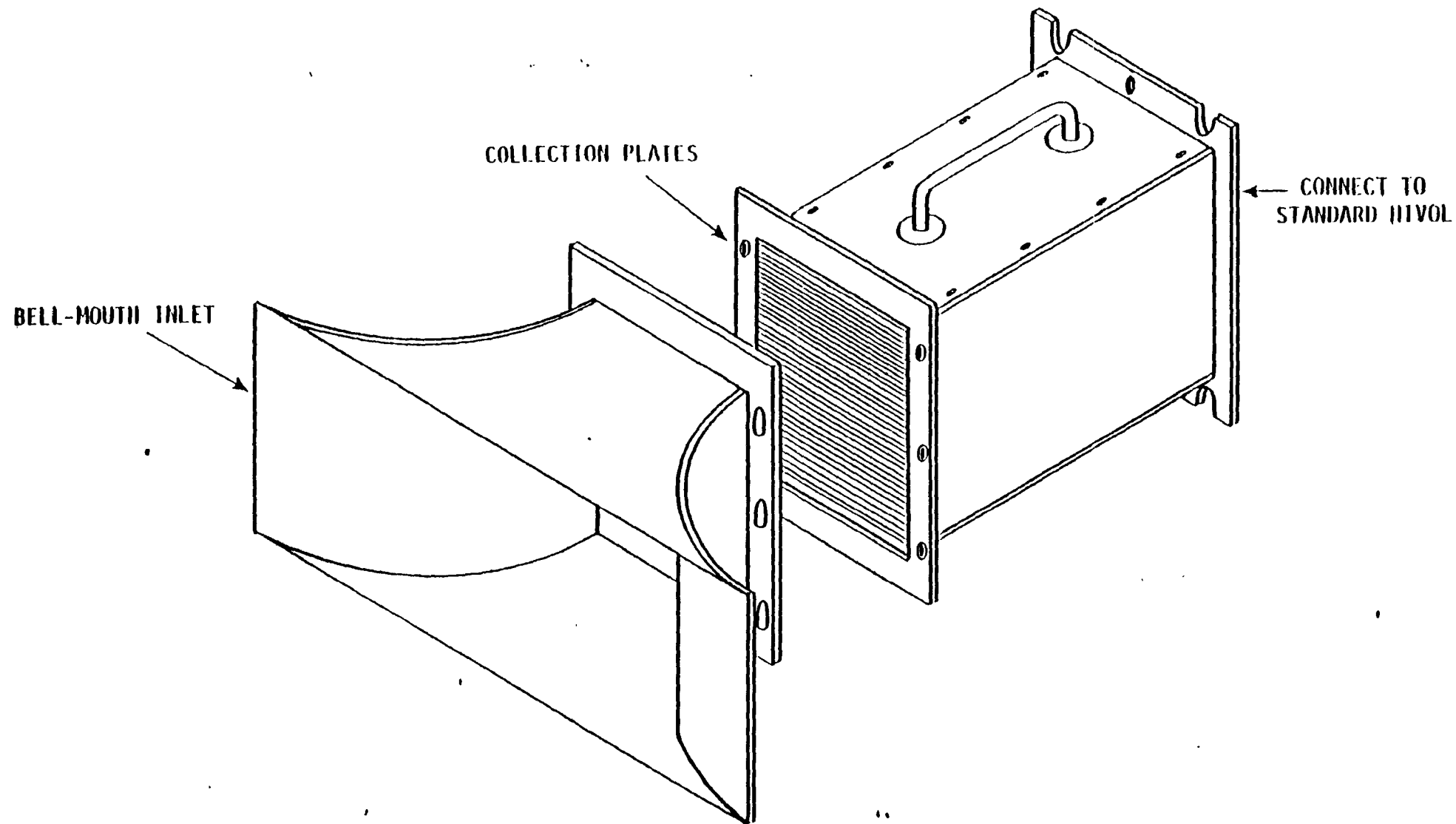


FIGURE 4: HORIZONTAL ELUTRIATOR

inlet configuration of the high volume sampling units have been changed to accomplish IF sampling, the operation of the unit is unchanged.

Meteorological Measurement for Upwind-Downwind Applications

Standard commercially available wind systems (such as a Climatronics Mark III) are acceptable for this application. Wind speed and direction measurements are continuously recorded at upwind and downwind stations during the sampling period. To compliment this information, meteorological observations are logged concurrent with the test periods. The observations should include such parameters as current weather conditions, sky cover and ground cover.

Mass Concentration Measurements for Upwind-Downwind Applications

The equipment used for upwind-downwind particulate sampling consists of various modifications to the standard high volume samplers. Included in these modifications are automatic flow controls, size selective inlets, and cascade impactors.

High Volume Air Samplers

Standard high volume samplers, which collect particulate matter samples in 8 x 10 inch filters at flow rates of about 40 cfm, have long been used to measure total suspended particulate matter in the ambient air. Their use in upwind-downwind samplings requires that the sampling flow rate, which is an important parameter in the particulate concentration calculations, be maintained at a constant value throughout the sampling run. Constant flow controllers are commercially available for almost all standard high volume samplers.

Size Selective Inlets (SSI)

Used in conjunction with the standard high volume air sampler is a size selective inlet which has a D_{50} of 15-micrometers when air flow is at 40 cfm. This device is practically insensitive to wind speed and there is no change in the operation of the sampler as a result of its addition. The size selective inlet is sold by various manufacturers, usually with adapters to permit its installation on any standard high volume unit.

High Volume Cascade Impactor

To determine the size distribution of the fugitive particulate, cascade impactors are used in conjunction with the SSI modified high volume sampler.

Since a 40 cfm sampling rate is desired to match the size selective inlet flow requirements, the use of a slotted-type impactor is indicated. The particle size cut-offs and Cunningham slip corrections of a commercially available unit are shown in Table 5 for 40 and 20 cfm flow rates for a four-stage model. Table 6 presents the impactor stage parameters for the same model.

The instruments are usually sold with a slide-rule calculator which can be used to determine the D_{50} for flow rates other than 40 cfm and particle mass densities other than 1g/cc.

There are various types of substrates available for use with the impactors. While Type A glass fiber filters are the most commonly used, cellulose and metal foils can also be used.

TABLE 3. CASCADE IMPACTOR CHARACTERISTICS⁽¹⁾(reference 8)

Stage Number	40 cm		20 cm		Geometric Standard Deviation
	$D_{P50}^{(2)}$ (microns)	$C^{(3)}$	$D_{P50}^{(2)}$ (microns)	$C^{(3)}$	
1	7.2 to ∞	1.02	10.2 to ∞	1.02	1.34
2	3.0 to 7.2	1.06	4.2 to 10.2	1.04	1.50
3	1.5 to 3.0	1.11	2.1 to 4.2	1.08	1.49
4	0.95 to 1.5	1.17	1.3 to 2.1	1.13	1.50
Hi-Vol Filter	0.0 to 0.95	-	0.0 to 1.3	-	-

(1) For spherical particles at 25°C and 760 mm Hg

(2) Cut-points determined from calibration with mono-disperse aerosols

(3) Cunningham slip correction factor

TABLE 6. HIGH VOLUME IMPACTOR STAGE PARAMETERS (Reference 8)

Stage No.	Slot Width, w (inches)	Number of Slots	Total Slot Length (inches)	Throat Length, T (inches)	Jet-to- Plate Distance, S (inches)	T/w	S/w	Slot Reynolds Number $\frac{V_2 w}{u}$	Jet Velocity, V(m/sec)
1	0.156	9	43.5	0.250	0.125	1.60	0.80	2245	4.30
2	0.064	10	48.8	0.050	0.075	0.78	1.17	2005	9.38
3	0.036	10	48.8	0.050	0.075	1.39	2.08	2005	16.7
4	0.018	10	48.8	0.050	0.075	2.78	4.16	2005	33.4

Portable Dust Monitors

In order to maximize the number of tests that may be conducted during any of the various sampling programs, the sampling time per test should be minimized. To accomplish this, an accurate estimation must be made of the particulate concentration prior to testing. This estimation is best performed during the pre-test survey of the facility. Since the pre-test survey is limited to a relatively cursory examination of the facility, the estimation of particulate concentrations must be made quickly using portable equipment. A Beta Gauge is recommended for this application for reasons of accuracy, ruggedness and reliability. Beta Gauges have been used for years to measure particulate concentrations and have established a satisfactory operating record. Several types of beta gauges are available. The RDM-101 respirable dust monitor manufactured by the GCA Corporation is discussed here because of its almost ideal operating characteristics for this application.

The RDM-101 uses a two-stage collection system. The first stage is a pre-collector which retains particles larger than 10 or 20 micrometers depending upon the configuration selected. The cyclone pre-collector retains virtually all particles larger than 10 micrometers while allowing almost all less than 2 micrometers to pass through. The other pre-collector effectively prevents particles greater than 20 microns from entering the unit.

Since this instrument collects particulate matter by impaction, particles having aerodynamic diameters less than 0.5 microns do not possess the inertia to be deposited and, therefore, are not effectively measured.

The second collection stage is a polyester impactor disc upon which the particles are collected. The particles collected absorb the beta radiation reaching the Geiger tube detector from a carbon-14 source. beta radiation attenuation is almost

exclusively dependent upon the mass per unit area of the particulates and is expressed as:

$$\frac{N}{N_0} = e^{-\mu m^0} \quad (3)$$

Where:

N_0 = initial beta count (without particulate absorption)
 N = final beta count
 μm = absorption coefficient
 0 = average mass per unit area of collected particulate

The particulate concentration can therefore be expressed as:

$$C = \frac{A (\ln N)}{\mu m Q t} \quad (4)$$

Where:

C = particulate concentration
 A = particulate collection area
 Q = volumetric flow rate
 t = effective sampling time

The instrument takes two counts; the first is taken during the twenty seconds at the start of the sampling; the second at the end of the cycle. The natural logarithm of the second count multiplied by a system constant is subtracted from the natural logarithm of the first count and displayed as the mass concentration.

The instrument can operate in three basic modes. The first two modes operate according to pre-set sampling times. These modes are "1 x" (one-minute sampling time) and a "10 x" mode which has a shorter sampling time (10 seconds) to enable measurement of high concentrations. The third mode consists of manual operation by which the sampling time can be varied. Figure 5 shows the measureable concentration ranges for the instrument in this mode.

Exposure Profiling Sampling Equipment

The exposure profiler designed to quantify dust emissions from paved and unpaved roads (Figure 6) consists of a portable tower (4 to 6m height) supporting an array of

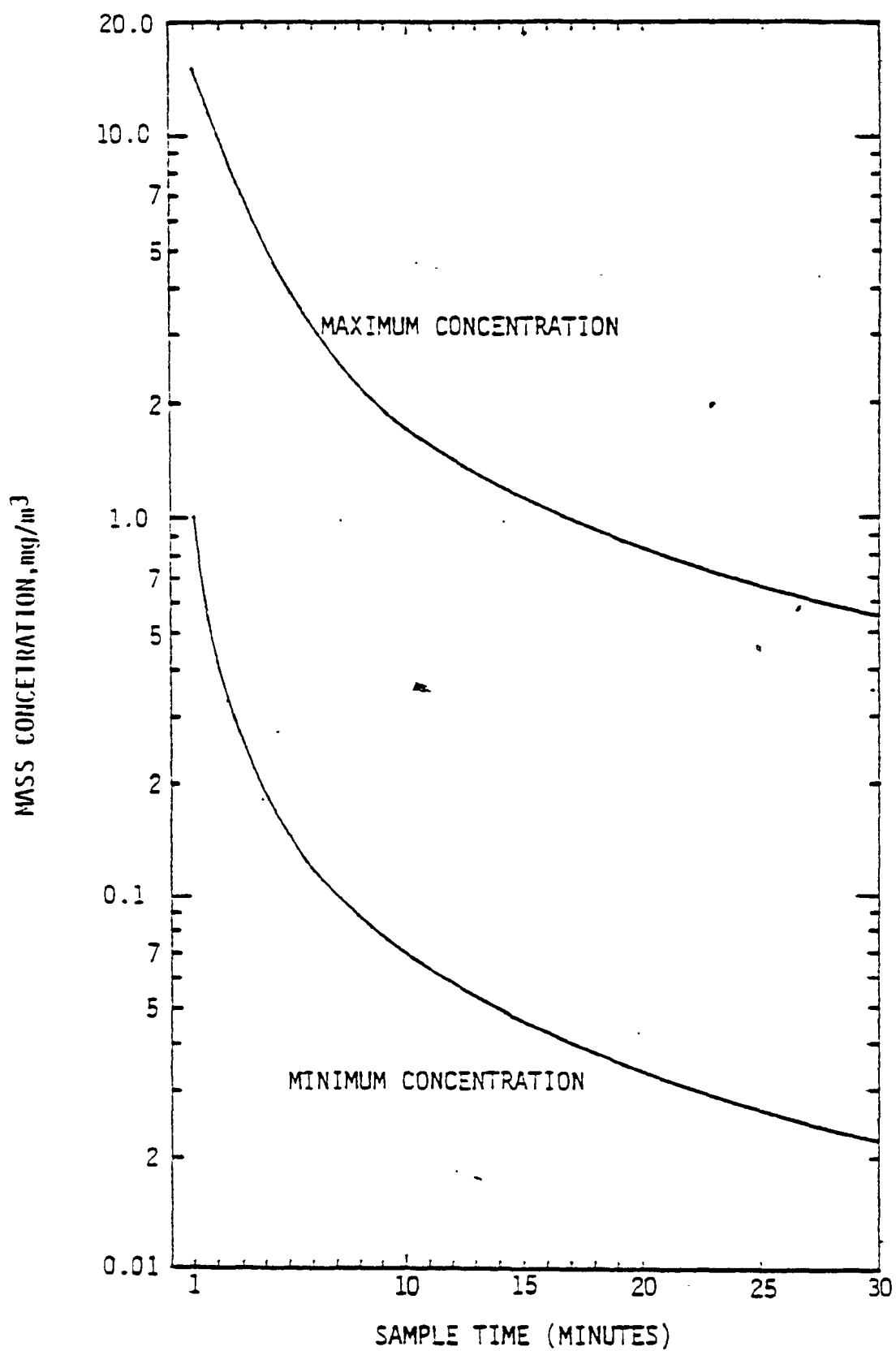


FIGURE 5: CONCENTRATION RANGE vs SAMPLE TIME FOR RDM-101
IN MANUAL MODE

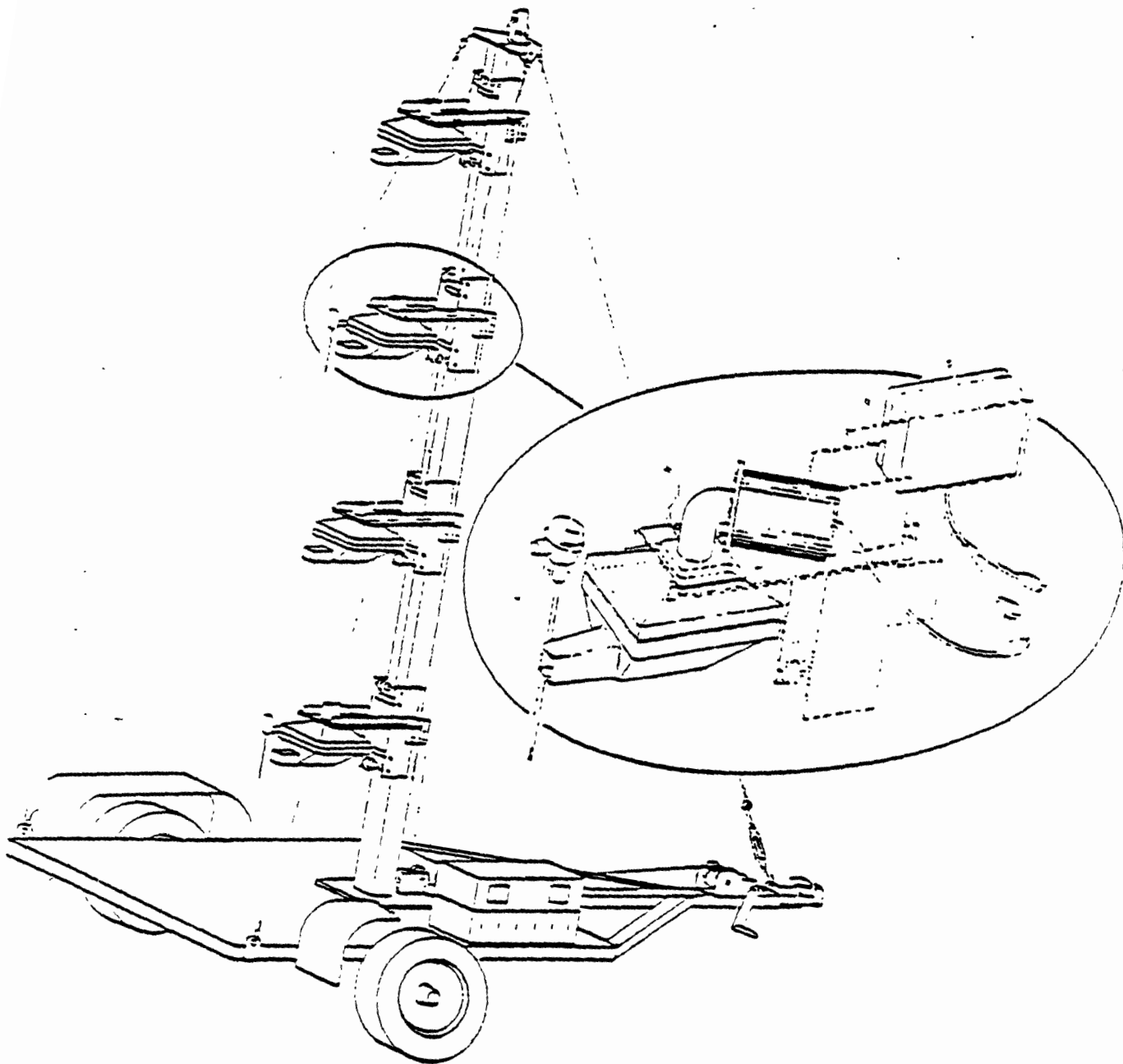


FIGURE 6: EXPOSURE PROFILER-LINE SOURCE MODE.

sampling heads. Each sampling head is operated as an isokinetic exposure sampler directing passage of the flow stream through a settling chamber (trapping particles larger than about 50 μm in diameter) and then upward through a standard 8-inch by 10-inch glass fiber filter positioned horizontally. Sampling intakes are pointed into the wind, and sampling velocity of each intake is adjusted to match the local mean wind speed, as determined prior to each test. Throughout each test, wind speed is monitored by recording anemometers at two heights, and the wind speeds at the other sampler heights are determined by assuming a logarithmic distribution.

In addition to airborne dust passage (exposure), fugitive dust parameters that are measured include suspended dust concentration and particle size distribution. Conventional high volume filtration units are operated upwind of the test source to measure background concentration. Because of the variation of particle size distribution with height above the surface, particle sizing devices should be operated at two or more heights in the fugitive dust plume.

High volume parallel-slot Cascade impactors with a $34 \text{ m}^3/\text{hr}$ (20 cfm) flow controller may be used to measure particle size distribution alongside the exposure profiler. Each impactor unit is equipped with a cyclone pre-separator to remove coarse particles which otherwise would tend to bounce off the glass fiber impaction substrates, causing fine particle measurement bias. The cyclone sampling intake is directed into the wind and fitted with a nozzle of appropriate size to provide for isokinetic sampling.

SECTION 4

DESIGN OF A SAMPLING PROGRAM

After the most appropriate measurement method has been selected for a specific source, the sampling program must be designed to apply the method in the most effective manner. Site specific factors need to be incorporated into a general plan design such that a tailored program is achieved. This section of the protocol presents a test plan design along with the information necessary to develop the detailed plan.

PRETEST SURVEY

The purpose of conducting a pretest survey at the site is to obtain enough detailed information about the sources of emissions to be measured to permit the preparation of a detailed test plan and sampling system design. The information required is essentially the same for each of the sampling methods. Table 7 lists the general information to be obtained as a result of the survey. Most of this information and additional information suggested by considerations of the specific on-site situation can be obtained by interviewing the cognizant plant supervisory personnel and from first-hand observations by the measurement program designers.

In order to increase the number of tests to the maximum achievable over a given time period, it is necessary to estimate the mass concentration during the pre-survey visit. This can be accomplished with the use of the Beta Gauge described in Section 3, EXPOSURE PROFILING SAMPLING EQUIPMENT. The use of this instrument is described for each application in the sampling techniques section for each method.

TABLE 7. PRE-TEST SURVEY INFORMATION TO BE OBTAINED FOR
APPLICATION OF FUGITIVE EMISSION SAMPLING METHODS

Plant Layout	<p>Drawings:</p> <ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Access routes to the areas where Test Equipment/Instrumentation Will be Located Names, Extensions, Locations of Plant Security and Safety Supervisors

TEST PLAN

To assure that none of the many details required in the conduct of an effective measurement program is overlooked, it is essential that all of the program planning and design be completed prior to the start of the field effort in the form of a detailed test plan. Using the information collected in the pre-test survey, the plan should provide a detailed specification of the procedures and equipment required to satisfy the objectives of the program and a step-by-step guide to its performance.

The test plan may be prepared in any of a variety of formats according to individual preferences, but should contain sufficient information to guide the test program personnel in the following areas:

Objective

A statement of the goals of the program, presented in terms of the end product; e.g., the determination of an emission factor for a specific source as pounds per ton of product.

Approach

A description of the measurement method, data reduction procedures and calculations to be employed to achieve the goals described in the objective.

Program Schedule

A detailed, chronologically-ordered description of each phase of the sampling program including sampling network design, site preparation, equipment preparation and calibration, site set-up and equipment check out, sampling and data collection schedule and procedures, data reduction and analysis, emission factor calculations and report preparation.

Equipment Specifications

A listing of the sampling and associated equipment required for the program including pertinent characteristics.

Facilities Requirements

A listing of the facilities such as electrical power, special constructions, work space, etc., required for the program.

Sampling Network

A detailed description of the network, including specific sampling and associated equipment locations; or, if this can not be determined, a description, including sample calculations, of the method to be employed in designing the network.

Site Preparations

A listing of the work required, such as the construction of platforms, installation of power lines, etc., to prepare the site for the installation of the sampling network.

Equipment Preparation

A listing of the check-outs, calibrations and other preparatory work to be conducted for each item of equipment prior to its delivery to the site.

Site Set-up and Check-out

A listing of the steps to be taken for the installation and operational verification of the sampling network.

Sampling and Data Collection Schedule

A description of the samples and associated data to be collected during a typical measurement run, including examples or actual data logging sheets.

Data Reduction and Analysis

An identification of standard procedures or a description of special procedures to be followed in the handling and analysis of samples and the reduction of associated data.

Emission Factor Calculations

A description, including equations and sample calculations, of the procedures to be employed in the calculation of emission factors from the reduced data and sample analyses.

Report Preparation

An outline of the format to be used in the preparation of the measurement program's documentation as a final report.

STATISTICAL BASIS FOR DESIGN

When a sample of a material is obtained for analysis, the number of sample increments necessary to insure a required precision of results at a given confidence level can be calculated if the standard deviation of the analyzed parameter has been established or estimated. In a similar manner, the number of fugitive emissions tests necessary for a given level of precision at a desired confidence level can be estimated based upon the standard deviation of the emission values. Unfortunately, there is little or no available data of this type for inhalable particulate fugitive emissions and, therefore, an estimate of the standard deviation cannot be reasonably made at this time. For each measurement program, therefore, the contractor must estimate the standard deviation of the inhalable particulate emissions for each source and for each test condition, set the degree of precision desired and then apply the appropriate formula to determine the required number of tests. Budgetary constraints will

obviously have a marked effect upon the setting of the precision limits and, consequently, the number of tests. In order to maximize the information developed by the testing program, a number of steps can be taken to insure that a statistically valid program is designed.

First, it is important to determine whether the type of source, or one having similar unit operations, has ever been tested previously. The best sources of information are the EPA task managers, the other EPA contractors in the fugitive emissions field and the open literature. Whatever data is gathered during this initial effort should be examined to determine the causative factors influencing the magnitude of the emissions and to establish, if possible, an estimate for the standard deviation of the emission values. The former is of importance since a proper understanding of the factors influencing the emission rate is necessary to set up the statistical experimental design for quantification of the influences. While the word "experimental" design is used here, it should be noted that in field experiments of this type little or no control of the operating factors can be obtained but, rather, whatever data is obtained must somehow be factored into the statistical analysis. For estimating the standard deviation of the emissions data differences between data gathered from different plants is of importance, since large differences would tend to indicate the existence of some influence not previously accounted for.

In determining which factors have the greatest effect upon emissions it is important to estimate the form of the predictive equation, since it may be necessary to transform (e.g., log transformation) the gathered data for statistical analysis. Knowledge of the form of the predictive equation is useful in determining the type of transformation most amenable to the statistical test chosen.

If it is not possible to estimate the standard deviation of the emission rate from the literature with respect to the suspected causative factors, the first part of the field program may have to determine it, requiring that some of the data be analyzed on site. This requires a field laboratory capable of making gravimetric determinations.

Having gathered the data, a number of tests of significance can be applied to verify if suspected factors do indeed affect the emission rates. Multi-factor analysis of variance is probably ideal for determining if complex interrelationships between factors occur. The most useful statistical tool, however, will probably be a multiple linear regression analysis, providing that the predictive equation can be linearized.

SAMPLING PROGRAM DESIGN PROCEDURES

Each of the inhalable particulate measurement methods described above requires specific and special calculations to accomplish the design of the sampling equipment or network. This section describes the procedures to be followed in the design of each method and in locating sampling sites for the roof monitor, upwind-downwind and exposure profiling methods.

Quasi-Stack Sampling Method Design Procedures

The following sections explain the techniques used to design the capture hoods for fugitive emission sampling by the Quasi-Stack method. Duct and fan design methods are also explained in detail.

Quasi-Stack Hood Design

Since the concentration determinations required for quasi-stack sampling will be made using the stack sampling techniques described in Reference 1, the only specific design consideration for the method is ensuring that the hood or enclosure installed over the source is capable of capturing and transporting virtually all of the source emissions to the sampling points in measurable concentrations.

The emissions capturing requirements for quasi-stack sampling can usually be met using one of three basic hood types - booths, canopies and exterior hoods. These are illustrated in Figure 7, along with the equations for calculating their required capture air volume flow rates. In these equations, V is the air velocity required to capture particles emitted from the source at their null point farthest from the hood face and X is the distance from the farthest null point to the hood face. The null point is the location at which the velocity of the particle becomes the same as that of the surrounding space.

To illustrate the relative capture air volume flow rates required for each type of hood, consider a hypothetical source as a cube 6 ft. on a side located in a moderately drafty location emitting moderate amounts of nuisance dust particles from any point on its surface with equal velocity, resulting in null points 1 ft. from the surface.

A booth enclosing the source would be about 7 feet high, 8 feet wide and 8 feet deep. All null points would then be within the booth, and the required air flow rate would be:

$$Q = VWH$$

The required capture velocity, V , determined from Table 9 (Reference 9) is 50 feet per minute, and

$$Q = 50 \times 7 \times 8 = 2800 \text{ cubic feet per minute}$$

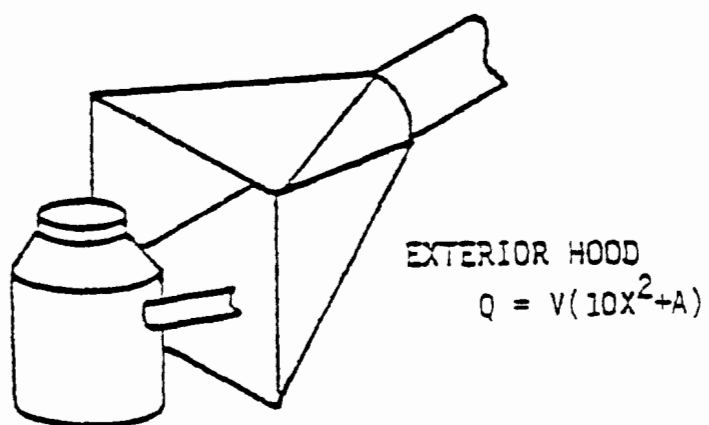
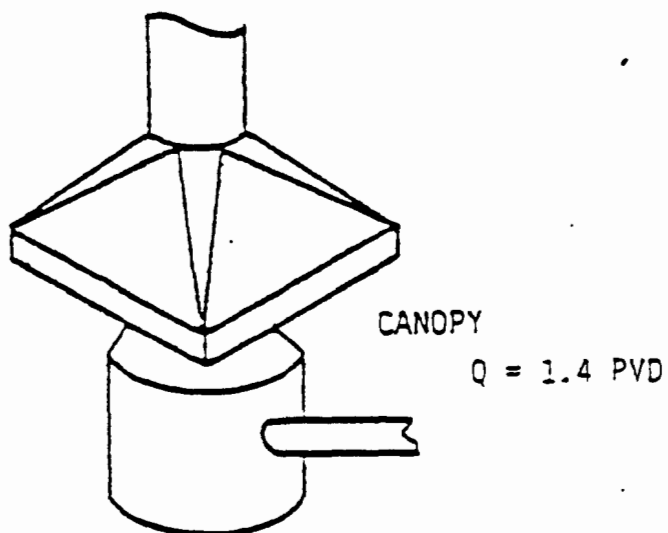
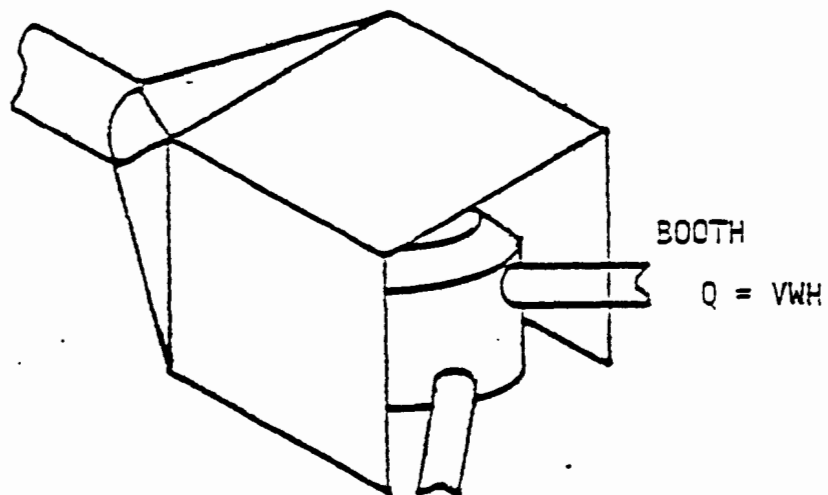


FIGURE 7: TYPICAL QUASI-STACK CAPTURE HOOD CONFIGURATIONS

A 7 by 7 foot canopy located 1 foot above the source would have an effective work perimeter of $(4 \times 8) = 32$ ft., and the required air flow rate would be:

$$Q = 1.4 PVD$$

V, from Table 8, is 60 feet per minute, and

$$Q = 1.4 \ 32 \times 7 \times 60 = 18,816 \text{ cubic feet per minute}$$

A 7 by 8 foot exterior hood located 1 foot from the source would have an effective L distance of 8 feet and the required air flow rate would be:

$$Q = V(10 \times L^2 + A).$$

V, from Table 8, is 60 feet per minute and

$$Q = 60 (10 \times 8 \times 8) + (7 \times 8) = 41,870 \text{ cubic feet per minute}$$

The required air flow rate for the canopy is almost 7 times that for the booth. For the exterior hood, it is almost 15 times that for the booth.

Design considerations and procedures for the three hood types are described in detail below:

Booth Design

A booth is one of the most preferred solutions to the problem of capturing emissions from industrial process operations, second only to the total enclosure. The equation

$$Q = VA_f = VWn$$

Where:

- Q = exhaust flow rate, CFM
- V = selected face velocity, ft/min
- A_f = open face area of booth, ft^2
- W = width of booth opening, ft.
- n = height of booth opening, ft.

TABLE 8. TRANSPORT AIR VELOCITIES REQUIRED
FOR PARTICLE CAPTURE (reference 9)

Draft Characteristics of the Space	moderate amounts of Particulates	Large amounts of Particulates
<u>Controlling velocities required at null point, fpm</u>		
Nearly draftless space, or process easily baffled	40-50	50-60
Medium drafty space	50-60	60-70
Very drafty; no opportunity for baffling	70-80	75-100

describes the relationship between the exhaust flow rate and the booth dimensions. For most processes a face velocity of 50 fpm should prove sufficient. Where the process is more active, higher velocities may be required. Reference should be made to "Industrial Ventilation," (Reference 10) where the required face velocities for most common operations can be found. For very active cold operations, the design equations for exterior hoods may be used. In such cases the null point should be noted with relations to the open booth face and the analysis should then proceed as with any exterior hood arrangement. For hot processes the convective heat flow should be calculated as in the following section.

Canopy or Receiving Hood Design

Receiving hoods or canopies serve as receptors of air and dust generated and directed into the hood by the process itself. The hood is placed directly on the axis of the emitted gas stream and proper design is dependent only on sizing the hood opening sufficiently and insuring that the exhaust flow rate exceeds the flow given off by the process. For cold processes, the extent and velocity of the emission cloud can be determined during the pre-test survey directly by measurement or estimated by observing the process.

In the case of hot processes, the convective action of the heated air is the driving force for the emissions. The flow of air induced by the convective force can be described as follows:

$$q_o = 29(H'A_p)^{2/3}$$

where:

q_o = air induction rate at upper limits of the hot body, CFM

A_p = cross sectional area of air stream, ft²

m = height of column receiving air - i.e., height of not body*, ft

H' = convective heat transfer rate, BTU/min.

The heat loss, H', in BTU/min can be estimated in the equation:

$$H' = \frac{n_c A_s \Delta t}{60}$$

Where:

n_c = convection coefficient, $\frac{\text{BTU}}{\text{min ft}^2 \text{ } ^\circ\text{F}}$

A_s = surface area emitting heat, ft^2

Δt = temperature difference between the hot skin temperature and the room ambient temperature, $^\circ\text{F}$.

Heat loss coefficients for various shapes are listed in Table 9. The use of the factors listed in the table in the above equations will yield the convective air flow rate from which the required exhaust flow rate can be determined.

As an example, consider the application of a low canopy hood over a hot emission source. Since the source is relatively close to the hood, it can be assumed that there is little mixing with the surrounding air and, therefore, the flow induced by the hot sources (q_0) would be the same amount exhausted by the hood. It can also be assumed that due to the proximity of the hood and the source that the horizontal surface area of the source, A_s , is the same as the face area of the hood. For a horizontal heated surface, therefore,

$$n_c = 0.38(\Delta t)^{1/4} \text{ and}$$

$$H' = \frac{0.38}{60} A_s (\Delta t)^{5/4}.$$

*For vertical surfaces, m is the height of the surface. For horizontal cylinders, it is the diameter. For horizontal planes, u is not defined but since, in most cases, a low canopy hood would be used for such sources, the height from the source to the hood can be used.

TABLE 9. HEAT LOSS COEFFICIENTS (Reference 9)

<u>Shape of heated surface</u>	<u>h_c, $\frac{\text{BTU}}{\text{min ft}^2 \text{ } ^\circ\text{F}}$</u>
Vertical plates, over 2 ft high	$0.3 (\Delta t)^{1/4}$
Vertical plates, less than 2 ft high (X = height in ft)	$0.28 \left(\frac{\Delta t}{X} \right)^{1/4}$
Horizontal plate, facing upward	$0.38 (\Delta t)^{1/4}$
Horizontal plate, facing downward	$0.2 (\Delta t)^{1/4}$
Single horizontal cylinders (where D is diameter in inches)	$0.42 \left(\frac{\Delta t}{D} \right)^{1/4}$
Vertical cylinders, over 2 ft high	$(0.4) \left(\frac{\Delta t}{D} \right)^{1/4}$
Vertical cylinders less than 2 ft high - multiply h_c from formula above by factors below:	
<u>Height (ft)</u>	<u>Factor</u>
0.1	3.5
0.2	2.5
0.3	2.0
0.4	1.7
0.5	1.5
1.0	1.1

Since

$$A_s = A_p,$$

$$Q_o = 0.4 A_s (m(\Delta T)^{5/4})^{1/3}$$

Example 1: A pot of molten metal (3 ft. in diameter) is held at 1500°F. What is the minimum rate of exhaust required to remove the generated fume if a low canopy hood is placed 3 ft. above the pot?

Using the above equation, and assuming a square hood of 3 ft. x 3 ft. is used, then

$$Q_o = 0.4 A_s (m(\Delta T)^{5/4})^{1/3}$$

$$Q_o = 0.4 (3 \times 3) (3(1500 - 70)^{5/4})^{1/3}$$

$$Q_o = 1447 \text{ cfm}$$

Example 2: A hot metal casting, approximately a cube in shape and 4 ft. on a side, is to be controlled by a hood located about 3 ft. above it. Calculate the required exhaust flow rate if the temperature of the casting is 1000°F.

From Table 7, the coefficient of heat loss for a vertical plate is given by the formula

$$h_c = 0.3 (\Delta T)^{1/4}$$

The equation for total heat loss is then:

$$H' = \frac{0.3 A_s (\Delta T)^{5/4}}{60}$$

Assuming an area of 80 sq ft,

$$H' = \frac{0.3 (80) (1000)^{5/4}}{60}$$

$$= 2,247 \frac{\text{BTU}}{\text{min}}$$

Then, assuming that the column of hot air has a cross-sectional area equal to the top of the cube,

$$\begin{aligned}q_o &= 29 (H'Ap^2m)^{1/3} \\&= 29 (2,249) (16)^2(4)^{1/3} \\&= 3830 \text{ cfm}\end{aligned}$$

As noted previously, the use of the quasi-stack technique is limited to relatively small sources. For this reason, it is envisioned that only a low (less than 3 ft. from the source) canopy hood would be required. In cases where hoods must be placed higher, a booth arrangement will most probably be required rather than having a free standing hood, since the amount of air required to compensate for the hot plume dispersion and cross flows would probably tend to dilute the air concentration to an excessive degree.

A "safety factor" can be applied to the design of canopy hoods for hot processes. The approach, however, is markedly different. With hot processes the hot air stream's cross-sectional area determines the size of the hood and convective action of the heated surfaces dictates the exhaust flow rate. A process upset or cross-wind could cause the exhaust cloud to deviate from its path, resulting in a loss of capture efficiency. Also, the phenomena illustrated in Figure 8 could also occur when there is a significant distance between the hood face and the throat. In this example, the convectively induced flow is q_z . Mixing inside the hood results in a total flow of $2 q_z$, then half of the air is not immediately exhausted and it will eventually result in the entire hood volume becoming filled with contaminated air. If the face area of the hood

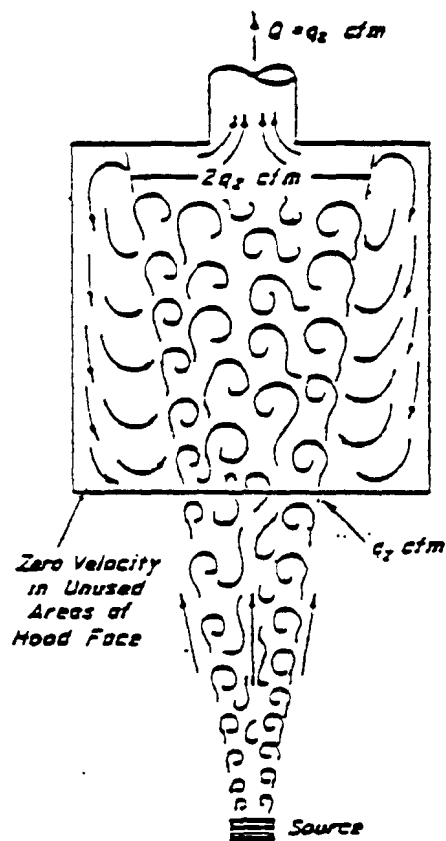


FIGURE 8: CANOPY HOOD ON HOT SOURCE SHOWING INTERNAL RECIRCULATION (REF 9)

is large with respect to the rising air column then there is no force acting on the downward components of the recirculating air to keep them from escaping. To rectify this, and the other noted situations, an increased exhaust flow is required as characterized by the equation:

$$Q = q_z + VA,$$

Where

- Q = total exhaust flow rate, CFM,
- q_z = hot air induction rate, CFM,
- v_z = face velocity, ft/min,
- A = the area of the hood face not occupied by the entering hot air column, ft²,

is required. Values of V are usually in the 100-150 ipm range for moderately drafty situations. Higher velocities may be required for other situations.

Exterior Hood Design

There are three aspects to the design of an exterior hood for cold processes: 1) the definition of the contour area serviced by the hood, 2) the location of the null point, and 3) the determination of the required capture velocity at the null point. First, the area effectively exhausted by the hood must be determined. By effective it is meant that the generated emissions are captured at the desired efficiency. This effective area is usually termed the significant contour area. By definition, this area is bounded by "the surface which is the focus of all points having the same air velocity induced by a source of suction" (Reference 9). In other words, the area is defined by a surface having velocity vectors of equal magnitude and direction. It is necessary to

define such an area, since it will determine the required air exhaust rate directly according to the formula:

$$Q = V A_C,$$

where:

Q = air flow rate,

V = velocity,

A_C = area of velocity contour.

If the velocity is taken to be the capture velocity and the null point is within the volume bound by the contour area, then the particles of concern should be collected at high efficiency.

To be effective for design work, the contour area must be definable for a wide variety of configurations. Fortunately, such relationships have been developed. For free standing hoods (round or rectangular of length five times their width), the contour area is defined by:

$$A_C = 10\lambda^2 + A_f$$

where:

λ = axial distance (radius) from hood face to significant contour,

A_f = area of face opening of hood,

and

$$Q = V (10\lambda^2 + A_f) .$$

Having defined the face area of the hood from the process configuration, it is necessary to know the distance of the null point from the hood face and the required capture velocity at the null point to determine the required exhaust flow. Exhaust flow formulas for other configurations and hood types can be found in Figures 9 and 10. Null points are usually determined by observation of the source as is illustrated in Figure 11.

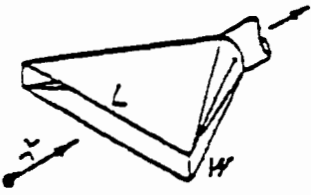
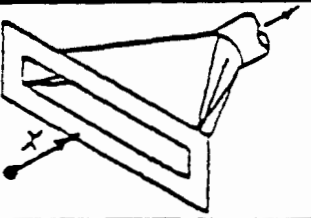
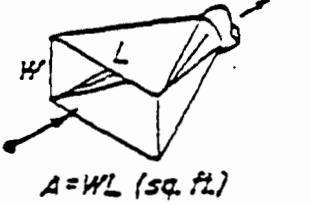
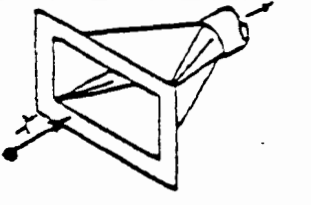
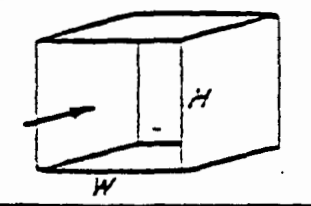
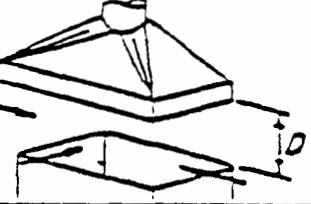
HOOD TYPE	DESCRIPTION	AIR VOLUME
	SLOT	$Q = 3.7 LVX$
	FLANGED SLOT	$Q = 2.8 LVX$
 $A = WL \text{ (sq. ft.)}$	PLAIN OPENING	$Q = V(10X^2 + A)$
	FLANGED OPENING	$Q = 0.75V(10X^2 + A)$
	BOOTH	$Q = VA = VWH$
	CANOPY	$Q = 1.4 PDV$ P = PERIMETER OF WORK D = HEIGHT ABOVE WORK

FIGURE 9: HOOD TYPES AND EXHAUST VOLUMES. (REF 10)


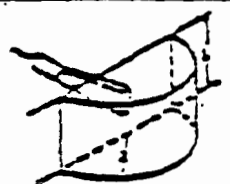

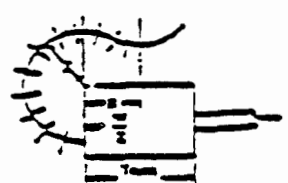

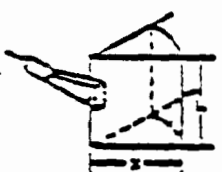
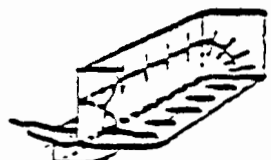

HOOD ARRANGEMENT	DESCRIPTION	EXHAUST VOLUME
	Quarter Sphere	$Q = 3.1 \frac{V}{s}$
	Half Cylinder	$Q = 3.1 \frac{V}{s}$
	Three-quarter Cylinder	$Q = 4.7 \frac{V}{s}$
	Half Cylinder plus Flange (or other flange)	$Q = 4.1 \frac{V}{s}$
	One-eighth Sphere	$Q = 2.6 \frac{V}{s}$
	Quarter Cylinder	$Q = 2.6 \frac{V}{s}$
	Quarter Cylinder	$Q = 2.6 \frac{V}{s}$
	Hood on Flange	$Q = 6.3 \frac{V}{s}$

FIGURE 10: HOOD ARRANGEMENTS AND EXHAUST VOLUMES. (REF 9)

For a lateral hood, as shown in the figure, the X value is the distance from the farthest null point to the hood.

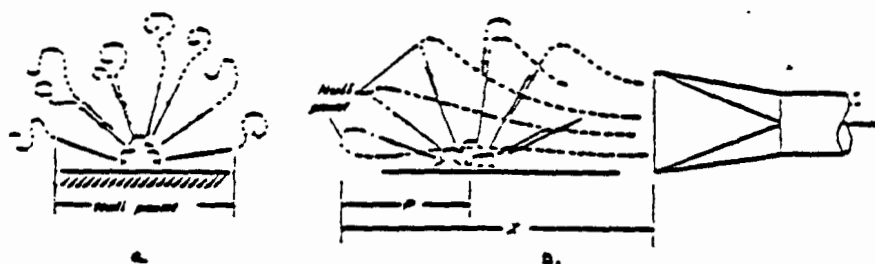
Use of the null point concept introduces an automatic safety factor into the design. Applying the control velocity at the null point assumes that the exhaust flow does not act to retard the velocity of the escaping particles. Since in reality it does, a margin of safety is built into this design concept. To complete the design calculation, it is necessary to define the capture or control velocity. In practice, this term is found to be dependent upon the draft characteristics of the surrounding space and the quantity of dust emitted. Values for various conditions can be found in Table 9. The values shown in the table should only be used as guides. The actual field situation may dictate that higher or lower control velocities are required.

Example

An industrial process results in a multi-directional dust cloud being generated as illustrated in Figure 11. Observations indicate that the particles tend to lose their initial momentum about one foot from the source. Due to the nature of the location a lateral hood arrangement is required as is shown in Figure 10 (hood on plane) which, due to locational constraints, cannot be placed closer than 1.5 feet from the source. Assuming various conditions of draft, what are the required exhaust flow rates?

It is given that the pulvation distance is 1 ft. Since the distance from the hood to the source is 1.5 ft., then the X distance is 2.5 ft. Since the hood is placed on a plane with its opening perpendicular to the floor on which the source is located, the equation relating the flow and X distance is

$$Q = 6.3 V X^2$$



- a - Pulvation action without hood
- b - With exterior hood; P is pulvation distance and X is P plus distance to hood

FIGURE 11: EXTERIOR HOOD ARRANGEMENT (REF 9)

Using the upper values from Table 9 for nearly draftless conditions,

$$\begin{aligned} Q &= 6.3 (60 \text{ fpm}) (2.5 \text{ ft})^2 \\ &= 2,363 \text{ ft}^3/\text{minute} \end{aligned}$$

for medium drafty conditions,

$$\begin{aligned} Q &= 6.3 (70 \text{ ft/min}) (2.5 \text{ ft})^2 \\ &= 2756 \text{ ft}^3/\text{min, and} \end{aligned}$$

for very drafty conditions,

$$\begin{aligned} Q &= 6.3 (100 \text{ ft/min}) (2.5 \text{ ft})^2 \\ &= 3938 \text{ ft}^3/\text{min.} \end{aligned}$$

The inclusion of the concept of a "safety factor" with regard to exterior hood design is achieved by the use of a "salvage zone" which exists beyond the selected area contour and whose width and the magnitude of the velocity vectors contained within serve as a buffer zone to the actions of transient drafts or process upsets. An example taken from Reference 9 illustrates this concept. A free-standing exterior hood is placed at a point near a particulate emitting source such that the X distance is 3-3/4 inches. If a control velocity at the null point is assumed to be 75 feet per minute, then, according to equation (ignoring the hood face area since this term is usually small when compared to $10X^2$), the required exhaust rate would be 75 cfm. If, however, the X distance was decreased by 1 inch due to faulty observation or process upset, then the control velocity at the new null point would have dropped to 47 fpm (a 37% decrease). Suppose, however, that the hood is located 12 inches from the null point rather than 3-3/4 inches. The exhaust flow rate would then be 750 cfm. Should the X distance decrease an inch, as was assumed for the other case, the new control velocity at the null point would be 630 fpm (a 16% decrease). Such a decrease is much more

acceptable than that noted for the previous case. Changes in the contour velocities for other distances are shown in Figure 12 for the two cases cited.

While velocities of 25 fpm are not very effective for primary control, they do exhibit some "salvage" value in collecting particles. The concept of a salvage zone (that is, the width of the zone between the desired control velocity contour and the 25 fpm contour) is useful in obtaining a feel for the extent of the safety factor. For the above example, the width of the salvage zone for the first case is 2-3/4 inches while for the second, about 8-1/2 inches. Obviously, the second case offers a larger safety factor than the first, and is preferred in instances of variable processes. Table 10 gives the equations for determining the salvage width for some common hood shapes (refer to Figure 10 for comparison).

The use of an exterior hood is not recommended for hot processes, since a low canopy hood almost always can be applied to a source and is usually more effective. When for some reason an exterior hood is required on a hot process the convectively induced flow and the exhaust flow rate required due to pulvation action must both be calculated. An estimate must then be made of the flow rate necessary to deflect all of the hot gases into the hood. There is no theoretical methodology which can be used to show how to accomplish this, and, therefore, a large safety factor must be included in the design.

Duct Design

The ductwork design for a quasi-stack sampling system must meet four basic criteria:

- a. The design must provide a minimum transport velocity for the collected particles.

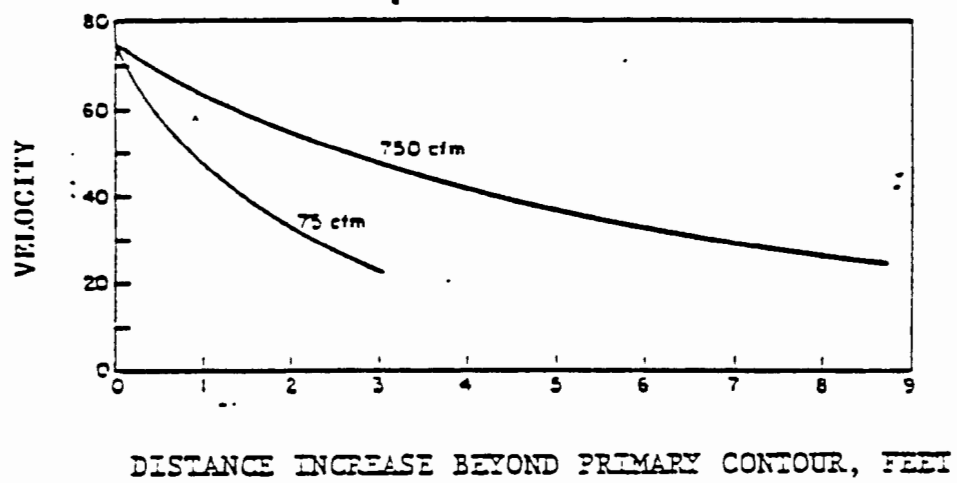


FIGURE 12: EFFECT OF DISTANCE ON CAPTURE VELOCITY (REF 9)

TABLE 10. EXPRESSIONS FOR WIDTH OF SALVAGE ZONE
FOR COMMON HOOD SHAPES (Reference 9)

hood Type	Contour Formula	Salvage Zone width, Ft.
Unobstructed or flanged opening	$Q = V(10X^2 + A)$	0.064 $Q - (X - \text{distance})$
Flanking plane parallel to hood axis	$Q = V(5X^2 + A)$	0.088 $Q - (X - \text{distance})$
1/4 Sphere	$Q = V(\pi X^2)$	0.113 $Q - (X - \text{distance})$
1/8 Sphere	$Q = V \frac{\pi X^2}{2}$	0.160 $Q - (X - \text{distance})$
1/2 Cylinder	$Q = V(\pi XL)$	0.013 $Q/L - (X - \text{distance})$
1/4 Cylinder	$Q = V \frac{\pi XL}{2}$	0.025 $Q/L - (X - \text{distance})$

- b. Sampling considerations with respect to minimum upstream and downstream distance from the sampling point must be met.
- c. Duct dimensions should be sufficient to allow for the use of the in-stack cyclones - if this is not possible then dimensions must be large enough to insure that the use of a sampling probe would not adversely affect the flow distribution.
- d. Flow should be in the turbulent region.

These criteria will ultimately aid in the specification of the duct dimensions and length, as well as the air velocity through the system. A discussion of points a, b and d follows:

Transport Velocities

For particles in the inhalable particulate range, the required transport velocity is usually insignificant. This is borne out by reviewing the equation for terminal settling velocity

$$V_T = 1.37 \rho d^2 \times 10^5$$

where:

- V_T = terminal velocity, (ft/sec)
- ρ = particle density, (lb/ft³)
- d = particle diameter, (ft).

For a 20 micrometer particle having a specific gravity of 2.0 the terminal velocity would be given by

$$V_T = 1.37 (2.0 \times 62.4 \text{ lb/ft}^3) \cdot \frac{20 \times 10^{-6} \text{ meters}}{.305 \text{ meters/ft}} \times 10^5$$

$$V_T = 0.07 \text{ ft/sec,}$$

or less than five feet per minute.

TABLE II. TYPICAL TRANSPORT VELOCITIES (Reference 9)

<u>Dust Type</u>	<u>Transport Velocity</u> <u>ft per minute</u>
metal turnings	4000 - 5000
Lead dust	4000 - 5000
Foundry tumbling barrels and shakeout	4500
Sand blast dust	3500 - 4000
Fine coal	4000
Wool	3000 - 4000
Grain	2500 - 4000
Cotton	2500 - 3000
Rubber dust	2000 - 25000
Sawdust	1200 - 3000
metal dust	1800

Larger particles do, however, require significant velocities to keep them suspended in a moving air stream. An empirical relationship between horizontal conveying velocity, particle diameter and specific gravity has been developed for particles larger than 1 millimeter.

It is given by:

$$V_h = 105 \frac{Z}{Z+1} d^{0.4}$$

Where:

- V_h = horizontal conveying velocity, (ft/minute)
- Z = specific gravity
- d = particle diameter, (micrometers).

For conveying velocities in the vertical direction,

$$V_v = V_h^{0.27} d^{0.2}$$

where V_v is the vertical conveying velocity in ft. per minute.

While these values were obtained under laboratory conditions they serve as a useful guide for setting minimum requirements for field conditions. Table 11 gives some typical values of V_h for various materials. Additional examples may be found in Reference 10.

Turbulent Region Consideration

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 minimum Reynolds Number of 2×10^5 for a typical smooth walled duct. Since the Reynolds number for air is typically calculated as

$$Re = 110 DV$$

Where:

Re = Reynolds Number, dimensionless

D = Duct diameter, ft.

V = Air velocity, ft/min

and since, for round ducts,

$$V = \frac{4Q}{\pi(D)^2}$$

by substitution,

$$D = 7 \times 10^{-4} Q$$

defines the maximum duct diameter allowing turbulent measurement duct flow.

Upstream/Downstream Consideration

The duct must be of sufficient length so that the air flow at the sampling point will be non-cyclonic. Usually, this would necessitate that the sampling point be 8 to 10 diameters downstream and 3 to 5 diameters upstream from any disturbance. Duct length at a minimum, therefore, would be 8 times the duct diameter.

Fan Selection

The previous sections have shown how to determine the required exhaust flow rate for hooding a process and the duct velocity, dimensions and length. From these various parameters, the fan required for a particular application can be selected. The specified flow rate for the fan should be about twice that calculated in order to provide for field adjustments due to inaccuracies in assumptions, calculations, etc. A variable bypass air

duct located downstream from the hood can be used to control the air flow rate as is shown in Figure 13.

The fan must also be designed as to overcome any losses in pressure due to resistance in the system. For convenience purposes, this discussion will use the concept of velocity head in calculating these losses. Basically, the velocity head is the pressure exerted by a moving air mass. It does not include, by definition, static pressure. For air moving systems it is described by the equation for velocity head due to friction loss in pipes:

$$n_v = \frac{v^2}{1100} \rho,$$

where:

- n_v = velocity head, inches of water
- v = air velocity, ft/min
- ρ = density of air, lb/ft³

Friction loss and shock loss due to sudden expansion or contraction are the two major sources of pressure loss. For most situations, friction loss can be determined by the use of the above equation and Tables 12 and 13. Shock losses are illustrated for various duct configurations in Figure 14.

Example: What is the friction loss in 50 ft. of 7" diameter smooth pipe when the air velocity is 4000 ft/min? Assuming the air density to be 0.075 lb/ft³, then from Table 12, the friction loss would be at most one velocity head unit and, therefore,

$$n_v = \frac{4000^2}{1100} (0.075)$$

$$n_v = 1" \text{ of water}$$

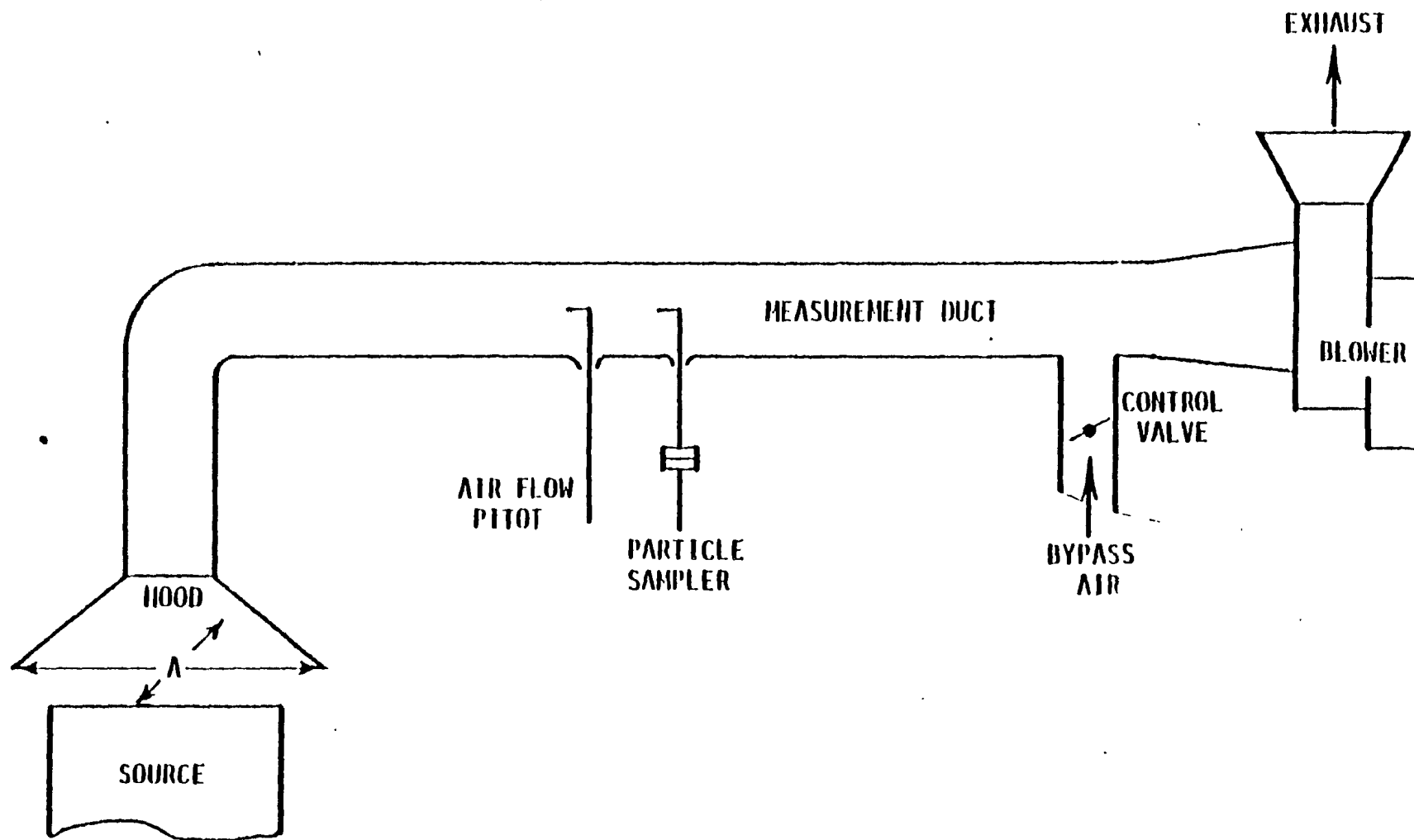


FIGURE 13: TYPICAL QUASI-STACK SAMPLING SYSTEM

TABLE 12. FRICTION LOSS IN AVERAGE GALVANIZED IRON DUCT¹ (Reference 9)

Duct size, inches	No. of diameters ¹	Duct size, inches	No. of diameters ¹
3	39	12	54
4	42	14	56
5	44	16	58
6	46	18	60
7	48	20	61
8	50	25	64
9	52	30	66
10	52	35	68
11	53	40	71

¹ Number of duct diameters for a loss of one velocity head, $(V/4005)^2$.

TABLE 13. MULTIPLIER FOR FRICTION LOSS VALUES
GIVEN ABOVE FOR VARYING ROUGHNESS (Reference 9)

Type of duct	Factor
medium smooth, e.g., steel pipe without joints, or exceptionally well constructed galvanized iron duct system, with smooth joints	0.9
medium rough; e.g., average concrete surface	1.5
Very rough; e.g., average riveted steel	2.0

For shock loss, Figure 14 gives an indication of what to expect for various configurations. To determine total system pressure losses, it is only necessary to add the contribution of the losses due to the hood, expansions/contractions, elbows, junctions and duct friction.

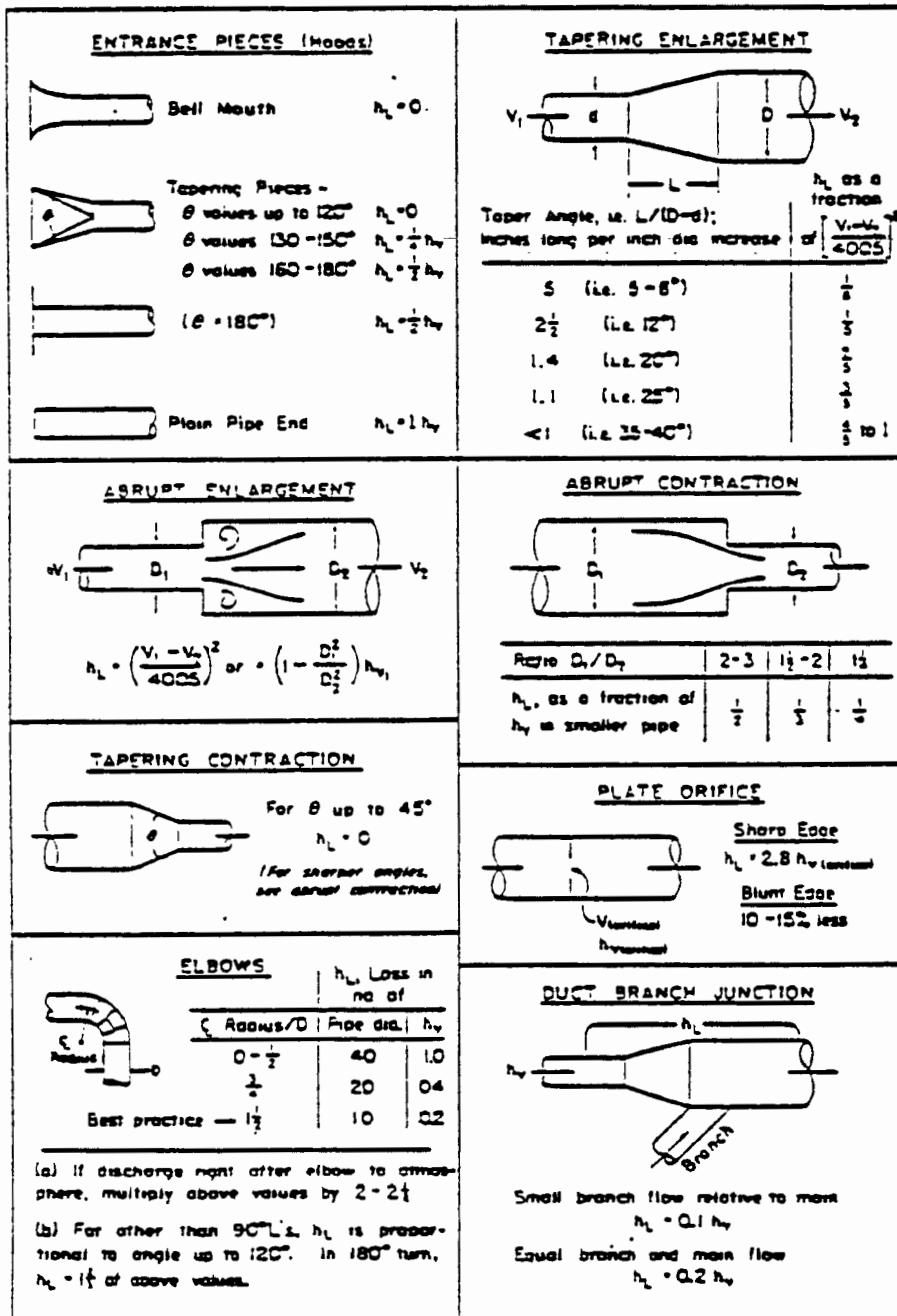
Quasi-Stack Method Sampling Techniques

A velocity traverse is conducted using EPA Methods 1 and 2. Sampling locations are depicted in Figure 15. Velocity measurements should also be made at these points to insure that isokinetic sampling rates are maintained within ± 20 percent.

Figure 16 can be used to determine the proper sampling duration for estimated particulate concentrations. These concentrations can be estimated during the pre-survey by use of the Beta Gauge. A sample is to be taken at each point. At least one replicate sample should also be taken.

Quasi-Stack Sampling Schedule

Unlike the other LP fugitive measurement methods, the quasi-stack sampling schedule does not depend upon the vagaries of wind speed and direction but, rather, is solely dependent upon the process cycle time and LP concentration. The time required to gather an adequate sample is illustrated in Figure 16. Since four samples are to be taken for each test it is necessary that the tests be conducted at the same period of the process cycle to insure repeatability. For steady-state processes this is not a concern. For processes where a definite cycle does exist (e.g., charging, tapping, casting, etc.) care must be taken that the entire operation is sampled and not that a given time per operation is set for each test. For example, a charging operation to a furnace may consist of three distinct changes. The time required to perform this operation may



• FIGURE 14: SHOCK LOSSES IN COMMON DUCT ARRANGEMENTS (REF 9)

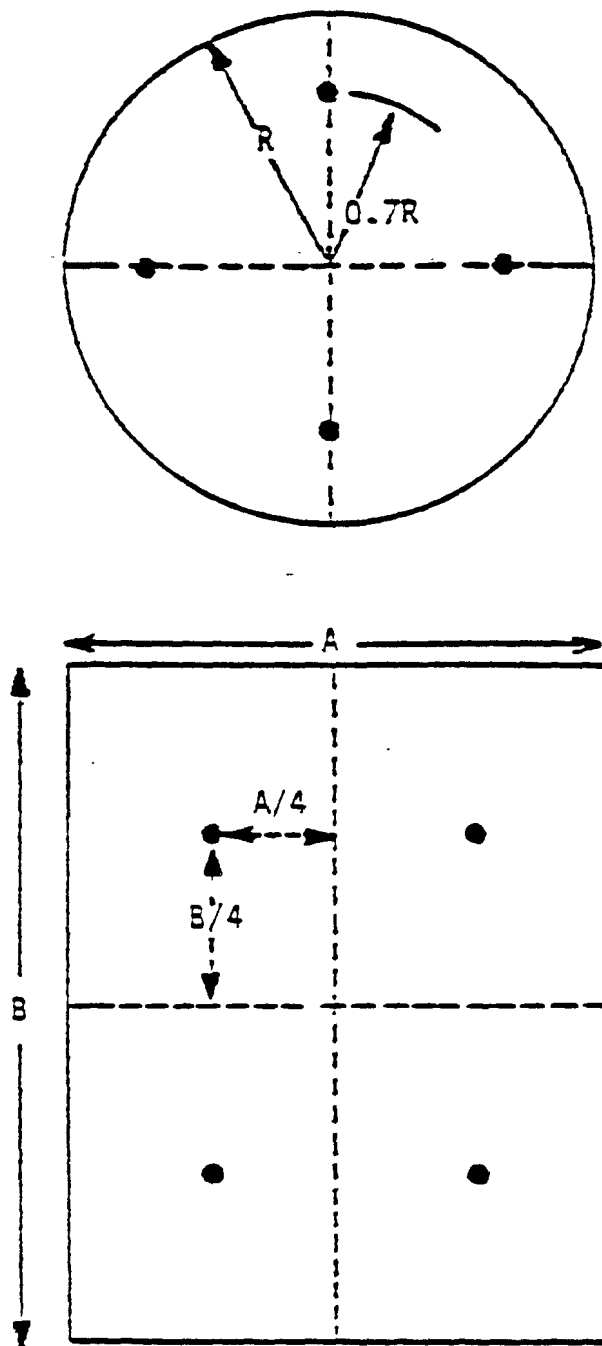


FIGURE 15: RECOMMENDED SAMPLING POINTS FOR CIRCULAR &
SQUARE OR RECTANGULAR DUCTS

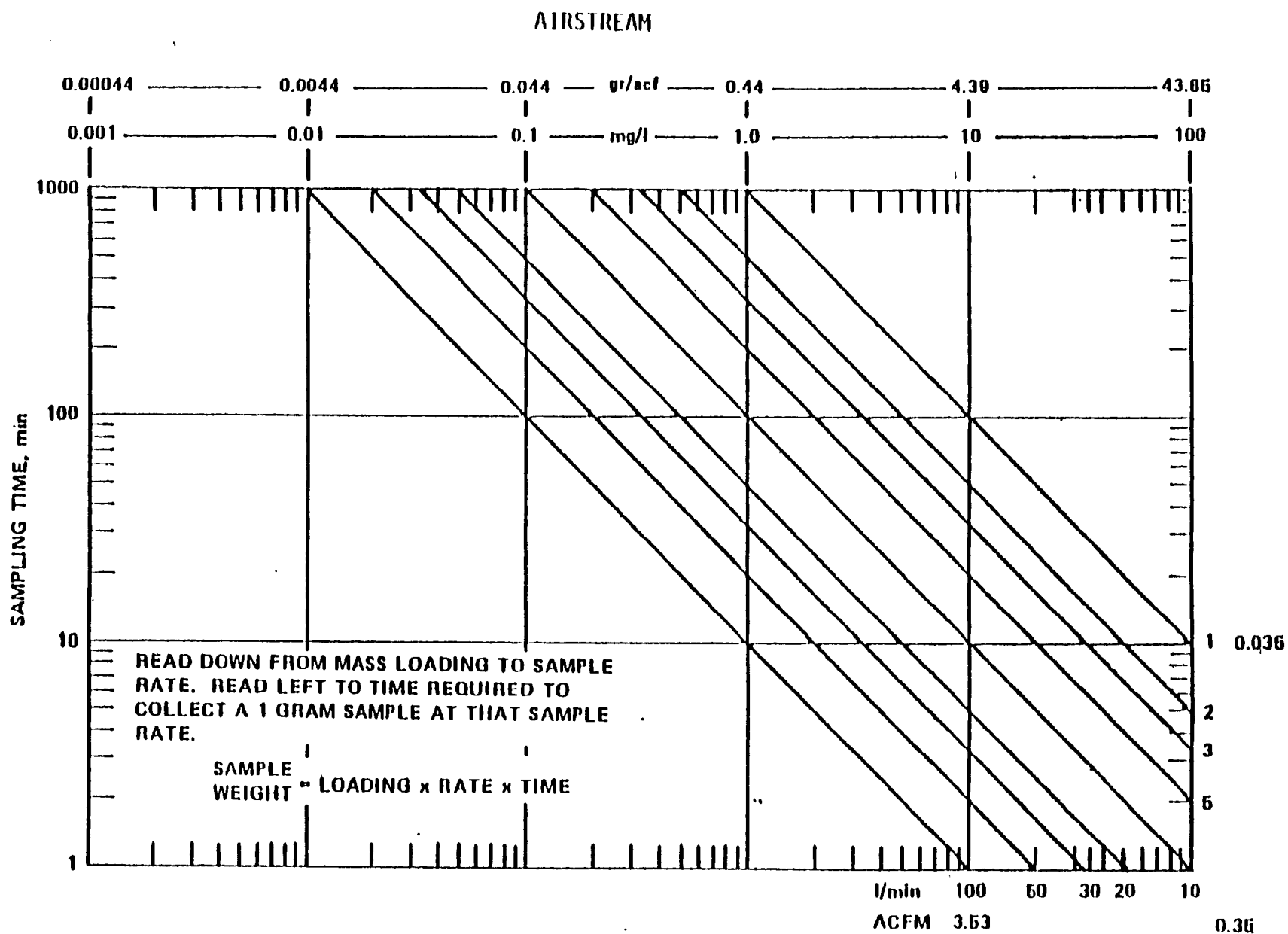


FIGURE 16: NOMOGRAPH FOR SELECTING PROPER SAMPLING DURATION. (REF 1)

vary. Therefore, the tests should be conducted over the entire changing period and not be set to a given time.

Quasi-Stack Data Collection

There are two distinct sets of data collected during a quasi-stack test. The first set is concerned with the test itself. The sampling rate, static pressure, gas stream temperature, etc. are examples of this sort of data and are well known to stack testing personnel. The other set of data concerns the operation being tested. Process data to be gathered are material throughput, process temperatures and pressures, number of loading operations etc. This type of information is usually obtainable from plant personnel.

Roof Monitor Sampling Method Design Procedures

The roof monitor sampling method is used to determine the total emissions rate of all sources within a building or enclosure as the product of the total emissions conveying air volume flow rate through an opening in the structure and the concentration of the emissions in this transport air. The volume flow rate is calculated as the product of the velocity of the air as measured in the opening and the area of the opening. The pollutant concentration is determined from samples collected in the plane of the opening taken concurrently with the velocity measurements. To assure that a sufficient number of both velocity and concentration measurements are obtained, the sampling system and program must be designed with careful consideration of such factors as source complexity and size, location and size of the measurement opening, and the characteristics of the emissions.

Source/Site Considerations

The principal source characteristics influencing the program design are the size and position of the emission points relative to the measurement opening and the variability of the source emission rate. Emission points located relatively close to the opening may result in the formation of a pollutant cloud or plume that will pass through only a portion of the opening or in the formation of a stratified cloud of variable concentration. Such a situation will require the acquisition of a greater number of concentration samples in the opening than would be the case with a widely distributed, homogeneous cloud generated by emission points more remote from the opening. Variations in emission rate will require that longer sampling periods be employed than those for more constant rates to ensure that a true average concentration is obtained.

The size of the measurement opening will govern the number and arrangement of velocity measurements and particulate sampling points required to obtain these average values. In general, the larger the opening, the greater the number of sampling points required.

Meteorological Considerations

External wind can affect the flow patterns of emissions-carrying air from building openings in a number of ways. Winds blowing across the surface of an opening may bias the flow of emissions toward the downwind end of the opening. Winds blowing across a roof in the same direction as the flow from an opening may create eddy currents or even a low pressure area outside the opening to change the flow pattern or rate through the opening. Winds of high velocity blowing directly into an opening may create areas of reverse flow through the opening, or, in the case of a double-sided monitor, blow directly through the monitor, adding to the volume flow leaving the opposite side. Care

should be taken to eliminate such wind effects during the sampling by restricting the sampling to periods when either the wind speed is low enough or its direction is such as to negate such effects. If this is not possible, wind screens may have to be installed to divert the wind from the opening.

Sampling Configuration Design

The selection of the most appropriate roof monitor sampling equipment is highly dependent upon each specific site condition. Parameters that effect the equipment choice include:

- Particulate loading
- Air velocity through the opening
- Process cycling time
- Process variability
- Sampling location
- Sampling rate
- Air stream temperature

Transport air velocities in almost all situations will be measurable using one of the low velocity sensors described in Table 4. To facilitate the velocity measurements when long-term sampling is required, or where large openings or potentially hazardous conditions prevent access to the opening by test personnel during the sampling, devices that operate in conjunction with recorders or other data-loggers must be used.

Particulate sampling will be accomplished by the use of two standard high volume samplers fitted with the horizontal elutriators as described in the section on sampling equipment.

The determination of the most effective velocity and concentration measurement sites within the opening is described below.

Velocity Profiling

In order to minimize the number of velocity measurements and the complexity of the velocity recording instrumentation required, a method for determining the average velocity through the opening from only a few measurements has been developed. The method requires the performance of manual traverses across the opening with suitable velocity measurement devices to establish velocity profiles and the calculation of velocities based on the profile values, for other points in the plane of the opening. The calculated velocities are then used to determine an area - integrated average velocity for the opening. The procedure for the method is as follows:

- o Perform a traverse along the vertical centerline of the opening to obtain velocity readings at convenient (say, 1 ft.) intervals. For openings longer than about twenty ft, either select a representative section about twenty feet long or select a number of locations for vertical traverses each in the center of about twenty feet of opening length.
- o Plot the measured velocities as a function of height along the traverse line and draw a smooth curve to represent the vertical velocity profile.
- o Perform a traverse along a horizontal line through the maximum velocity plotted for the vertical velocity profile. Use the horizontal centerline of the opening if it falls within the area of maximum velocity.
- o Plot the measured velocities as a function of length along the traverse line and draw a smooth curve to represent the horizontal velocity profile.

The traverses should be performed under the same process, atmospheric and meteorological conditions as those expected during the sampling.

To determine the velocity profile over the entire opening or selected section area, divide the area into convenient (preferably square) small areas. Locate the center of each area on a set of coordinates with the crossing of the two measured velocity profiles as its center (0,0), the vertical traverse line as the Y axis (0,Y), and the horizontal traverse line as the X axis (X,0). Calculate the velocity at the center of each area (X,Y), as:

$$V_{(X,Y)} = \frac{V_{(X,0)} V_{(0,Y)}}{V_{(0,0)}}$$

where $V_{(X,Y)}$ is the velocity at any point, $V_{(X,0)}$ and $V_{(0,Y)}$ are the velocities at corresponding X and Y distances along the horizontal and

vertical axis profiles, and $V_{(0,0)}$ is the maximum velocity at the junction of the axes.

- o Calculate the average velocity, V_A , as the sum of the area velocities divided by their number. Calculate the velocity adjustment factor, F_v , as the quotient of the average (calculated) and the maximum (measured) velocities, in:

$$F_v = \frac{V_A}{V_{(0,0)}}$$

In the sampling program, velocity measurements then need only be made at the maximum (0,0) point to calculate the average velocity as $V_A = F_v V_{(0,0)}$, since the velocity profile may be reasonably assumed to remain constant for a given opening and operating condition as long as the conditions noted previously are observed. In most programs, velocity measurements are made at one or more additional points on the traverse axes to provide a check on the constancy of the profile.

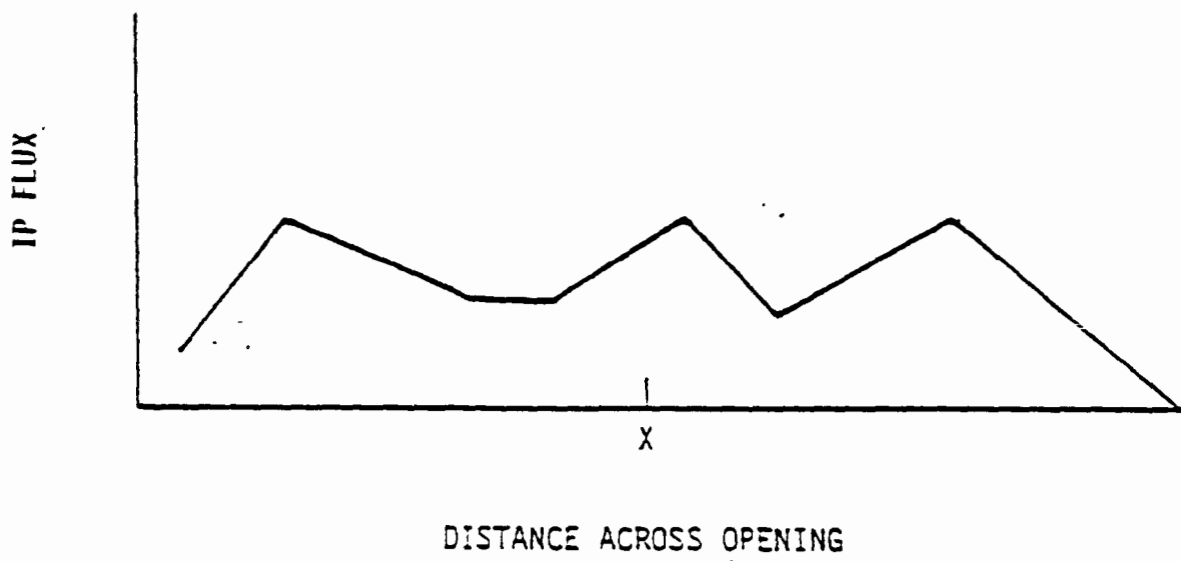
Mass Concentration Measurement

It is anticipated that each contractor will have two of the horizontal elutriators for use in this program. For this reason, the pre-survey of the source is of paramount importance for determining not only the placement of these samplers, but also whether the technique can be used at all for the source under consideration. If, for example, less than 75% of the emissions come from the two largest openings in the structure, the roof monitor measurement method should not be used. The Beta Gauge instrument (RDM) previously described, along with a hot wire anemometer, can be used to determine if such is the case. Having determined that sufficient material does pass through the opening, the RDM may be used to map the particulate concentration distribution across the openings. Should two openings from a given source need to be sampled, this means that each sampler must extract a representative sample from a

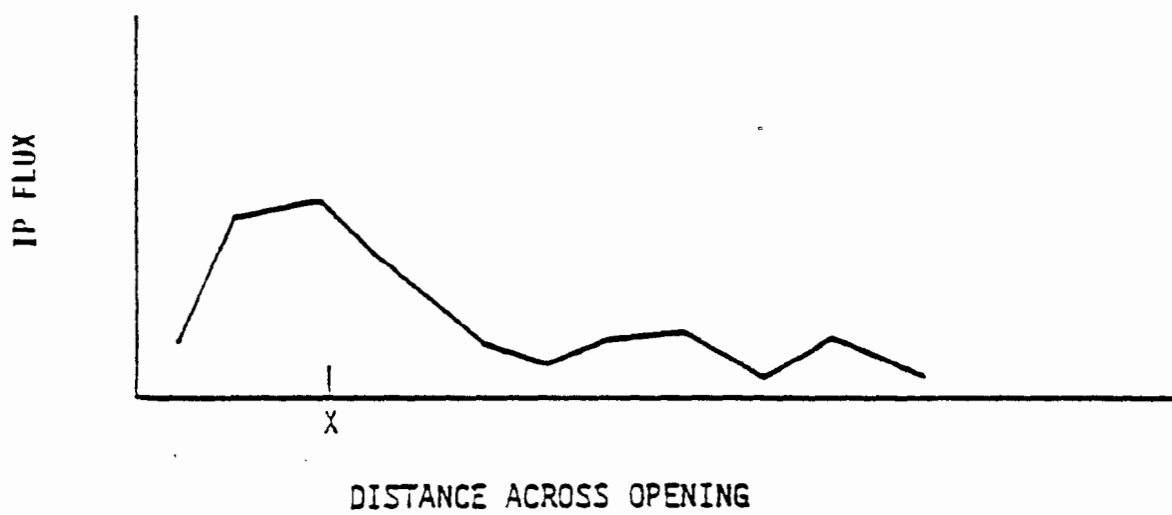
single location. For such a situation, the particulate flux must be of the distribution type shown in Figure 17. Samplers placed at the X position for case (a) would extract average concentrations which could then be multiplied by the total flow from the monitor to calculate the source's emission rate. The Beta Gauge measurements should be taken every ten feet (four measurements should be taken for sources less than ten feet long). Vertical profiles should also be obtained to determine if a vertical concentration gradient exists. The profiles for a small (less than 10 feet long) opening should be taken at the centerline of the horizontal plane for case (a). If a vertical gradient does exist for a situation like case (a), the sample should be taken at the point exhibiting average flux. For monitors larger than ten feet in a case (a) situation, three vertical measurements should be taken every twenty feet. If the vertical profiles are identical (± 20 percent for mean value and range), then the centerline horizontal/average concentration vertical point is again used. If the vertical gradients are not identical, then the roof monitor method cannot be used. For the horizontal measurements, if more than 25% of the readings are more than 50% from the mean value, then this method cannot be used.

For case (b), virtually all of the particulates are being emitted through a limited section of the monitor. The particulate measurement along the horizontal plume is to be taken at the point of highest concentration. Mass flux is to be determined using the concentration and the flow through the reduced section. The extent of this section is to be determined by the beta gauge. Vertical measurements are to be taken at one point in this region and the sampler positioned at the average flux level.

For those cases where bimodal distributions occur, two samplers must be used. Positioning of the samplers would follow the same reasoning as that outlined for the one sampler situation except that the monitor is divided into two distinct sections. Any



A



B

FIGURE 17: ROOF MONITOR FLUX DISTRIBUTIONS

particulate distribution more complex than this bimodal cannot be sampled using this method because of the two sampler limitations.

Roof Monitor Sampling Schedule

As was the case with the quasi-stack measurement technique process conditions have a large effect upon the sampling schedule for the roof monitor technique. Sampling times must be set up to measure distinct parts of or complete process cycles. When different operations are occurring in the same building it may be necessary to increase the sampling time to include a complete set of cycles for all of the operations. This may require a test duration of one day.

Besides process conditions the local wind speed and elevation could influence the sampling schedule should they have an effect upon the air flow from the building. For IP measurements it is not expected that normal updraft velocities could change enough to affect the total IP flux. However, high velocities or rapid shifts in wind direction could interfere with the sample collection sufficiently to cancel test.

Roof Monitor Data Collection

Velocity measurements will be automatically recorded at the site. The high volume samplers are set at a given flow rate to insure proper functioning of the elutriator and, as such, data collection is not associated with their operation. Process parameter collection will be more difficult than the quasi-stack since multiple operations will be occurring and throughput data, process temperature and pressures, number of loading operations etc. will be required for each operation.

UPWIND-DOWNWIND SAMPLING METHOD DESIGN PROCEDURE

In order to successfully utilize the upwind-downwind method for the acquisition of data sufficient to calculate source emission rates, a number of source- and site-specific parameters must be considered.

The most important consideration is the location of the downwind samplers within the plume of particulates generated by the source. The samplers must be located to provide measureable samples in sampling periods of reasonable duration, without contamination by particulates from other sources, except those included in the background upwind samples. A number of site-specific parameters (such as source location, wind direction, and topography) can restrict the location of samplers. Figure 1a illustrates the influence that a combination of source location and wind direction may exert. In this reasonably simple arrangement, only the wind direction shown in "A" will permit unrestricted location of samplers within the plume of source (A) along with acceptable location of upwind samplers between source (A) and the area source. With the wind direction as shown in (b), no location within the plume of (A) is acceptable. Wind directions as shown in "C" and "D" limit the acceptable locations to that portion of the plume between source (A) and its interference from the other sources or plumes. Similar interferences occasioned by topographical features of the site may also occur.

In most instances, such restrictions will be recorded by the initial observations made in the pre-test survey. A portable responsible dust monitor (RDM), used as a preliminary indicator of a plume's limits, will also reveal less obvious restrictions.

Since all of the equipment designated for use in upwind-downwind samplings in this measurement program are based on high volume samplers designed to sample at a constant flow rate of 40 cfm ($1.13 \text{ m}^3/\text{min}$), this sampling rate may be used as the basis for the calculation of required sampling periods and sampler locations. Assuming a

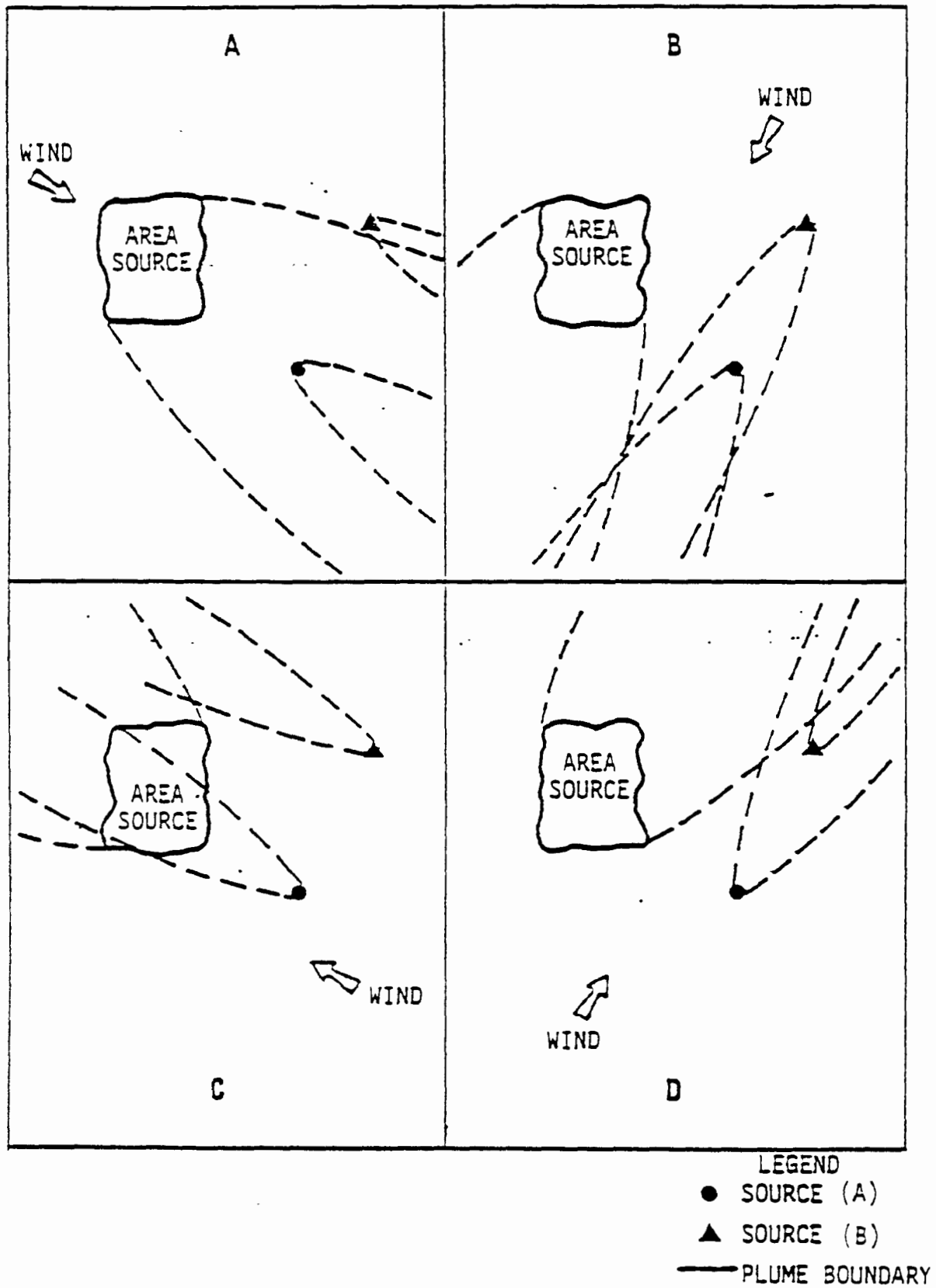


FIGURE 18 : UPWIND - DOWNWIND SOURCE CONFIGURATION VARIATIONS

minimum sample mass of 10 milligrams for any sampler, the minimum required particulate concentration at the sampler may be determined from

$$X = M/FT$$

Where:

- X = concentration, $\mu\text{g}/\text{m}^3$
- M = sample mass, μg
- F = sampling rate, m^3/min
- T = sampling period, min.

Using the known values of $1.13 \text{ m}^3/\text{min}$ for F and 10 mg ($10^4 \mu\text{g}$) for M, this equation may be used to determine

$$XT = 147 (\mu\text{g}/\text{m}^3)(\text{hr})$$

the constant value of the product of concentration and sampling period required for the minimum sample mass. This value will be used as the basis of all sampler locations and sampling duration calculations.

Pre-Test Survey Concentration Measurements

In order to best locate the downwind samplers for a specific site/source combination, approximate downwind particulate concentrations may be determined during the pre-test survey using the portable RDM. The basic procedure is as follows:

- o Determine, by observation or the use of portable wind instruments, the direction and approximate speed of the wind blowing across the source.
- o Select a point on a line from the source along the wind direction 20-40 meters downwind of the source. (For sites with limited access to the downwind area, select a point about midway in the accessible area.) Obtain a particulate concentration (X) reading at this point with the RDM. Record the concentration value, wind direction, and wind speed.

- o Repeat the concentration and wind measurement at points along a line through the initial point and perpendicular to the wind direction, on either side of the initial point at a distance of about 1/4 the downwind distance from the source (x_1 and x_2), as illustrated in Figure 19A. Restrict measurements to periods when the wind speed is within $\pm 10\%$ of the initial (x_1) measurement wind speed.
- o For initial-point concentration values of $20 \mu\text{g}/\text{m}^3$ or less, select another wind center-line point about half the initial distance from the source and repeat the three-point measurements (x_3 , x_4 , x_5) performed at the original distance (Figure 19B). Restrict measurements to $\pm 10\%$ of the initial wind speed.
- o For initial-point concentration values greater than $20 \mu\text{g}/\text{m}^3$, select another wind center-line point about twice the initial distance from the source and repeat the three-point measurements (x_7 , x_8 , x_9) (Figure 19C).
- o Obtain, in the wind center-line upwind of the source at any convenient distance greater than about 10 meters a concentration (x_{10}) and wind measurement.
- o If the wind direction varies during the foregoing, the measurements should be suspended if the wind deviates more than ten degrees from the initial direction and resumed when the direction is once again within the desired limits.
- o Tabulate the concentration and wind measurements as shown on Table 14.

Calculation of Downwind Sampler Locations

The concentration of inhalable particulates at downwind locations along the wind or plume centerline is approximated by

$$x = \frac{Q}{\pi \sigma_y \sigma_z \mu}$$

Where:

- x = concentration, $\mu\text{g}/\text{m}^3$
- Q = source emission rate, $\mu\text{g}/\text{sec}$
- σ_y, σ_z = standard deviation of horizontal (y) and vertical (z) concentration distribution, m
- μ = wind speed, m/sec.

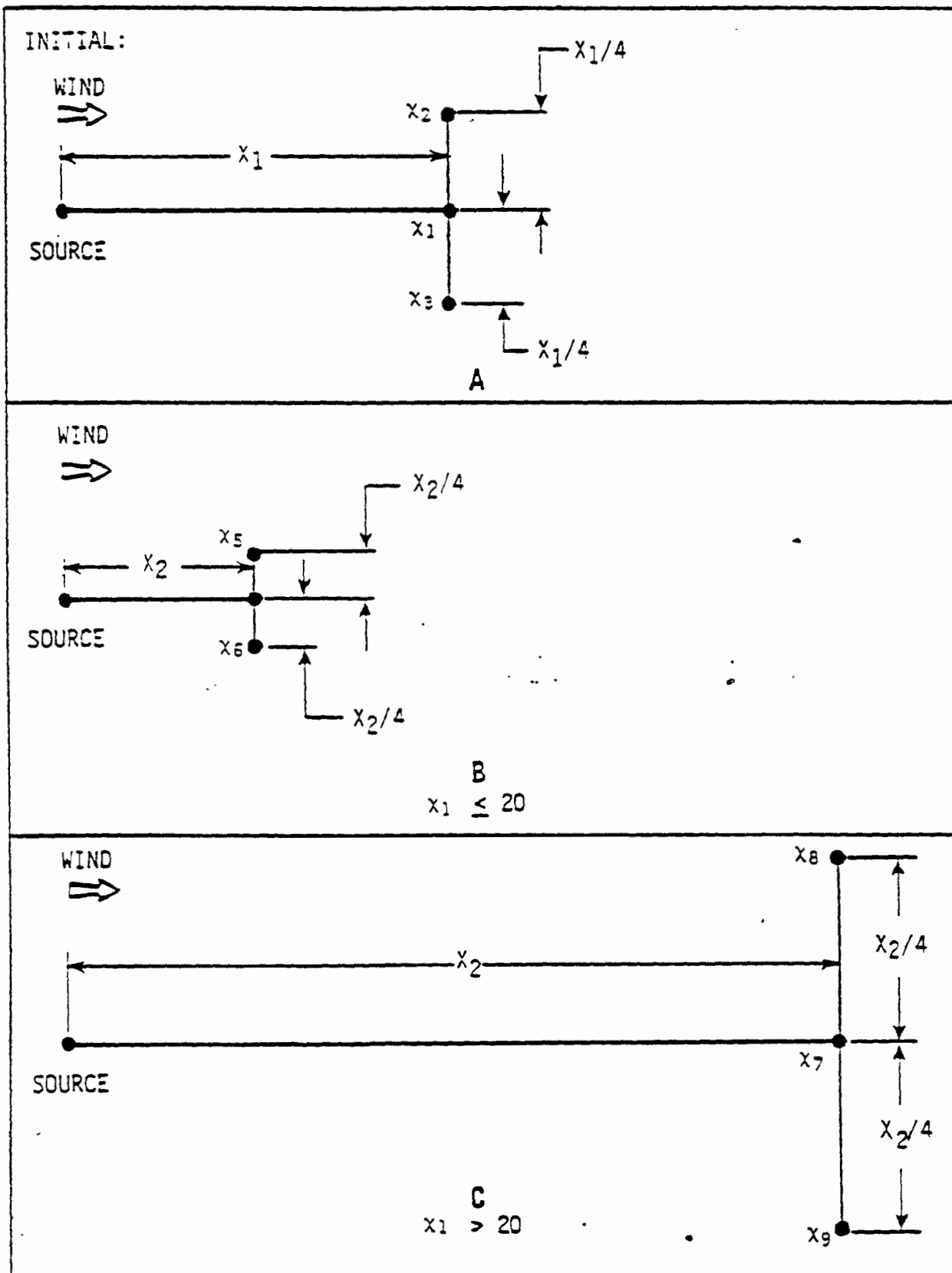


FIGURE 19: DOWNWIND RDM CONCENTRATION SAMPLING POINTS

TABLE 14. TABULATION OF MEASUREMENTS

Sampling Points	Concentration χ , $\mu\text{g}/\text{m}^3$	Wind Speed μ , m/sec
$(X_1, 0)$	χ_1	μ_1
$(X_1, X_{1/4})$	χ_2	μ_2
$(X_1, -X_{1/4})$	χ_3	μ_3
$(X_2, 0)$	χ_4, χ_7	μ_4, μ_7
$(X_2, X_{2/4})$	χ_5, χ_8	μ_5, μ_8
$(X_2, -X_{2/4})$	χ_6, χ_9	μ_6, μ_9
Upwind	χ_{10}	μ_{10}

For downwind distances up to about 500 meters, the product $\sigma_y \sigma_z$ is approximately linear with distance, so that the centerline concentration varies inversely with downwind distance and wind speed.

The measured values of concentration obtained in the pre-test survey may, therefore, be used to establish approximate sampler locations through a simple calculation procedure as follows:

- o Calculate concentrations at the RDM sampled locations as follows:

$$X_{(x_1)} = X_1 - X_{10}$$

$$X_{(x_2)} = X_4 - X_{10} \text{ or } X_7 - X_{10}$$

$$X_{(x_1, y)} = \frac{(X_2 - X_{10}) + (X_3 - X_{10})}{2}$$

$$X_{(x_2, y)} = \frac{(X_5 - X_{10}) + (X_6 - X_{10})}{2}$$

$$\text{or } \frac{(X_8 - X_{10}) + (X_9 - X_{10})}{2}$$

- o Calculate distance along centerline for one-hour sampling period:

$$\lambda_c = \frac{X_{(x_1)} \lambda_1 + X_{(x_2)} \lambda_2}{294}$$

- o Calculate average concentration for points $X_{c/4}$ from centerline at X_c :

$$X_{(c, y)} = \frac{147 (X_{(x_1)} + X_{(x_2)})}{(X_{(x_1, y)} + X_{(x_2, y)})}$$

- o Calculate maximum sampling time for sampler at $(X_c, X_{c/4})$ as $T_m = 147/X_{(cy)}$.

If the value of T_m is compatible with the emission schedule from the source (i.e., if the emissions from the source will be produced at a reasonably constant rate for the time duration T_m), the downwind sampler points $(X_c, 0)$, $(X_c, X_{c/4})$ and $(X_{c_1} - X_{c/4})$ may be

utilized. If a shorter sampling period, T_s , is required, the calculated distance λ_c should be adjusted to

$$\lambda_{c(adj)} = \frac{\lambda_c T_s}{T_m}$$

and the last two steps of the calculations repeated using the adjusted value.

These calculations are made for the single wind speed value that prevailed during the pre-test survey. If variations from this wind speed are expected or observed during the sampling periods, the value of λ_c should be adjusted by a factor equal to the ratio of the pre-test measured wind speed and that expected or observed at the time of the test,

$$\lambda_{c(adj)} = \lambda_c \frac{\mu_{pre-test}}{\mu_{actual}}$$

The last two steps of the calculation should then be repeated using the adjusted value of λ_c , to determine $\lambda_{(c,y)}$ and maximum sampling time.

Sample Station Configurations

The downwind sampling station locations determined in the previous section have been selected to provide sufficient data on the distribution of particulates generated by the source, to perform calculations of the inhalable particulate fraction source strength. To ensure that the most effective data is obtained, the sampling stations should be configured as follows:

- o Downwind centerline ($X_c, 0$) - wind speed and direction, ground level standard (TSP) ni vol, ground level ni vol with size-selective inlet, and four-stage impactor, elevated (2-4 meters) ni vol with size selection inlet (SSI).
- o Downwind laterals ($(X_c, \lambda_{c/4}), (X_c, -\lambda_{c/4})$) - ground level ni vol with SSI.

- o Upwind centerline $(-X,0)$ - wind speed and direction, ground level standard n : vol, ground level n : vol with SSI and four-stage impactor.

The upwind station, intended to obtain background concentration level data, should be located as nearly as possible along the extension of the plume centerline and as close as possible to the source outside of the influence of wind eddy currents caused by the source.

Upwind-Downwind Sampling Schedule

The calculation of the sampling period duration required to obtain the assumed minimum acceptable sample mass was described in the section Calculation of Downwind Sampler Locations. This calculation assumes that the sampling is performed during a period of constant wind speed and direction, so that the concentration of particulates at the samplers is subject to minimal variability. Such conditions are unlikely to prevail under actual field conditions for any significant length of time, and sampling periods must be adjusted to account for variations in wind speed or direction.

The most effective method of adjusting the sampling period is simply to turn off the samplers whenever the variations in wind speed or direction result in significant concentration variations and extend the sampling period so that the calculated sampling duration includes only "sampler-on" time periods.

As a general rule, the downwind sampler should be turned off whenever the wind speed is below 75% or above 125% of the design calculation speed for periods longer than about three minutes, and turned back on after the wind speed has returned to the acceptable range (90 to 110%) for about two minutes.

Samplers should also be turned off when the wind direction varies by 10° or more

from the design calculation direction for periods longer than three minutes and turned back on after the wind direction returns to the acceptable range for two minutes.

While variations of these magnitudes in wind speed and direction will usually have less effect on the upwind sampling array, since it is not located in a specific source plume, the general practice should be to turn off the upwind samplers whenever the downwind samplers are turned off.

Upwind-Downwind Data Collection

The use of a meteorological equipment set that includes strip-chart recording of wind speed and direction as a function of time greatly reduces the volume of manual data collection required. A single operator can easily record sampler on and off times (directly on the strip-chart in most cases, or on a supplemental data sheet), along with observations of prevailing weather and sky conditions. Observations of cloud cover and ambient temperature should be recorded at the beginning and end of each test and whenever any significant change occurs.

Process data required in the calculation of emission factors, such as material throughput, process temperatures and pressures, number of loading operations and the like, should also be recorded. In many instances, such information may be obtained directly from plant operational records. These should be reviewed prior to the test to ensure that the proper data will be available.

Exposure Profiling Sampling Design Procedures

This method is used primarily to quantify the emissions caused by vehicular traffic by measuring pollutant levels immediately downwind from the road.

Measurement of the wind speed and direction at the road are combined with inhalable particulate levels to calculate source strength.

Source/Site Consideration

The exposure profiler should be sited downwind of the test road in an area characterized by flat terrain and unobstructed wind flow. Normally the profiler is positioned at a distance of 5 m from the downwind edge of the road for roads traveled by light duty vehicles. For road traveled by larger vehicles, it may be necessary to locate the profiler as far downwind as 10 m from the road in order to avoid the momentary changes in wind direction readings which occur near a vehicle as it passes by.

Horizontal wind direction must have a standard deviation less than 22.5° . This restriction excludes sampling under Stability Class A, which is characterized by large horizontal wind meander and low wind speeds. The angle between the mean wind direction and the direction of the sampling axis should not exceed $\pm 20^{\circ}$. In this range, sampling error is less than about 5% for particles for 12 μm aerodynamic diameter (Reference 11).

In the wind speed range of 4 mph to 20 mph, sampling rate can be readily adjusted and matched to the corresponding mean wind speed. An isokinetic flow ratio (IFR = sampling rate/wind speed) of less than 0.8 or greater than 1.2 may lead to large concentration errors. For particles of 12 μm diameter, it has been shown that sampling error is less than about 15% for IFR between 0.8 and 1.2 (Reference 11).

Moderate sampling substrate loadings are desirable. The loadings should be high enough to permit accurate determination of the sample weights but low enough to insure that the particle catch is not lost through flaking of collected particulate or inability of the substrate to hold the particulate catch.

TABLE 15. CRITERIA FOR SUSPENDING OR TERMINATING
AN EXPOSURE PROFILING TEST

A test will be suspended or terminated if:

1. Rainfall ensues during equipment setup or when sampling is in progress.
 2. Wind speed during sampling moves outside the 4 to 20 mph acceptable range for more than 20% of the sampling time.
 3. The angle between wind direction and the perpendicular to the path of the moving point source during sampling exceeds 45 degrees for more than 10% of the sampling time.
 4. Mean wind direction during sampling shifts by more than 20 degrees.
 5. Daylight is insufficient for safe equipment operation.
 6. Source condition deviates from predetermined criteria (e.g., haul trucks traveling on access road).
-
-

Sampling Configuration Design

For testing of emissions from light duty traffic on a two-lane or four-lane road, the four exposure sampling heads are positioned at vertical distances of 1 m, 2 m, 3 m, and 4 m above the ground. For testing of emissions from roads traveled by a substantial portion of medium or heavy duty vehicles, the spacing between samplers is increased to 1.5 m with the top sampler at a vertical distance of 8 m from the ground. The particle sizing devices used to determine inhalable particulate fractions (cascade impactors with coarse particle pre-collectors) are positioned such that sampling intakes are located at the same distance as the profiler from the road at the same heights as the first and third exposure sampling heads counting from the ground.

Once the exposure profiler is assembled, the anemometers are operated for a period of at least 15 minutes to determine the mean wind speed. The mean wind direction is determined from the wind station located upwind of the test road near the background particulate sampler (usually a standard high volume sampler).

After the mean wind direction and mean wind speed profile have been determined, the profiling tower is rotated so that sampler intakes are pointed directly into the wind. Then the isokinetic sampling flow rates are calculated. At the start of a test, the traffic flow is interrupted while the air samplers are activated and adjusted to the proper flows.

Table 15 lists the criteria for suspending or terminating an exposure profiling test. Some of these criteria address the wind conditions in relation to the requirements for isokinetic sampling. Testing may also cease if rainfall ensues (reducing emissions to negligible levels) or if light is insufficient for safe operation. The final criterion deals with an unacceptable change in source condition.

Throughout a test of traffic-generated emissions, a vehicle count is maintained either by direct observation or by an automated technique. Periodically (e.g., during 15 minutes of each hour), vehicle mix should be determined by compiling a log of vehicles passing the test point segregated by vehicle type (usually the number of axles and wheels).

Depending on the road surface, dust loading and the traffic density, an exposure profiling test of a paved road will require about two to eight hours. A test of an unpaved road may be completed in a period of 30 minutes to one hour, because of substantially greater emissions.

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SECTION 5

DATA REDUCTION

The ultimate objective of an LPFE measurement program is the calculation of an emission factor which related the amount of LPFE generated by a specific process to one or more readily-determined parameters of that process. The procedure begins with the particulate matter samples and related data obtained in the field, and progresses through analysis of the samples, calculation of the sampled air volume, calculation of the particulate concentrations at the sampling sites, calculation of the source emission rates, and finally, determination of the process emission factor.

The procedure can be relatively straightforward, involving largely routine filter weighings, and standard, well-documented calculations up to the calculation of concentrations. In relating concentrations to emission rates, some complications begin to appear, most notably in the upwind-downwind method where diffusion equations must be utilized to back-calculate the source strength from the concentrations, and the appropriate background concentrations must be subtracted from the measured concentrations. Also, in roof monitor measurement systems, the determination of the appropriate area of the opening which enters into the volume flow calculation to which the concentration is applied, requires a careful review of assumptions and measured velocities.

SAMPLE ANALYSIS

While weighing of filter catch is probably the most straight-forward sample analysis of an air pollutant, there is sufficient variety in the sizes, types and materials used for filters and substrates in the IPFE methods described, to suggest that the user be wary of the apparent simplicity. As a general rule, the instructions provided by the sampler and filter media manufacturers should be followed completely. Deviations should be undertaken only in consultation with the manufacturers' experts and should be reviewed by a recognized sampling specialist before implementation. Examples of potential problem areas include:

- o Determination of proper tare weight by appropriate drying.
- o Insertion and removal of filter or substrate to prevent loss of either filter material or sample.
- o Handling and transport of samples after removal from sampler to prevent loss or concentration.
- o Final laboratory handling, including drying to assure proper relationship to tare weight.
- o Utilization of weighing equipment suited to the job. Laboratory balances with a sensitivity in the 10 to 100 microgram range can be expected to result in sample weights within the expected range of accuracy of the several sampling methods described.

SAMPLE VOLUME CALCULATION

Since many of the IPFE measurements involve the operation of sampling systems which are left unattended for substantial periods, the means used to calculate the total volume of air passed through the samplers must be thoroughly understood and foolproof. Flow controlled high volume samplers are ideal, since the flow is held constant and a direct readout in standard cubic feet per minute is available. The total volume of air sampled is therefore given directly by:

$$V_s = q_s t_s$$

where V_s = volume of air sampled at standard conditions, ft^3
 q_s = flow rate of sampler at standard conditions, ft^3/min
 t_s = sampling time, min.

High volume samplers which are not flow controlled involve periodic recording of the flow rate, which declines as the sample is accumulated. Thus, the total volume is determined by averaging the flow rate during the sampling period. In some cases several averagings are possible if field personnel are available to check the sampler more than once during the period. If not, the average is determined at the beginning and end, assuming that the decay is linear with time.

In addition, if the samplers are not flow controlled, the volume of air collected must be converted to standard conditions. This requires recording of the temperature and pressure for the sampling period, so that an average can be obtained for use in the equation:

$$V_s = V_a \frac{T_s P_a}{P_s T_a}$$

where V_s = volume of air sampled at standard conditions, ft^3
 V_a = volume of air sampled at actual conditions, ft^3
 T_s = standard temperature, $^{\circ}\text{K}$
 T_a = actual temperature, $^{\circ}\text{K}$
 P_s = standard pressure, in Hg
 P_a = actual pressure, in Hg

The same comments apply to the averaging of temperature and pressure as for the flow determination.

PARTICULATE CONCENTRATION CALCULATION

The particulate concentration determined by any of the LPFE methods described is calculated by dividing the weight of the captured sample by the total air volume sampled. The general equation for this calculation, based on a multistage impactor, is:

$$C_j = m_j / Q_s$$

where C_j = concentration of particulate matter whose aerodynamic diameter is defined by the jth stage of the impactor (mass units per standard condition volume units)

m_j = mass caught on jth stage of the impactor (mass units)

Q_s = total volume of air sampled at standard conditions (volume units)

The total concentration of particulate matter, C_T , is the sum of the individual impactor stage concentrations:

$$C_T = \sum_{j=1}^n C_j = \frac{1}{Q_s} \sum_{j=1}^n m_j$$

where C_T = total mass concentration (mass units per standard condition volume units)

n = number of stages in the impactor and backup filter(s).

In the case where no impactor is used, $n = 1$, and the equations simplify to

$$C_T = M / Q_s$$

In those cases where a background concentration exists, as in upwind-downwind measurements, the appropriate value must be subtracted from the calculated concentration to determine the source-generated concentration:

$$C_{TS} = C_T - C_B$$

where C_{TS} = source-generated concentration

C_T = total measured concentration

C_B = measured background concentration.

EMISSION RATE CALCULATION

The emission rate calculation entails the conversion of the source-generated concentration into a mass emission rate for the source. This step requires the multiplication of the concentration by a total volume flow rate as generated by the source. In the case of quasi-stack and roof-monitor measurements, this volume is determined by means of velocity measurements in the cross-section through which the flow passes. The integration of velocity times area segments gives the total source volume flow rate. In the case of the upwind-downwind method, the emitted material has been dispersed in the atmosphere, and the source emission determination requires application of diffusion equations.

Emission Rate Calculation Involving Velocity Measurements

Where pitot tubes are used to measure velocities in quasi-stack measurements, the velocity at a given point is given by the following equation:

$$V_a = 85.48 C_p \left(\frac{T_a \Delta P}{P_a M_a} \right)^{1/2}$$

where

V_a = point velocity; ft/sec

ΔP = velocity head; in H_2O

M_a = molecular weight of gas

C_p = dimensionless pitot tube coefficient

P_a = pressure of air stream; in Hg

T_a = temperature of air stream; $^{\circ}R$

When other velocity measurement equipment is applied, the point velocity relationship will be different, and in many cases, the instrument can be read directly in terms of the velocity in ft per sec, ft per min, etc.

Once the point velocities are determined, the average velocity, \bar{V}_a is obtained and the total flow calculated by $Q_a = \bar{V}_a A$.

where Q_a = the total flow rate from the source in actual volume units. (e.g., ft^3/min)

A = the total area of the flow opening in area units (e.g., ft^2)

In the case of the pitot equation,

$$\bar{V}_a = 85.48 C_p \frac{(\bar{\Delta P})^{1/2} (\bar{T}_a)^{1/2}}{P_a M_a}$$

where: $\bar{\Delta P}$ is the average velocity head (in. H_2O)

\bar{T}_a is the average air stream temperature ($^{\circ}\text{R}$)

(P_a and M_a are assumed constant across the flow opening)

The total volume flow at standard conditions is determined from:

$$Q_s = \bar{V}_a A \left(\frac{T_s}{T_a} \right) \left(\frac{P_a}{P_s} \right)$$

where: Q_s = total flow rate from the source in standard volume units (e.g., $\text{std ft}^3/\text{min}$)

T_s = standard temperature ($^{\circ}\text{R}$)

P_s = standard pressure (in Hg)

The foregoing relationships for flow are for "wet" conditions. If the flow is to be expressed in dry standard cubic feet per minute, the equation becomes:

$$Q_s = \bar{V}_a A \left(\frac{T_s}{T_a} \right) \left(\frac{P_a}{P_s} \right) (1 - b_{ws})$$

where b_{ws} = fraction by volume of water vapor in the sampled air stream.

The emission rate from the source is determined by multiplying the source volume flow rate by the particulate concentration, assuring that the flow units match the concentration units. The general equation is:

$$E = C_{TS} Q$$

where E = source mass emission rate in mass units/time units

Q = source flow rate in volume units/time unit

C_{TS} = source-generated concentration in mass units/volume units consistent with E and Q units.

Emission Rate Calculations for Upwind - Downwind Sampling Programs

Particulate matter samples obtained at the upwind and central downwind sampling sites are analyzed as described in the section Sample Analysis to provide particulate concentrations at each sampling location for total suspended particulates (hi vol sampler), inhalable size fraction (hi vol sampler with size-selective inlet) and size distribution (hi vol samples with SSI and 4-stage impactor). Samples from the downwind cross-plume sites are analyzed to provide inhalable size fraction concentrations only.

To calculate the source emission rate, the upwind concentration is subtracted, as a general background level of particulates, from the downwind concentrations to yield the concentration attributable to the source (at each downwind site). These source contribution concentrations are then substituted into diffusion equations averaged to back-calculate source strengths from concentrations, taking into account corrections for wind velocity, meteorological conditions and atmospheric stability variations. The simplest form of the basic diffusion equation, for a ground level source with a ground level sampler on the plume centerline is:

$$\chi = Q / \pi \sigma_y \sigma_z \mu, \text{ where}$$

χ	=	concentration at receptor, $\mu\text{g}/\text{m}^3$
Q	=	source emission rate, $\mu\text{g}/\text{sec}$
σ_y	=	standard deviation of horizontal concentration distribution, m
σ_z	=	standard deviation of vertical concentration distribution, m
μ	=	wind velocity, m/sec

Rearranged to:

$$Q = \pi \chi \sigma_y \sigma_z \mu,$$

the basic equation can be used to determine source emission rates from the measurement receptor concentrations and wind speeds and the concentration distribution standard deviations obtained from Reference 13.

For source/site configurations of increased complexity, the basic equation is expanded to include exponential terms to correct for differences in source and receptor heights, samples obtained at off-centerline locations and other physical parameters. Most of the more complex revisions of the diffusion equation have been used to develop diffusion models available from such sources as the EPA's User's Network for Applied Models of Air Pollution (UNAMAP), maintained at the Research Triangle Park Computer Center. Selection of the most appropriate model for a specific site and combination of atmospheric conditions should be left to an experienced diffusion meteorologist to ensure that all pertinent parameters are considered and the most accurate source emission rate is obtained.

EXPOSURE PROFILING DATA REDUCTION

Data reduction for measurement of IPFE by Exposure Profiling is sufficiently different than for the other measurement methods to warrant this separate section.

The passage of airborne particulate, i.e., the quantity of emissions per unit of source activity, is obtained by spatial integration (over the effective cross-section of the plume) of distributed measurements of exposure (mass/area). The exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement.

Mathematically stated, the total mass emission rate (R) is given by:

$$R = \frac{1}{t} \iint_A \frac{m(n,w)}{a}$$

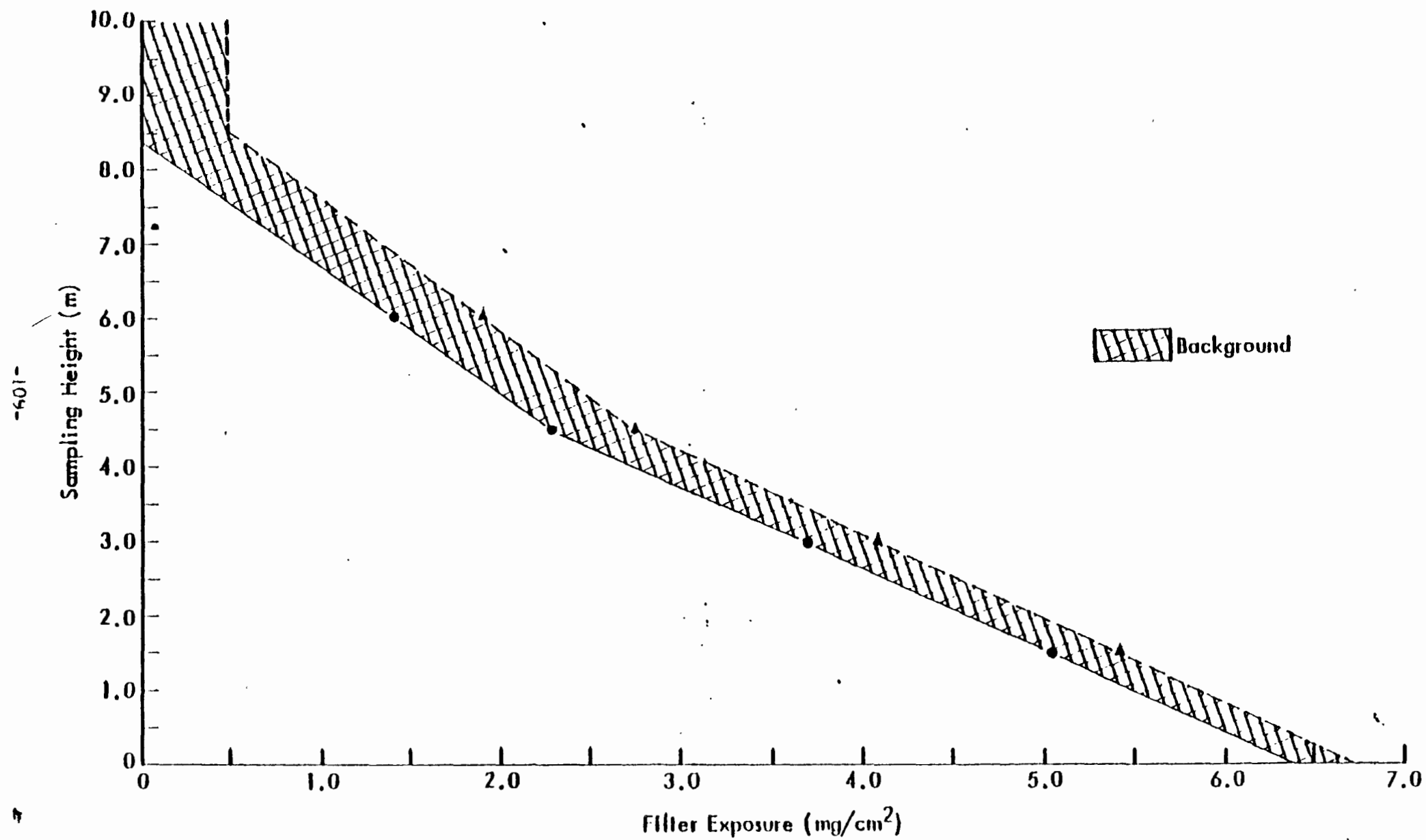
where
 m = dust catch by exposure sampler after subtraction of background
 a = intake area of sampler
 t = sampling time
 h = vertical distance coordinate
 w = lateral distance coordinate
 A = effective cross-sectional area of plume

In the case of a line source or moving point source with an emission height near ground level, the mass emission rate per source length unit being sampled is given by:

$$R = \frac{W}{t} \int_0^H \frac{m(n)}{a} \quad dn$$

where:
 W = width of the sampling intake
 n = effective extent of the plume above ground

The integration of filter exposure values as a function of profiler sampler heights is subject to an error based on insufficient point data to completely describe the plume exposure profile. A four-point integration over a plume of less than 9 m height is considered adequate to reflect the exposure profile. Figure 2-0 shows a typical exposure profile measured downwind of an unpaved road.



Isokinetic Corrections

If it is necessary to sample at a nonisokinetic flow rate (e.g., to obtain sufficient sample under light wind conditions), the following multiplicative factors would be used to correct measured exposures and concentrations to corresponding isokinetic values:

	<u>Fine Particles</u> <u>(d < 5 μm)</u>	<u>Coarse Particles</u> <u>(d > 50 μm)</u>
Exposure multiplier	U/u	1
Concentration multiplier	1	u/U

where: u = sampling intake velocity at a given elevation
U = wind velocity at same elevation as u
d = aerodynamic (equivalent sphere) particle diameter

For a particle-size distribution containing a mixture of fine, intermediate, and coarse particles, the isokinetic correction factor is an average of the above factors weighted by the relative proportion of coarse and fine particles. For example, if the mass of fine particles in the distribution equals twice the mass of the coarse particles, the weighted isokinetic correction for exposure would be:

$$1/3 (2(U/u) + 1)$$

EMISSION FACTOR DETERMINATION

The determination of an IPFE emission factor is straightforward once the source emission rate has been calculated. The emission rate is related to a readily measurable process parameter whose variation is determined during the emission measurements. The most common process parameter is one which describes the process throughput, generally in mass terms. Thus, emission factors may be in terms of mass of emissions per mass of raw material input, or product output.

4

It is critical that the process parameter is one which is either already routinely monitored, or for which information can readily be obtained, in a time frame which matches the averaging period of interest. For example, process throughput information determined from annual, raw material purchase records will not provide an accurate hourly or daily emission estimate. In the design of an LPFE measurement program, the pertinent process parameter for the ultimate emission factor may be rather obvious from the start. However, there may be many other emission-influencing process variables, some of which may be more significant, and there will rarely be sufficient numbers of tests to directly account for all of these influences. It is important, therefore, to gather as much process and related data as possible during the test program. The data should include production outputs, feedstock inputs, etc., and a listing of the frequency of the operations taking place. Included in the parameters gathered should be:

- o production output
- o feedstock inputs
- o process cycling time
- o process temperature
- o physical dimensions of equipment generating emissions
- o number of emission points per operation
- o fuel type/amount
- o composition of product/feedstocks

The question of proprietary information should be resolved in advance of the measurement program. Often the process owner will be reluctant to release information on process related parameters which could allow outsiders to estimate production figures. While an emission factor by itself will rarely lead to such deductions, the back-up measurement program data can provide such leads to well-informed persons. It is therefore prudent to explore the probable form of the

emission factor, and the related process information needed, before the measurement program plan is finalized.

Fugitive emissions are also frequently dependent upon meteorological parameters, such as:

- o wind speed
- o wind direction
- o precipitation index
- o humidity

Additional parameters that could relate to area sources are:

- o silt content
- o activity factor
- o vehicle miles traveled
- o acres of construction activity
- o pile shape factor

The effects of variations in such parameters should be considered in the determination of emission factors.

As mentioned in the Introduction, this protocol has not discussed measurement accuracy in a quantitative reuse. Emission factor reliability is directly influenced by individual measurement accuracy, the number of measurements made, and the degree to which these are organized to account for the process and other variables. Since fugitive emissions measurements are generally about an order of magnitude more costly than conventional point source stack testing, budgetary limits will usually preclude the completion of enough measurements to satisfy the requirements of statistical experiment design. Thus, inhalable particulate matter fugitive emission factors determined from measurements made in accordance with the procedures described in this protocol can be expected to exhibit a wide range of variation.

The format of AP-42, "Compilation of Air Pollutant Emission Factors" utilizes an "Emission Factor Rating" which was developed from a numerical ranking system applied

by knowledgeable technical personnel who reviewed the bases for the emission factors.

The numerical rankings and their associated letter ratings are as follows:

<u>Numerical Rank</u>	<u>Letter Rank</u>
5 or less	E (Poor)
6 to 15	D (Below average)
16 to 25	C (Average)
26 to 35	B (Above Average)
36 to 40	A (Excellent)

The numerical rankings were developed in three categories with the following maximum scores. The score which is entered in the above table is the sum of the three category ratings.

Measured Emission Data:	20 points (max)
Process Data:	10 points (max)
Engineering Analysis:	10 points (max)
Total	40 points (max)

For the purpose of elevating the reliability of IPFE emission factors which may be developed from this protocol, the AP-42 rating scheme described above is considered adequate.

The protocol user is encouraged to complete as many well-planned measurements as his budget will allow. He should then subject his resultant emission factors to an objective review to establish the reliability rating. If the emission factors are then ultimately published in a document similar to AP-42, document users will be able to relate their reliability to prior published factors in a consistent manner.