GUIDELINE FOR CONTINUOUS MONITORING OF CARBON MONOXIDE AT HAZARDOUS WASTE INCINERATORS

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INTRODUCTION AND SUMMARY

Because of increasing public concern over problems that had emerged regarding the treatment, storage, and disposal of hazardous waste, the U.S. Congress passed the Resource Conservation and Recovery Act (RCRA) of 1976. To implement this legislation and subsequent amendments to it, the U.S. Environmental Protection Agency (EPA) has periodically issued regulations and guidelines. One of the main areas in which EPA issued regulations is for the permitting and operating of hazardous waste incinerators. These regulations which are included in Title 40, Part 264 of the Code of Federal Regulations (40 CFR 264) require that hazardous waste incinerators continuously monitor emissions of carbon monoxide (CO) and that permit limits for CO emissions be established to ensure the proper operation of the incinerator. This document is designed to provide guidance to applicants, and permit-writers and reviewers at the state and federal levels to aid in obtaining and operating CO monitors in a manner consistent with the intent of the requirements in the regulations.

Specific regulatory requirements for CO levels and continuous emission monitors (CEMs) include the following:

- A permit for a hazardous waste incinerator must specify the operating limits for the CO level in stack exhaust gas and allowable variations in those levels. The incinerator must be equipped with a functioning system to automatically cut off the waste feed if those limits are exceeded. (40 CFR 264.345)

- CO must be monitored continuously at a point downstream of the combustion zone and prior to release to the atmosphere. (40 CFR 264.347)

To assist in the review of permit applications, the Office of Solid Waste (OSW) is issuing this guidance to enable the permit writers to ensure that CO monitors on hazardous waste incinerators adequately represent the CO emissions during the trial burn and continue to do so during subsequent operation.

EPA is also considering certain maximum requirements for CO emissions to augment the current regulatory standard regarding trial burn test results. CO limits are currently based on levels achieved during the trial burn. Maximum CO limits are considered as a simple, reliable means of ensuring that incinerators operate at high combustion efficiency over

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the life of the permit. In addition, limiting CO, and thus ensuring high combustion efficiency is an important step to minimizing the emission of "products of incomplete combustion" (PICs). Detailed discussions of the technical and policy aspects of these limits are contained in a separate report (Ref. 1).

Currently, the regulations do not specify any time-averaging period for establishing the required CO permit limits and common practice has been to set short-term limits (5 minutes or less) based on highest recorded values during the trial burn. The required tests for destruction and removal efficiency (DRE) are usually the result of several hours of testing and thus short-term CO limits do not relate directly to the DRE tests.

This document provides technical guidance for two major purposes: (1) to ensure that the required CO measurements are made within known limits of measurement error, and; (2) that the systems are operated and maintained so as to continue to operate properly. A separate document is being prepared describing oxygen monitoring. Appendix D describes the required performance characteristics of the monitoring system needed to measure CO levels in the range of the limits under consideration. Should these limits change, appropriate changes will be required in the performance specifications. Table 1 summarizes the numerical standards for the monitoring systems; the text of Appendix D decribes how these parameters are measured and calculated. The format of Appendix D is taken from the CO CEM guideline prepared by the Office of Air Quality Planning and Standards (OAQPS). The OAQPS CEM requirements for CO specific monitors were developed for petroleum refinery catalytic crackers and although the requirements are not all directly applicable to hazardous waste incinerators, the general approach is.

Section 2 of this document discusses in detail the various types of analyzers available, theory of their operation, and the operation of ancillary equipment. CO monitors can be classified according to the analytical methods currently available, as follows:

- Nondispersive infrared spectrometry - Correlation detection (NDIR)

- Nondispersive infrared spectrometry - Gas-filter correlation detection (GFC)

- Electro-analytical methods including catalytic oxidation (EAC) and polarographic (EAP)

- Gas chromatography (GC)

Although there are other, more exotic analytical methods that can be used, these are the most common in commercially available monitors. Appendices A and B provide lists of the manufacturers' specifications for specific models and a list of instrument manufacturer's addresses and phone numbers.

TABLE 1. SUMMARY OF CO MONITORING SYSTEM
PERFORMANCE SPECIFICATIONS

Parameter	Specifications	
	Low range	High Range
Measurement Range, ppmv	0-200 max	0-1000 min
System Response Time	$\leq$ 1.5 minutes to 95%	
Drift, Zero (as operating)* (guide only)	$\leq$ 10 ppmv, 24 hour	$\leq$ 20 ppmv, 2 hour
Drift, Span*	$\leq$ 20 ppmv, 24 hour	$\leq$ 50 ppmv, 2 hour
Precision*	the lesser of 5.0% FS or 10 ppmv	the lesser of 2.0% FS or 20 ppmv
Linearity*	the lesser of 10.0% FS or 20 ppmv	the lesser of 5.0% FS or 50 ppmv

* expressed as the sum of the mean absolute value plus the 95% confidence interval of a series of measurements

Other considerations discussed in Section 2 are the methods used to obtain flue gas samples for the CEMs including extractive sampling, cross-stack analysis, and in-situ analysis. Extractive sampling which is the method used by many, if not most, CEMs on hazardous waste incinerators requires that a properly conditioned sample be extracted from the stack or duct and transported to the measurement chamber of the instrument. Primary concerns include: the sampling location; the probe, sample lines, and prime mover or pump used to extract the sample and transport it to the measurement chamber; and sample conditioning. Finally, typical operating characteristics such as precision and accuracy, instrument sensitivity, response time, and calibration are discussed in Section 2.

There are a number of special considerations that affect the design and operation of CEMs on hazardous waste incinerators. These issues are discussed in Section 3. The four major topics covered in Section 3 are sampling/analysis location, interferences to the analytical method, design and operating characteristics of the specific incinerator, and some considerations related to the trial burn.

Although the RCRA regulations do not specify an exact location for CEMs on hazardous waste incinerators, they are usually placed in one of three locations, i.e., at or near the combustion zone, at or near the point of discharge to the atmosphere, or somewhere in between those locations. Because the combustion zone is quite turbulent, hot, and dirty, sampling in that location is quite difficult. Prior sampling to establish the concentration profile during stable and unstable conditions is important to determine whether a single or integrated multiple-point sample is required. If the sample is to be extracted from the stack, EPA Performance Specification 1 (40 CFR 60, Appendix B) provides some guidance for location of sample sites. In addition, care must be taken to ensure that potential in-leakage prior to the sampling port does not create stratification of the sample gas stream, although the O_2 correction provisions of the limits being considered minimize the concerns about dilution of the stack gases. Problems associated with intermediate points include ensuring the representativeness of the sample, damage to the equipment from high temperatures, high dust concentrations, and acid gases, and physical constraints related to access and operating environment.

For CO monitors that are based upon the absorbance of infrared energy, any other gases present that absorb infrared energy at the same wavelengths will interfere with the measurement. The most common interferents are carbon dioxide and water vapor. Carbon dioxide interferes positively, i.e., the measured CO concentration will be greater than the actual level if carbon dioxide is present. Vapor-phase water also interferes positively. Techniques are available to correct for these specific-wavelength interferences. Liquid-phase water and dust attenuate the entire spectrum of the infrared beam and these effects are usually handled by the signal processing electronics. Cross-stack GFC analyzers are designed to pass a reference and measurement beam alternately through the path to eliminate the effects of droplet or particle interference. The sample conditioning process used by extractive-sample NDIR instruments eliminates most of the problems of interference caused by particles and liquid-phase water.

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Proper sample conditioning is an important consideration in the design of CEM systems. Sample conditioning systems are designed to remove or mitigate the impact of temperature, moisture, and particles. In hazardous waste incinerators, acid gas removal may also be important. Although high temperatures, i.e., above 250°F, prevent the condensation of moisture or acid gases, most instruments require a cooler sample. The problem of condensation is mitigated by including condensation and/or permeation devices in the conditioning system. Particles cause the same attenuation problems as water droplets and are filtered from the sample. Since most of the particles created in hazardous waste incinerators burning process sludges may be fine, i.e., <10 micrometers (μ) in diameter, more efficient filters with a high pressure drop may be needed on CEM sample conditioning systems.

Because the flue gas characteristics depend upon the design of the incinerator itself, consideration must be given to the unit's characteristics in the design of the CEM system. Hazardous waste incinerators can be characterized as liquid injection, rotary kilns, and fluidized bed combustors. In general, liquid injection incinerators have operating conditions that produce fewer problems for CEMs than the other two types. Because rotary kilns are used primarily to incinerate wastes with high solids content, wastes that cannot be pumped or tanked, and wastes that have solid residues, they usually have dusty flue gases that require extensive dust removal. Fluidized bed incinerators also usually generate flue gases with high dust loading. In general, hazardous waste incinerators, and rotary kilns in particular, tend to operate at low CO concentrations, e.g., 20 ppm, with high spikes, e.g., >2000 ppm, multiple analyzers with different operating ranges or monitors with auto-range changing are likely to be necessary.

Section 4 presents an approach by which the permit writer can review a proposed monitoring system. This approach is presented in conjunction with Appendix D which provides recommended quality assurance and performance specifications for continuous monitoring of carbon monoxide at hazardous waste incinerators. The review process is divided into the following elements:

- System design
- System performance test
- Trial burn plan

In the system design review, recommendations are provided for the following:

- Sampling location
- Sample interface
- Analyzer performance review
- Data handling system review

This section also includes specific recommendations for reviewing the procedures, test schedule, and data reduction and test report format for the system performance test which is required to ensure that the CEM system

meets the specifications contained in Appendix D. Finally, monitoring during the trial burn and data reduction and reporting for the trial burn are discussed.

Section 5 suggests procedures for reviewing the trial burn report itself and translating these test results into permit conditions. The CO monitor performance test must be reviewed to ensure the completeness of the data, to calculate or verify the quality assurance (QA) values, to compare the QA values from the test with the specifications, and to iden- tify remedial actions if needed. The CO limits under consideration make interpretation of trial burn results less cumbersome, but the concen- trations measured during the trial burn must be compared with 10 minute and 60 minute averages and QA data must be considered in the calculations of the CO concentrations. The treatment of anomalous data must be consistent with established practices. Oxygen correction procedures must be reviewed to ensure that they are appropriate. Finally, the waste feed cut-off system operation must be reviewed by evaluating the combustion control logic and comparison of setpoints to standards.

The final section of this document, Section 6, focuses on operating and maintenance procedures. Operation and maintenance of the CEM requires calibration, audit, and preventive maintenance. The frequency of these procedures are "as required", daily, weekly, monthly, and annually or semi-annually with increasing attention and effort as the frequency of activity decreases. Procedures for the operation and maintenance of the waste feed cut-off systems should include the control logic and testing of the following:

- Analog-to-digital signal conversion precision and accuracy

- Digital signal integration accuracy

- Mathematical processing and calculation algorithms (hardware or software or both)

- Corresponding output (control) signals

Data reduction and reporting requirements are recommended. Finally, equipment replacement and repair requirements are discussed. Specific recommendations are impossible to make because of the diversity of possible systems; general requirements are discussed.

Several appendices are included. Appendix D is the recommended standard for determining the adequacy of the CEM; it includes performance standards for the systems and describes the procedures required to demon- strate compliance with the performance standards. Partial lists of instru- ment vendors are given, along with the manufacturers reported instrument performance in Appendices A and B. Appendix C shows some typical CEM system schematics.

TABLE 2. SUMMARY OF MEASUREMENT CHARACTERISTICS

Characteristic	Measurement Principle			
	NDIR	GFC	EA(C,P)	GC
Sample Type	cont. extract	cont. cross stack & extract.	cont. in-situ	discrete extract
Major Positive Interferents (unconditioned)	CO_2 $H_2O(v)$	CO_2 $H_2O(v)$	hydro-carbons, combust-ibles	none
Analytical Range* Low High	 0.5 ppm 50 %	 10 ppm 100 %	 20 ppm 20 %	 0.1 ppm 100 %
Other Analytes**	limited	yes(4)	no	many
Conditioning Requirements	extensive dust, water, acid gas	none	minimal dust	moderate dust, acid gas

* Analytical range includes lowest detectable and highest measurable concentration for the analyzer type; the range of a particular analyzer will not be as great; cross stack instrument ranges are dependent on path length, i.e., stack diameter.

** Other analytes indicates the number of other parameters that can be measured with a single instrument; a given type can often be built to measure other analytes.

Nondispersive Infrared Spectrometry (NDIR) - Conventional Detection

NDIR is the most common technique in use today for measuring CO in gases, although GFC is gaining some acceptance for stack gas measurements. The NDIR method takes advantage of the property of carbon monoxide to absorb IR energy at distinctive wavelengths. A beam of IR energy is generated and passed through a gas sample. Any CO in the sample will absorb IR at the characteristic wavelengths and, through appropriate selection of filters and detectors, the degree of attenuation caused by CO can be measured. Figure 1 is a simplified schematic of the major components of an NDIR analyzer.

The source beam is "chopped" with a motor-driven filter wheel which passes the beam, optionally through narrow-bandpass filters, alternately through the reference cell and the sample cell. The reference cell is a sealed unit filled with an inert, CO-free, dry gas such as helium or nitrogen. The sample cell is a flow-through unit and the sample gas is constantly pushed or pulled through it at a known and fixed flow rate and pressure. The sample cell is lined or coated with gold foil which is highly reflective of IR radiation to minimize cell wall absorption. The transmitted energy from each cell is directed to the detector section of the analyzer where the differential energy between the beams is converted to an electrical signal, amplified, and displayed on a meter of some type.

In the "Luft" microphone (pictured in Fig. 1), a sealed chamber is placed at the end of each cell and the two chambers are separated by a flexible diaphragm. The energy difference heats one chamber more than the other and the resultant pressure increase deforms the diaphragm. This diaphragm distortion is translated into an electrical signal (condenser microphone) and the resulting signal is amplified and processed (linearized) to obtain an analog voltage corresponding to the amount of CO in the sample cell. The voltage is displayed on an analog voltmeter calibrated to the concentration scale for which the instrument was designed. The instruments are designed to optimize performance in the measurement range of interest: cell geometry, chamber and microphone design, and detector selection are combined to yield optimimum electrical output and inter- ference rejection; signal processing electronics are built to provide a linear output from the specific instrument components.

The other detector types also employ differential measurement of the transmitted energy. Photodetectors are photovoltaic cells in which the incident radiation is directly converted to an electrical voltage. Dif- ferential measurement is obtained by alternately measuring the energy transmitted through the reference and sample cells. Early versions were not sensitive enough for environmental analysis, but advances in solid-- state electronics have permitted the use of photodetectors in source and ambient monitors. Thermocouples and thermistors measure temperature dif- ferences created by the transmitted energy differences, either directly (thermocouples) or indirectly (thermistors).

Like most devices with mechanical parts, NDIR analyzers are subject to malfunction from vibration, mechanical misalignment, friction, etc. The

LUFT-TYPE
DETECTOR

BANDPASS
FILTERS

I R
SOURCE

CONDENSER
MICROPHONE

FLOW-THROUGH
SAMPLE CELL

DIAPHRAGM

SEALED
REFERENCE CELL

BEAM COLLIMATORS

MOTOR

MODULATING
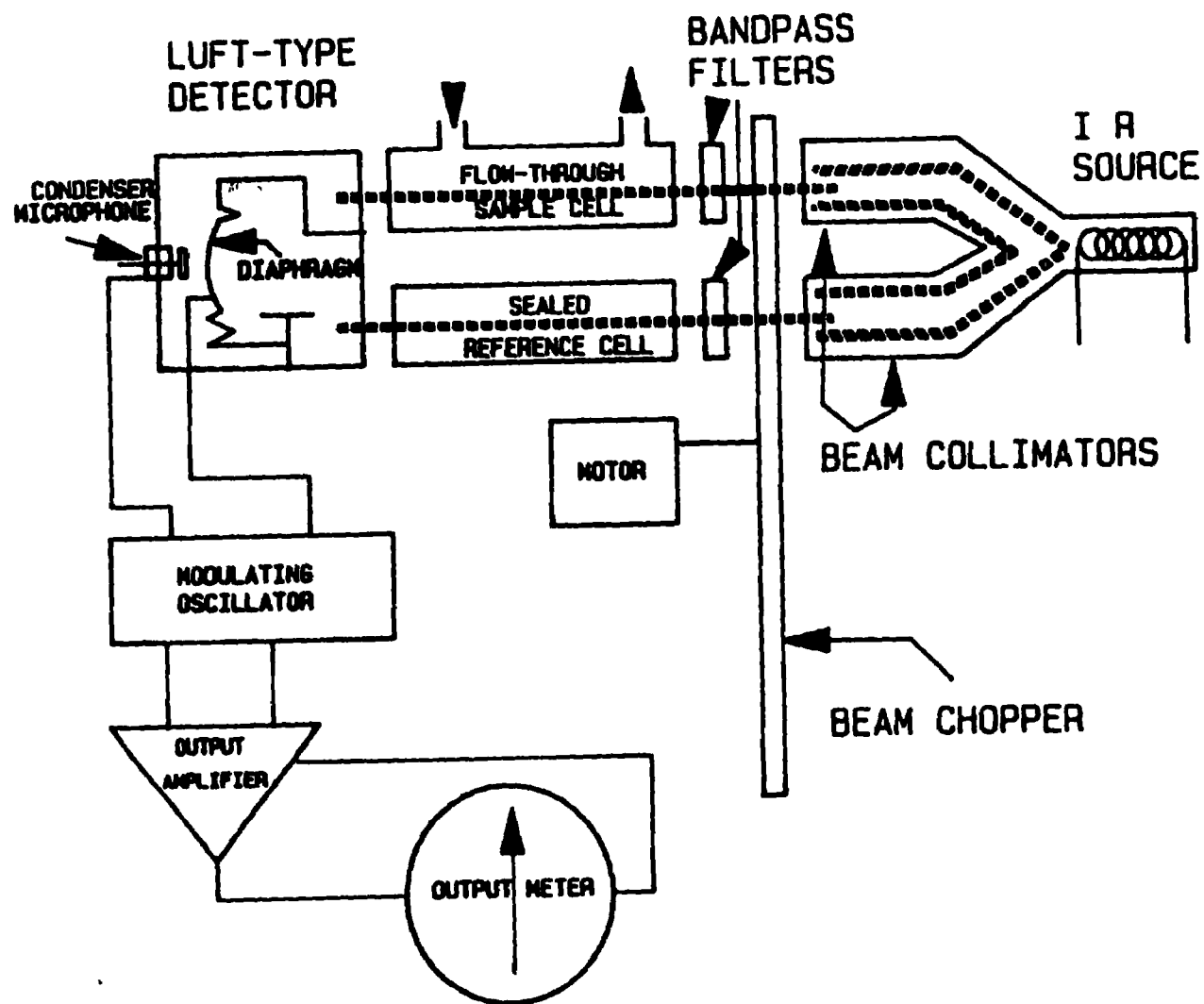OSCILLATOR

BEAM CHOPPER

OUTPUT
AMPLIFIER

OUTPUT METER

Figure 1. NDIR Luft-type
Analyzer Schematic

manufacturers have solved, or at least minimized, problems related to chopper/motor failure, IR source spectral decay, detector chamber leaks, response/linearity, and cell materials. The instruments are not maintenance-free, however, and a regular program of inspection and preventive maintenance is needed to maintain on-line reliability. Many of these instruments were designed for use in coal-fired power plants; application to HWIs has identified some additional difficulties. Acid gas (HCl) corrosion of cell walls, presence of interferents, and instrument ruggedness are problems that users and suppliers must consider in a given application.

NDIR - Gas Filter Correlation Detection (GFC)

Gas filter correlation analyzers also use the infrared absorption properties of CO to quantify the amount present in a sample, but do so in a manner different from conventional NDIR analyzers. In GFC analyzers, a reference cell containing a sample of the pure (or a high concentration) gas of interest is used to filter the source beam to remove the exact IR absorption spectra of the analyte gas. A second cell containing an inert gas, such as N_2, is used as the measurement beam. As both the measurement beam and the reference beam pass through the sample gas, some of the disadvantages of separate sample and reference paths can be eliminated. The effect of source intensity variations, spectral shifts, optical misalignments, and certain interferences can be minimized through the detailed comparison of IR spectra afforded by the GFC instrument. A narrow-bandpass filter is placed in front of the detector so that the measurement is taking place at the CO absorption peak (~ 4.7 m). The usual detector is a photocell and the photocell output is electronically synchronized with the gas filter chopper to make the measurement comparisons. Simplified schematics of GFC analyzers are shown in Figure 2.

One of the major advantages of GFC units is that the gas filter analyzer permits automatic correction for source/detector aging. Cross-stack continuous emission monitors for CO are GFC analyzers, but there are also extractive GFC units. GFC cross-stack units are either double-pass design where both the source and detector are located on the same side of the stack and the measurement beam is sent across the stack and returned by a retro-reflector, or single-pass units which have the source and detector located on opposite sides of the stack. The various manufacturers have used a number of approaches to dealing with such problem areas as alignment shifts with stack movement, maintaining clean optical windows, and compensating for stack temperature changes and stack radiation effects, and internal calibration mechanics and electronics.

Electro-analytical Methods

Catalytic Oxidation --
Catalytic oxidation sensors use the heat of combustion of carbon monoxide to quantify the amount of CO present in a sample. Several different methods are used to convert the heat of combustion into a measurable entity. The most common method is measurement of the current change in a Wheatstone bridge resulting from the temperature-driven resistance change
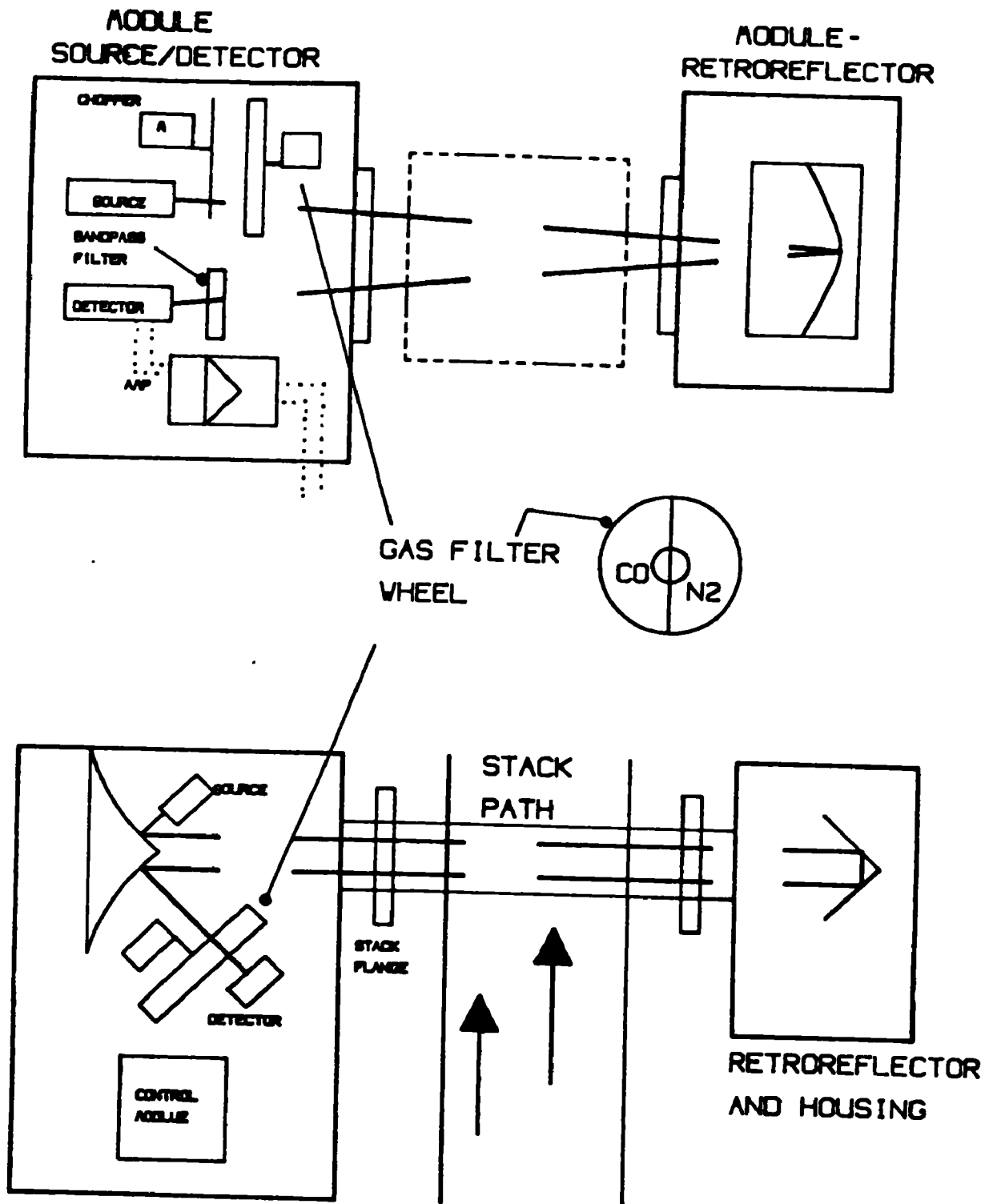
Figure 2. GFC Analyzer
Schematics

of a thermistor caused by oxidation of the combustibles. The Wheatstone bridge consists of a combination of series and parallel electrical circuits arranged so that electrical flow among the various paths can be balanced and any imbalance in one leg (as from a resistance change) can be measured in another leg of the bridge circuit. Manually variable resistors are used to set the zero and span of the instrument. Normally, two separate catalyst beads are used in the system; one is used to compensate for ambient temperature changes and is not exposed to sample gas, and the other is the measuring bead.

As CO monitors, EA units are not sufficiently specific; any other combustible compounds oxidized at the temperature/catalyst combination used for the sensor yield a positive interference. As combustion optimization monitors, this interference is actually a benefit in that unburned fuel is also measured. However, the response factors for some of the materials burned in HWIs is low in comparison to fossil fuels so these units are less effective as HWI combustion monitors than as boiler combustion monitors. In recent years, the sensitivity of these units has been improved so that the detection limit is as low as 100 ppm rather than 1000-2000 ppm found in earlier instruments.

The units are usually placed on or near the stack, with an extractive probe having the sensors mounted at the end of the probe outside the stack. The extractive probe systems are optionally combined with an O_2 sensor measuring the same gas as the combustibles/CO sensor. The in-stack sensors do not have the capability for calibration with standard gases so instrument zero and span are set electrically. Some of the extractive systems have provisions for flowing calibration gases in the probe.

Polarographic --
The use of voltammetric (polarographic) analytical procedures has been applied to CO measurement with some success. An electrochemical cell is used with specifically chosen electrolytes to measure the product of reaction of the pollutant of interest and the reagent. The reaction produces a current flow as the pollutant is oxidized or reduced in the cell and this current flow is measured with a galvanometer. A semi-permeable membrane is used between the cell electrolyte and pollutant gas and the system is designed so that the rate of diffusion of the pollutant through the membrane is solely dependent on the concentration of the pollutant. Thus, the rate of reaction, and rate of reaction product reaching the sensing electrode, are directly proportional to the analyte concentration in the sample gas.

Each manufacturer claims sensitivity and interference-rejection capabilities based on their particular cell design. Generally these units are small, portable and designed as explosion or other warning monitors. They are commonly used as toxic gas detectors for prevention of worker exposure to unsafe concentrations of CO. More sophisticated versions have been used for monitoring ambient concentrations of carbon monoxide where the operating environment can be well controlled and the sampling system used to minimize interferences. These ambient systems generally do not function very well in an industrial environment.

Gas Chromatography

Gas chromatography provides precise and specific quantitative results even though it is not generally considered a continuous monitor. Chromatography offers the potential for analyzing a sample for several different analytes with little or no additional cost over a single analyte. The process of chromatography involves using a "stationary" medium which has the ability to retard the passage of one or more chemical compounds relative to other compounds. In general, gas-liquid chromatography (often referred to as gas chromatography) is used for analysis of organic compounds and gas-solid chromatography (GSC) is used for fixed-gas (SO_2, CO_2, CO etc.) analysis. Both types have been employed for stack gas analysis. In gas-solid chromatography, (GSC) the column is filled with a solid material, referred to as the support, that is coated with a viscous liquid, known as the stationary phase. These columns are referred to as packed columns and the combination of solid support and stationary phase is the packing. In gas-solid chromatography, then, the solid is the packing. The packing is chosen for the particular analysis to retard the passage of the compound(s) of interest with respect to other compounds present in the gas sample. Detection is accomplished by measuring some property on the gas exiting the column and converting this property change to an electrical signal.

A number of detector types are available and selection depends on the required sensitivity, presence of interferences, nature of the analyte, and concerns for the operating environment. Common detectors for stack gas analysis include flame ionization (FID), photoionization (PID), thermal conductivity (TCD), electron capture (ECD), flame photometric (FPD), and Hall detectors. Each has some particular advantages and disadvantages and selection involves weighing the advantages and disadvantages. CO is usually measured with a TCD using GSC as the separation process. CO can't be directly quantified with an FID, but can be indirectly by reduction of the CO to methane and measurement of the methane with an FID. This indirect method is most often used for measurement of total hydrocarbons but could be adapted to CO-specific measurements. ECDs respond well to metallo- and chlorinated organic compounds. FIDs, on the other hand, respond to the C-H bond and thus very well to aliphatic and aromatic hydrocarbons, but poorly to oxygenated (aldehyde and ketone) and chlorinated compounds. PIDs can be selected to exhibit a much greater sensitivity to aromatic compounds than to aliphatic ones. Most detectors used for GC analysis are non-specific; that is they respond to a variety of compounds, although the response will vary depending the compound. Chemical-specific detectors like FPDs are not generally required for GC analysis as the separation and identification is performed by chromatographic process. What is required is a detector which responds to the compound of interest and much of the choice centers around the detection limits. A semi-specific detector, such as the PID, can be used to simplify the chromatographic separation process if there is an interferent which is difficult to separate from the analyte but which doesn't generate a significant detector response.

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GC analysis is a semi-continuous process; GCs are not continuous monitors within the definition of the performance specification. Each analysis is performed on a discrete parcel of sample gas and can be repeated as soon as the analytical cycle time (usually several minutes) has elapsed. The advantage of GC analysis is that several components can be measured with a single instrument. Disadvantages are absence of continuous output and expense. Typical laboratory GCs are not sufficiently rugged for an industrial process monitor environment and industrial process GCs are relatively expensive, especially compared to NDIR analyzers.

FLUE GAS SAMPLING

Regardless of the type of measurement system used, the sample being measured must be representative of the flue gas composite. The end use of the data is a significant element of what constitutes a representative sample. A sample taken at a given point may be representative for one purpose but not for another. For example, a sample location downstream of quench air addition would not be representative for combustion control purposes but would be representative for correction of stack gas CO concentration to 7% O_2.

Extractive Sampling

Sample Extraction and Transport --
The sampling extraction and transport system consists of a probe, sample lines, and sample prime mover. The sample probe is the interface between the stack gas and the sampling system and should be constructed of materials which will withstand exposure to the stack gas but not change or react with the sample. This also applies to the rest of the sampling system, but the probe is constantly exposed to the most severe service, the rest of the system is exposed to less severe service as a result of conditioning. Figure 3 displays a schematic of a complete system and includes a number of components which may not be present in any particular system. Some manufacturers, for example, combine particle filtration and moisture removal in a coalescing filter.

Probe. The sample probe may either be a single or multiple inlet type and may be equipped with a coarse particle filter. Combustion-zone or hot-location probes often need to be cooled and air, steam, or water are used as coolants. Stainless steel, Hastelloy®, Inconel®, and ceramic materials are used for probe construction. For low temperatures and small ducts, probes are sometimes constructed of Teflon®.

Sample Lines. The most common material for sample lines is Teflon®, although stainless steel and, sometimes, polyolefin tubing are used successfully. Depending on the instrument conditioning requirements and environmental conditions, the sample lines may need to be heat-traced with steam or electrical-resistance heaters. Sample lines are sized to obtain the required flow rates with minimum pressure drop, while minimizing residence time.
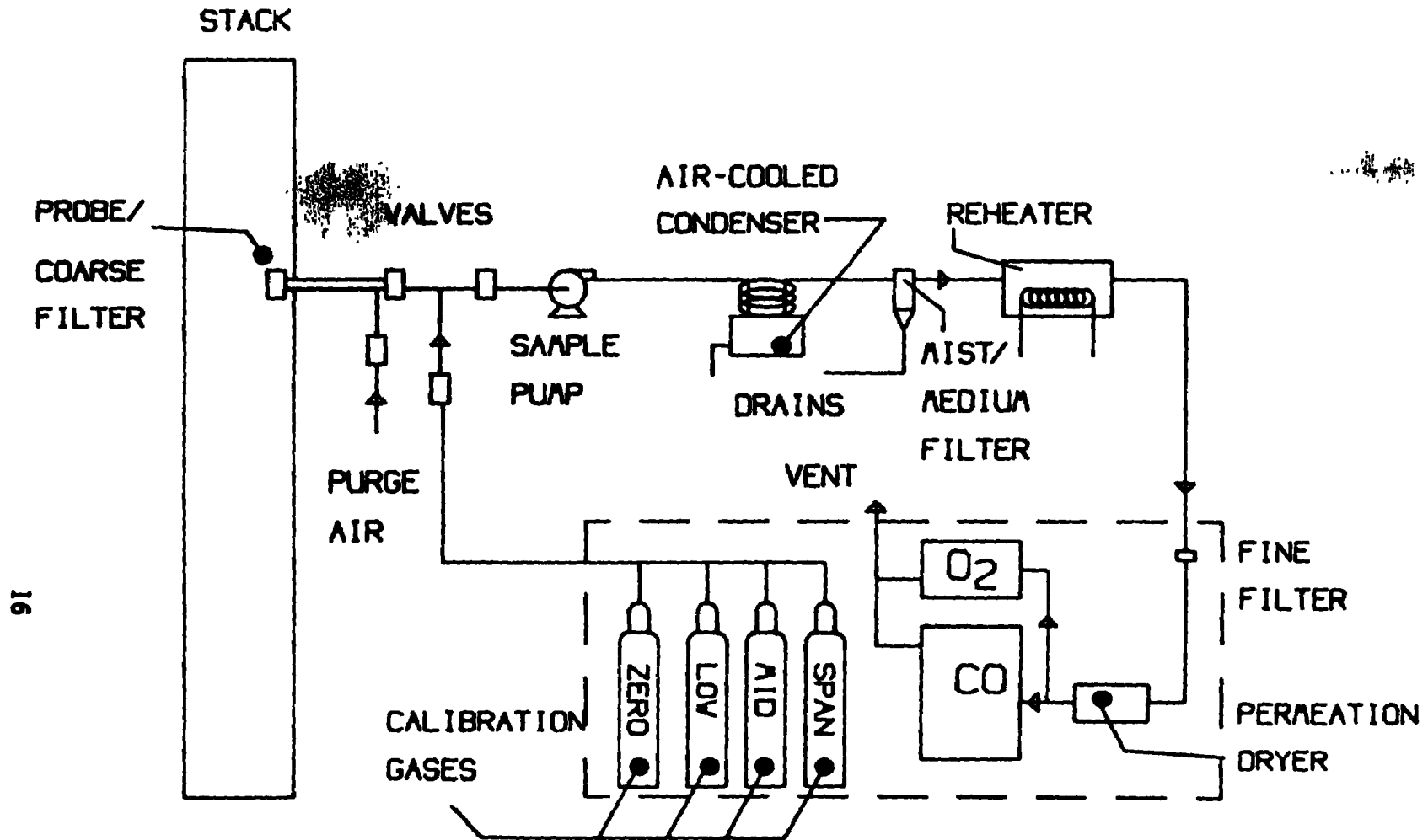
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Figure 3. Sampling System Schematic

Prime Mover. Samples are extracted from the stack with pumps or with ejectors or eductors, or both in combination. Each mode has advantages and disadvantages for a particular application. Eductors and ejectors use air or steam to induce a vacuum by aspiration and are common industrial fluid movers, simple (no moving parts), inexpensive to operate, and offer easy flow regulation. Disadvantages include mixing of the sample and ejector fluid at the unit discharge which limits the use to locations downstream of any use of the undiluted sample gas. Pumps are relatively expensive and prone to mechanical failure but maintain the integrity of the sample gas and can easily be used in either pressure or vacuum service.

Sample Conditioning --
The sample conditioning system is critical to proper operation of the extractive analyzer monitoring system. Most analyzers require a particle- and moisture-free gas for accurate and continued operation and the focus for conditioning systems is on dust and water removal. In some cases, other interfering components are removed, but general practice and sound design is to use an analyzer which is not subject to or corrects for other interferences. Sample gas temperature and pressure are also controlled. The sample conditioning elements can be interspersed throughout the sample train. Coarse particle (>20 μm) filtration is usually done at the inlet end of the sample probe, and often the filter is configured so that it can be periodically back-flushed. It is desirable to have provisions for introducing calibration gases as near to the front of the sample system as possible so that the entire system is evaluated, including the conditioning system. Following the coarse filter are fine filters, acid gas scrubbers, gas coolers and condensers, moisture droplet filters, and gas dryers. Heaters and pressure regulators are usually the final stage of gas conditioning before delivery to the analyzer.

Cross-Stack Sampling

The cross-stack analyzers, such as the GFC instruments described previously, avoid many of the problems of the extraction systems such as sample line leaks, material corrosion, and conditioning system malfunctions because the sample remains in the stack. However, calibration of the entire system with standard gases is not practical (e.g., filling the stack with calibration gases); interferences cannot be removed from the sample gas so corrections or elimination must be done optically and/or electronically; and instrument repair and maintenance is much more difficult for an instrument on the side of the stack than one in a control room.

The sample interface for cross-stack analyzers consists of optical windows exposed to the stack gas environment and through which the IR beam passes. The instruments are usually bolted to flanges located on opposite sides of the stack wall. Double-pass instruments usually have only a retroreflector on one side and the source/detector on the other; single pass instruments have the IR source module on one side and the detector on the other with various control elements located in the source and/or, detector module or a separate control module. Some form of keeping the optical windows clean is provided, usually by purging with clean air.

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In-situ Sampling

In-situ analyzers are those where the sensing/detection element is placed directly in the gas passage and there are no true "in-situ" analyzers for CO. Many of the EA units are referred to as in-situ because the sensor is located on the stack and a small quantity of sample gas is diverted into the probe, passed over the sensor, and discharged back into the stack. Thus the sample has not been extracted in the conventional sense although it has been conditioned to some extent. For the most part, these analyzers for CO are improvements on the "combustibles" analyzers used for combustion control purposes, so they have been designed for use in more severe environments than the emission monitors. At this time, there are no EA analyzers meeting the recommended performance specification although some units nearly comply. If a complying EA unit with an extractive probe were used, stratification in the sample gas can be tolerated because the probe can be designed to sample gas from several points along its length. These extractive probes are usually steam ejectors which induce a sample gas flow over the sensor and discharge the steam/gas mixture back into the duct downstream from the probe.

OPERATING CHARACTERISTICS

Each of the analyzer types discussed in the previous section has its own set of operating characteristics and some of these have already been described. In this subsection, some quantitative comparisons among the types are made. These comparisons are intended to provide the reader with a basis to choose the best-suited analyzer for a particular application rather than rate these instruments independent of their application. Many of the parameters are inter-related in that an improvement in one area may be to the detriment of performance in another area. For purposes of comparing instruments, either generically (by type) or specifically (by manufacturer and model), the data reported in the manufacturers literature are the best available and are used in the following comparisons.

The major parameters of concern for monitoring CO from HWIs are sensitivity, precision and accuracy, response time, and instrument drift. Other factors of interest include calibration requirements and procedures, linearity, interference rejection, and environmental requirements. The source of the definitions and explanations in the succeeding subsection is the **Quality Assurance Handbook for Air Pollution Measurement Systems: Volume I. Principles,** USEPA-EMSL, EPA-600/9-76-005, Dec. 1984, and will hereafter be referred to as the QA Handbook.

Precision and Accuracy

Table 3 summarizes the general range of precision and accuracy for the various analyzer types as reported by manufacturers. Detailed information on specific analyzers can be found in Appendix A.

The data in the table would suggest that precision and accuracy are not a problem for CO analyzers, especially when one considers that values of ±10% are often used as a general rule for laboratory analyses. However,

the values really represent the best obtainable performance in controlled conditions. When a complete system is operating in the real world, it is much more difficult to achieve the kind of results shown in Table 3. The performance criteria of Appendix D reflect very good, but achievable, performance of a complete system. In general, Appendix D requires ±5%.

TABLE 3. SUMMARY OF REPORTED PRECISION AND ACCURACY
(ANALYZERS ONLY)

Parameter	NDIR	GFC	EAC	EAP
Precision, %FS				
Lowest	.5%	1.0%	1.0%	1.0%
Highest	2.0%	1.0%	2.0%	nr*
Typical	1.0%	1.0%	2.0%	
Accuracy, %FS				
Lowest	1.0%	2.0%	1.0%	nr
Highest	2.0%	3.0%	2.0%	nr
Typical	2.0%	2.5%	2.0%	nr

* nr - not reported

Sensitivity

In general, most of the analyzers reviewed offer minimum detection limits (MDLs) of approximately 2 to 3% of the full scale measurement range. Conversely, the full scale range is 30 to 50 times the MDL. These factors become significant when both high range and low range values are of concern, as they often are in the case of HWIs. If both high and low concentrations of CO (peaks and long-term averages of near-baseline levels) then a single analyzer selected to measure one or the other accurately will not likely measure the remaining one very accurately. The significance of the operating range or quantification range will be discussed in a later section.

Response Time

The NDIR analyzers have the slowest response time of the units described here, while the GFC instruments have the quickest. The response time of a gas chromatograph is nearly always much longer than the response of conventional "continuous" analyzers. Most NDIRs (analyzer only) have response times on the order of 30 seconds, while the GFC units are 1-5 seconds. The EA units show response times in the range of 2-30 seconds, while GC operating times are usually several minutes. In addition to the actual instrument response time, the time for conveying the sample to the measurement section must be included. For the cross-stack and in-situ units, this time is effectively nil. For the GC and NDIR systems, which are extractive and require a sample extraction/conditioning system, this time can be as much as several minutes, although the sampling systems are generally designed to achieve residence times of less than 1-2 minutes.

Many of the faster-responding units have adjustable response times so short-term spikes can be damped out. These systems are often designed for combustion control purposes (setting fuel flow rates, modulating air dampers, controlling fan speeds) so a very rapid response time can be detrimental. The extractive systems have a built-in damping effect due to the internal volume of the system. The use of the analytical results, therefore, needs to be considered when evaluating the desirability of a particular response time. Appendix D establishes a maximum permitted response time for emission measurement purposes. If other uses of the data are to be made (e.g. combustion trim control), then faster response times may be necessary and cross-stack types are probably needed.

Calibration

The extractive systems permit the use of standard calibration gases to calibrate the entire monitoring system, while the cross-stack units must be calibrated using surrogate calibration devices. Most extractive systems (refer to Fig. 3) are, or can be, designed to flow calibration gases through nearly all of the system, although the probe, and sometimes the coarse filter, are not included in the calibration loop. The recommended procedures for system calibration are included as Appendix D to this manual.

SECTION 3

GENERAL APPLICATION TO HAZARDOUS WASTE INCINERATORS

INTRODUCTION

This section describes the application of continuous CO analyzers to hazardous waste incinerators and highlights possible problem areas and their solutions. There are four major topics to be considered when designing or evaluating a system for a HWI. These are sampling/analysis location, presence of interferences to the analytical method, consideration of the design and operating characteristics of the specific incinerator, and some considerations related to the trial burn.

SAMPLING/ANALYSIS LOCATION CONSIDERATIONS

The RCRA regulations require that CO be monitored continuously, either in the stack (264.345(b)(1)) or at a location downstream of the combustion zone but prior to release to the atmosphere (264.347(a)(2)). The rules, therefore, permit some latitude in selection of a monitoring location. The choice of a monitoring location cannot be separated from the objectives of the monitoring. CO measurements serve to indicate good combustion (CO below proposed guidelines) and acceptable DRE (CO less than trial burn values). The trial burn evaluation provides DRE results averaged over the time period used for sample collection (usually 20 minutes or greater) and the minimum time-averaging period in the proposed CO limits is 10 minutes. This suggests that the instantaneous CO concentration at a given time is not particularly important except as it affects the time-averaged value. Thus, it is not necessary to measure the CO concentration either spatially, at the end of the flame or combustion zone, or temporally, within seconds of the actual occurrence. What is necessary is to measure the concentration at a time and place which provide reproducible measurements. The time factor for most HWIs is not significant because the residence time of flue gases from time of generation in the combustion chamber to discharge to the atmosphere rarely exceeds five seconds. Choice of a physical location for a sampling probe or cross-stack path requires consideration of dilution of the flue gas by non-combustion gases (e.g. ambient air or baghouse cleaning air), flue gas stratification, presence of potentially interfering components, and structural considerations.

General

The primary concern in selection of a sampling location is that there be no stratification of gas-phase pollutants, i.e., that the concentration

be uniform across the stack or duct at the point (or points) of sampling. Generally, this means that the sample point should be as far downstream from any potential in-leakage or reaction as possible. Fortunately, finding a well-mixed location is not as difficult as finding a suitable location to sample particulate matter; gaseous pollutants are not subject to differentiation by inertial forces as are particles. The criteria contained in EPA Reference Method 1 (40 CFR, Title 60, Appendix A) provide a basis for selecting sampling locations. These specifications are intended for selecting representative velocity locations. However, they are often used for selecting monitor locations without consideration of the intent. The minimum duct diameter criteria of Method 1 suggests that the sample point be at least 8 equivalent duct diameters downstream of any disturbance. The guidelines for siting continuous emission monitors (EPA-450/2-82-026) are different from Method 1 and suggest that monitor locations be a minimum of 2 equivalent duct diameters downstream from any disturbance. If the 8-diameter criteria of Method 1 can be obtained without much difficulty, additional assurance of homogeneity is obtained over a lesser value, but it is generally not a significant improvement. The 2 diameters downstream/one-half diameter upstream criteria will generally produce acceptable results.

More important to obtaining representative CO measurements is the homogeneity of the sample obtained in the absence of in-leakage of ambient air or other diluent gas and absence of chemical reactions (like combustion) at the sample point. For these purposes, a sample location in the discharge stack is usually acceptable. While the gas velocity profile might not be acceptable for particle sampling because of flow irregularities, it is usually acceptable for gaseous pollutant sampling. Potentially stratified locations should be avoided but if this is not feasible, then a stratification check should be performed. A stratification check can be done measuring the CO_2 and O_2 concentration at several points across the duct cross section using an Orsat analyzer, or using a portable continuous analyzer for CO, CO_2, or O_2. In some cases, flow-straighteners are installed to eliminate problems with velocity profiles for manual sampling (HCl, particulate matter) and these will actually create stratification by preventing mixing of the flue gases. If flow directors are required to obtain valid particle measurements, the location is not recommended as a CEM location and alternatives should be sought. If no alternative is available, stratification checks should be done with and without flow straighteners and judgement exercised regarding whether the flow modifiers have to remain or are removed after the DRE tests. The best solution to this problem is likely to be a multiple-point sampling probe.

There may be a number of reasons to monitor at a location other than the stack discharge as there are some disadvantages to locating a monitor in the stack. Alternative locations may be desired because of multiple unit discharges through a common stack, desire to monitor for combustion control purposes, difficult access to sample probes and/or conditioning systems, or to minimize sample line lengths. Whatever the reasons, other locations are acceptable as long as the criteria regarding homogeneity are met. If the location is under pressure, then any leakage at the sample point would be out of the system and dilution would not be a factor. If,

however, the duct were under vacuum (e.g. after the air pollution control device and before the ID fan), then in-leakage could be problematical. The CO limits under consideration require correction of the measured CO concentrations to a 7% O_2 dry basis so in-leakage is not important as regards compliance with the limits but it is important as to whether or not it creates a non-homogeneous gas stream.

Combustion Zone

The combustion zone is not a particularly good sampling location for a continuous monitor for several reasons. The combustion zone is quite turbulent and obtaining a representative sample of the flue gas stream is very difficult. The high temperatures require special and expensive probe systems to withstand the thermal and chemical stresses of the environment. The high particle concentration places great demands on the particle filtration system, and the probe system can alter the chemical composition of the localized gas stream by chilling it or serving as a reaction site. Perhaps the most salient disadvantage to combustion zone monitoring relates to instrument availability.

Equipment exposed to conditions as severe as those in the combustion zone have a tendency to fail often. The RCRA regulations mandate no incineration of hazardous waste unless the monitors are operational. Thus, any monitor downtime shuts off waste feed. This can, and often does, create an upset to an otherwise steady-state and acceptable combustion process because of instrument failure. The net result is worsened combustion from stopping and starting waste feed and results in higher emissions of unburned or partially burned material.

If it is necessary to monitor CO in the firebox, the location should be selected carefully. The location should be as far from the flame front as possible to minimize damage to the probe and reactions with the flue gas. It is necessary to define the concentration profile at the sampling point by measuring CO concentrations at several points in a plane normal to gas flow. The equal-area method of Ref. Meth. 1 is recommended for locating sample points. The disturbance criteria will almost certainly be violated by the nature of gas passage design, so the number of sample points should be as many as possible. Conventional profile sampling is conducted with at least 12 sample points for ducts of the size commonly encountered in HWIs. This number represents a balance between the physical difficulties of sampling and obtaining a statistically sound sample. The sampling should be repeated at least three times during each of three conditions: (1) stable operation at high load; (2) unstable operation at high load; and (3) unstable operation at low load. These data will permit selection of an appropriate point for sampling. If the concentration profile remains constant, a single point at the location of the average concentration can be used. A constant profile means that the concentration at a given point relative to a reference point remains constant even though the actual concentration may vary. If the profile changes with load or conditions, an integrated multiple-point sample is recommended. Otherwise, the measured CO value will be representative during one condition but not during another.

Exhaust Stack

In most cases, a stack location is acceptable and desirable for obtaining the needed CO data. The flue gases have been partially conditioned by the air pollution control devices (APCDs), the gas stream is reasonably homogenous, and the physical situation is generally amenable to installation of monitors. The time delay between occurrence of change in concentration and its appearance at a stack location is acceptable.

The sampling point location criteria contained in EPA Ref. Meth. 1 provide the basis for selecting a sample site, with the following caveats. Method 1 is intended for obtaining representative samples during multiple-point isokinetic manual sampling for solid and liquid particles and addresses the velocity profile of the gas stream with regard to size differentiation of the entrained particles. Gaseous pollutants are not subject to this inertial separation so the criteria are not directly applicable. Method 1 requires that a sampling location be at least 2 equivalent duct diameters downstream of any flow disturbance. At any location closer than 2 diameters, the flow is presumed to be too turbulent to obtain accurate velocity readings. This turbulence, however, works to the advantage of gas monitoring by ensuring a well-mixed gas stream. The condition to be avoided is one where there is the possibility of diluent gas in-leakage into a non-turbulent gas stream. This condition would likely create stratification. One need not be concerned about dilution of the stack gas; the proposed CO limits require correction of measured values to a standard oxygen basis (7% O_2). However it is good practice to locate monitor sites as far from any possible leaks as possible, especially for negative pressure locations. If a candidate location is under vacuum (upstream of a fan inlet), then care must be exercised to ensure that the gas stream at the location is well mixed so that any leakage will be distributed over the entire gas stream. In these cases, the sample site should be as far as possible from the source of potential in-leakage; certainly not less than the 2-diameter criteria of Method 1. If there is a question about the degree of mixing or presence of stratification, then a sample traverse should be performed. In positive-pressure systems (downstream of a fan), any leakage will be out to the atmosphere and will not affect the accuracy of the monitored concentration.

The procedure discussed above concerning combustion zone monitoring can be applied for any stratification check. The load considerations will probably be less significant than for a combustion zone location, but should not be overlooked. For the most part, duct locations will exhibit a constant degree of stratification at varying loads because the bulk flow of gas is created by mechanical means, and phenomena such as on-going reactions are not a factor. At least twelve sample points are usually necessary to identify stratified gas streams. If stratification is found, and the location is the only practical one, additional sampling will be necessary to quantify the degree and nature of the problem. If at all possible, however, stratified locations should not be used. For purposes of CO monitoring, stratification is considered present if a single point shows a concentration different from the average value by more than 15%

of the average value or if two values are different from each other by more than 20% of the average value.

Locations between Stack and Combustion Zone

There may be valid reasons for monitoring CO at locations other than those discussed in the previous sections. For example, the operator of a facility with a caustic wet scrubber for acid gas removal might prefer to measure CO_2 upstream of the scrubber to avoid the problems of CO_2 absorption. Carbon monoxide absorption by scrubber media is not a problem because CO is practically insoluble. It would probably be cost-effective to monitor CO at the same location. Generally, the types of locations can be classified as pre-APCD, mid-APCD, and post-APCD but before the stack. Each type has a particular set of circumstances to be considered, but the factors discussed above remain valid. Basically, the closer to the combustion zone the sampling location is, the more severe the sampling conditions will be and the more conditioning that will be required. As the gas stream receives treatment, the sample conditioning requirements are lessened.

The most common problem encountered in monitoring these intermediate locations is finding a representative location. The incineration facilities are designed to occupy the least amount of space, use the minimum amount of materials of construction and to have the minimum amount of ductwork, consistent with such other criteria as temperature stresses, and fabrication and maintenance requirements. Other common problems are high temperatures, high dust concentrations, acid gases (primarily SO_2 and HCl), and physical constraints factors of access and operating environment.

FLUE GAS COMPONENT CONSIDERATIONS

Interferents

For those CO analyzers that use infrared absorption as the method of detection, any flue gas component which absorbs IR in the same wavelength region as CO is a potential interferent. The most common of these are CO_2 and water vapor. Carbon dioxide and water vapor coincidentally have molecular bonds which absorb IR energy in the same region as CO. While the absorption peaks are not identical to those for CO, they are similar and close enough to interfere unless measures are taken to eliminate the interference. Most manufacturers have gone to great lengths to minimize the effect of these interferents and have been fairly successful through judicious use of precision optical filters, sophisticated electronic signal processing, and other techniques. These interferences, if present, yield a positive result even if no CO is present. For the purposes of RCRA monitoring, these interferences yield conservative results because they indicate the presence of CO even if there is none. If the interference level is too great, however, real changes in the CO concentration can go undetected, or at least unnoticed.

Table 4 below demonstrates the effect of various CO and CO_2 concentrations with analyzers with different CO_2 rejection ratios. A 5,000:1 CO_2 rejection ratio means 5,000 ppm of CO_2 will be measured as 1 ppm.

TABLE 4. EXAMPLE INTERFERENCE EFFECTS

Case 1 - CO_2 Rejection Ratio - 5,000:1

	Condition 1 (a)	Condition 1 (b)	Condition 2 (a)	Condition 2 (b)
True Values				
CO_2	10%	10%	5%	5%
CO	150 ppm	0	150 ppm	0
Measured Value	170 ppm	20 ppm	160 ppm	10 ppm

Case 2 - CO_2 Rejection Ratio - 1,000:1

	Condition 1 (a)	Condition 1 (b)	Condition 2 (a)	Condition 2 (b)
True Values				
CO_2	10%	10%	5%	5%
CO	150 ppm	0	150 ppm	0
Measured Value	250 ppm	100 ppm	200 ppm	50 ppm

A CO_2 rejection ratio of 5,000:1 is fairly typical; there are instruments with CO_2 ratios as low as 1,000:1 and lower. When selecting an instrument, the actual (or estimated) flue gas conditions and the acceptable measurement error will determine what capability is required.

Water vapor also interferes with NDIR analysis. Like CO_2 and CO, water vapor absorbs IR in the same region by molecular absorption. Manufacturers provide water vapor rejection ratios in their specifications. Liquid-state water, or droplets, also interferes with the measurement but the nature of the interference is different than vapor-phase interference. This droplet interference is the same as that caused by dust particles, i.e., scattering of the transmitted beam from reflection and refraction by the particles, and generally affects the entire spectrum of the beam. The problem of droplet or particle interference is handled by both cross-stack and extractive analyzers. The cross-stack units use the sample path for both reference and measurement beams and eliminate the effects of intensity attenuation by electronic comparisons of the spectra. The conditioning system for extractive systems removes the droplets and particles prior to analysis. The conditioning system also removes virtually all of the vapor-phase water, as well.

Measurement Basis

Another consideration related to the flue gas components is the basis of the CO concentration measurements. The limits now being considered identify the components of a standard basis as 7% O_2 and dry. The preceeding discussion addressed water as an interferent and pointed out that cross-stack and extractive systems handle the problem differently. By the nature of the measurement systems, cross-stack analyses yield a wet-basis measurement and extractive systems yield a dry-basis measurement. Most emission standards expressed as concentrations (ppm, %, gr/dscf) are dry-basis standards and the CO limits currently being considered will likely be expressed as dry-basis. The procedures for correction to a standard basis are discussed in Section 4 under data handling system review. A separate manual discusses oxygen monitoring. The data generated by all the analyzers needs to be corrected to 7% O_2; the data generated by cross-stack systems needs to be further corrected for stack gas moisture content.

Measurement of Other Pollutants

Carbon monoxide is the only atmospheric emission that the RCRA regulations specifically identify for continuous monitoring. The rules do require monitoring of several process parameters on a continuous basis, but these requirements only peripherally affect monitoring for CO. There are other pollutants monitored at HWIs for a variety of reasons. The limits under consideration require oxygen monitoring to correct the measured CO values to 7% O_2. Some state agencies and some EPA regional offices require monitoring for one or more emitted pollutants, including sulfur dioxide, nitrogen oxides, total hydrocarbons (THC or total unburned hydrocarbons, TUHC), and opacity, to verify compliance with air quality regulations. Some permittees are required to monitor some combination of CO_2, O_2, THC or TUHC, opacity, or stack gas flow rate. The effects of these requirements should be considered in the selection of the analyzer type and in the sampling location.

If THC is to be measured as a combustion indicator, an extractive system will probably be used because the only practical method of analysis is with an FID analyzer which requires that the sample be pumped to the analyzer. In this case, it is likely that CO will also be monitored at the same location and from the same sample line. In this example, the CO analyzer should be placed ahead of the THC analyzer or in a split stream from the main sample line because the FID analyzer uses a "destructive" detector which would tend to oxidize any CO in the sample gas to CO_2 and thus give erroneous CO values. If several parameters are to be monitored, the different conditioning requirements and analytical methods of different analyzers may conflict and the system should be designed to avoid these conflicts or minimize any bias that might result.

Sample Conditioning

Sample conditioning systems are designed to remove or minimize the negative effects of three major elements of the sample gas stream: temperature, moisture, and particles. Removal of interfering species is also

done in the conditioning system if the analyzers internal interference-handling capabilities are inadequate but this can usually be avoided. Some stack gases will also contain significant quantities of acid gases (HCl, SO_2) and these will be removed to some extent as a result of moisture and temperature control.

Any sampling extraction location requires particle filtration. There are two aspects of particle filtration; removing the particles from the sampled gas stream and maintaining the filtration system in an effective operating condition. Locations upstream of the particle removal devices have a much higher particle loading than a stack location so particle removal is more problematic. Filtering the particles from the gas stream is not technically difficult but maintaining a reasonable pressure drop can be difficult. Systems are designed with prefilters, coarse filters and fine filters using porous media which can either be cleaned by back-purging or removed and thrown away. Some sophisticated systems include multiple filtration loops and are designed to automatically change filtration loops when the pressure drop in the system exceeds a setpoint. The particle size distribution is an important factor in selecting filtration media. HWIs disposing of waste solvents and the like tend to generate small particles ($< 10 \mu m$) while HWIs disposing of process sludges can generate very small or very large particles ($> 50 \mu m$ in diameter) depending on the process. Large particles are much easier to remove from the gas stream than small ones but a preponderance of large particles is generally associated with a high dust load so filters tend to plug more readily. Fine particle removal requires a more efficient filter; usually at the expense of high pressure drops.

High temperatures can be a benefit if the analyzer can accept a hot gas in the measurement chamber because the sample gas can be kept above the water and acid dew points. In the context of an analyzer, temperatures above about 150°F are considered high. A sample gas temperature of >220°F is required to prevent water vapor condensation; prevention of sulfuric acid condensation can require temperatures as high as 320°F. If the analyzer and sampling system can withstand these temperatures, sample line heaters can be used. More often, though, cooling of the gas and moisture and acid gas removal are desired and are accomplished with controlled condensation and/or permeation devices.

Moisture removal is required for several reasons. Very few extractive analyzers operate very well for very long with condensation in the measurement section. Some units exhibit an interference to water in the vapor state. Further, the presence of acid gases (condensible or not) with free moisture creates severe corrosion problems. Most extractive systems contain water removal systems. The dryness of the sample gas after conditioning is expressed by the dew point and most systems are designed to achieve a dew point of 30-50F° below the lowest expected operating temperature of the analyzer. Figure 3 (Section 2) shows a sampling system with all of the major components of a conditioning system. A typical system will not include all elements, nor are all elements needed; the schematic is illustrative of the types and locations of devices involved.

CONSIDERATION OF INCINERATOR DESIGN AND OPERATING CONDITIONS

Unit Type

The type of combustion source has some bearing on the design and operation of the monitoring system. The flue gas characteristics are defined by the combustion type. The three major types of combustion chambers for hazardous waste incineration are the liquid injection (LI), the rotary kiln (RKI), and the fluidized bed combustor (FBC). Many units are built with multiple combustion chambers and include more than one type.

Liquid Injection --
    In general, the liquid injection units require less special consideration than the other types. Comparatively, LI units operate with a more homogeneous feed, at more stable conditions, lower flue gas dust loadings, and often with lower temperatures because of waste heat recuperation. LI units are designed to operate with lower excess air and potentially higher CO than the other types. In terms of the time rate of change of CO concentrations, LI units change more rapidly than fluidized bed units but less rapidly than RKIs. However, LI incinerators respond to intentional process changes more rapidly than do the others, which is significant if the CO monitor is being used for either trim or gross combustion control. If CO concentrations are used for fine adjustment of operating parameters (trim control), a rapid response time (< 15 sec) is required; if CO levels are used for gross control, rapid response is not necessary and may even be detrimental.

Rotary Kiln --
    RKIs are usually used to destroy wastes which cannot be pumped, which contain high concentrations of solids (percent level rather than ppm level), where the solid residue has economic value (like plating sludges), or when the waste cannot be tanked for one reason or another. RKIs are usually equipped with an afterburner section to burn the volatile or destructively distilled waste components. RKIs are subject to rapidly occurring changes in CO, primarily in the form of upscale spikes. The CO monitoring system needs a rapid response time (on the order of 10-15 seconds) if these peaks are to be accurately measured. Most RKIs are designed to operate with low CO concentrations (high excess air) so the difference between the average and peak concentrations can be great (20 ppm vs. 2000+ ppm). Since most analyzers do not have this great operating range, multiple analyzers or at least auto-range changing is necessary to measure both peaks and averages accurately. RKIs also generate dusty flue gases so sample locations downstream of particle removal equipment are preferred.

Fluidized Bed Combustors --
    For the most part, FBCs are the most stable of the combustion chamber types. FBCs are used for process sludges which are too "sticky" for RKIs or for solids with low fusion temperatures. The most significant concern relative to CO monitoring systems is the extremely high dust loading at sample locations ahead of the dust removal equipment. The fluidizing medium is sand or other refractory granular solid and the off-gas from the fluid-

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izing chamber entrains a substantial portion of the bed material. An integral cyclone or other particle collector is used to recapture entrained bed material and return it to the fluidized section. Quench air is often added to the combustion products to minimize the thermal stresses on the downstream components of the system. Even with O_2 correction, large enough volumes of quench air are added such that the stack gas concentration of CO after quench addition is at the low end of the analyzer measurement range and random variations can often conceal combustion-related changes in the CO level. This is one of the cases where the stack may not be the best monitoring location; the disadvantages of high temperature and high particle loading may be offset by the advantages of obtaining CO data representative of combustion and useable for process control. If a combustion zone sampling location is being considered, the effect of dilution or quench air on peak and average CO concentrations should be calculated. If the dilutions would mask the changes in CO concentration needed for combustion control, the stack location would not be the best choice.

Waste Characteristics

Generally, the nature of the waste to be burned does not have much direct effect on CO monitoring as the effects appear in the combustion design (type of unit, excess air, etc.). The major consideration for the sampling system is the presence of waste components giving rise to acid gases, particularly sulfur and chlorine. The amount of HCl and SO2 in the flue gas needs to be considered when specifying the sample conditioning system and the materials of construction for sample interface components, and the concerns are much greater for sampling locations before acid gas removal components of the APCD system. Samples extracted from the stack generally need minimal acid gas conditioning because most HWIs are built with acid gas removal APCD systems.

Waste Feed Cut-off Requirements

The purpose of the CO monitor is to discontinue waste feed to the incinerator when some preestablished condition is reached. The monitoring system and waste feed cut-off system interact and these interactions need to be considered. Sections 4 and 5 discuss in detail the specific operation of the waste feed cut-off relative to the CO monitor and DRE requirements, but the technical issues related to integration of the two systems are presented here.

When matching the cut-off system hardware and operation to the CO system, several factors should be evaluated. The time-averaging aspects of the CO analyzer/data processing system should be considered relative to issuance of the signal to the cut-off system. Cut-off system parameters to be considered include: response time (or lag time) of the cut-off controller; bandwidth (signal level, overshoot, etc.); and whether the cut-off controller is a proportional type (like a metering valve or pump speed controller for combustion trim control) or an on/off type (like a pump switch or shut-off valve). Other considerations include the method of handling redundant analyzers and switching CO analyzers without gener-

ating a cut-off signal, procedures for calibrating analyzers without generating a cut-off signal, and starting up a system on non-hazardous fuel and dealing with the high CO values associated with a startup.

TRIAL BURN CONSIDERATIONS

The monitoring system used for the trial burn should be the same system used for subsequent operation and for determining compliance with permit conditions, insofar as possible. In certain cases (new units particularly), the trial burn may reveal problems with the CEM system and necessitate modifications to the system. Generally, the shakedown period allowed by the regulations will provide ample opportunity to remedy these problems before the trial burn. In the event that modifications are necessary, the modified system should be subjected to the same type of QA tests as would a permanent system, with the exception of the 24 hour zero and span drift test. A temporary system should be calibrated before and after each day's testing and zero and span checks conducted between test runs. Response time tests need only be conducted once unless the system is altered during the trial burn testing.

If possible, the monitor performance tests recommended in Appendix D should be conducted before the trial burn. If the system meets the specifications, the CO analyzer data will be directly comparable to the DRE test data and to subsequent operating data and can be used to narrow the scope of trial burn testing and target the DRE evaluation to those conditions of most concern. The trial burn conditions should be checked to ensure that the monitor can adequately detect the expected or desired responses.

MONITORING COSTS

Costs of monitoring CO and O_2 have been estimated for three different types of system. These three systems are: 1) a typical existing system; 2) a GFC cross-stack system with backup analyzer and; 3) an extractive system with dual on-line NDIR analyzers with a backup unit. The cost data include purchase and installation of the capital equipment and for conducting the performance tests required by Appendix D. Tables 5, 6, and 7 summarize the cost elements of these systems along with "ball park" values for the typical performance characteristics of the system. System 1 represents a common configuration in use at HWIs today and generally would not meet the performance specification. Systems 2 and 3 are different configurations of systems which would meet the performance specifications. The total installed cost of these two systems are not significantly different from each other; the more expensive cross-stack GFC analyzer does not require the sampling system. If an operator elected to comply with the not-to-be-exceeded standards, the sophisticated data processing system could be replaced with a simpler system costing $10-12,000 each. The back-up analyzer could also be eliminated and some savings in as installation realized by the simpler data systems, but the costs associated with performance testing would remain. The cost for a minimum system which meets the performance specifications would be approximately $42,000 for a cross-stack GFC system and $63,100 for an extractive NDIR system. These data are based on the assumption that 2 separate extractive NDIR analyzers

are required to meet both the high- and low-range specifications. If manufacturers can supply multiple-range analyzers which meet the specifications, some cost savings may be effected.

TABLE 5. TYPICAL EXISTING SYSTEM COSTS

System Description:
    Single range analyzer with full-scale of 1000 ppm; no
    continuous oxygen monitor; simple single-valued limit-
    type control output signal (yes/no above setpoint)

System Performance:

Range	0-1000 ppm
Zero/Span Drift, 24 hour	± 25 ppm
Minimum Detection	± 25 ppm
Precision	± 2% FS
Accuracy	± 5% FS
Response Time	± 2 min.

Typical System Components:

Air or steam-educted probe with integral filter, sample
conditioner with moisture and fine particle removal, NDIR
analyzer, manual zero and calibration, "off-the-shelf"
data logger/recorder with capability of averages and
excursion calculations, strip chart backup.

Cost Estimates:

Sampling System	$ 3,400
Analyzer	$ 6,600
Data Recording/Processing	$ 2,700
System Installation	$ 3,800
Performance Testing	$ 6,400
Total Installed Cost	$22,900

TABLE 6. CROSS-STACK - GFC WITH BACKUP ANALYZER COSTS

System Description:
Dual range analyzer; continuous oxygen monitor; simple single-valued limit-type control output signal (yes/no above setpoint) but microprocessor-based (PC-type) data system, continuous correction to 7% O2

Performance Specifications:

Range	0-200,1000 ppm
Zero/Span Drift, 24 hour	± 2.5% FS
Minimum Detection	± 2.5% FS
Precision	± 2.0% FS
Accuracy	± 5.0% FS
Response Time	± 30 sec.

Typical System Components:

Dual channel GFC cross-stack analyzer with dual range calibration cells & oxygen measurement, backup GFC analyzer, microprocessor analyzer control, PC type data acquisition system for historical trend analysis and proportional process control.

Cost Estimates:

Sampling System	(not req'd)
Analyzer	$39,700
Data Recording/Processing	$15,000
System Installation	$13,600
Performance Testing	$11,500
Total Installed Cost	$79,800

TABLE 7. NDIR DUAL ANALYZER SYSTEM WITH BACKUP ANALYZER COSTS

System Description:
    Dual analyzers; continuous oxygen monitor; control output
    signal and data processing by micro-computer (PC type)

System Performance:

Range	0-200,1000 ppm
Zero/Span Drift, 24 hour	± 2.5% FS
Minimum Detection	± 2.5% FS
Precision	± 2.0% FS
Accuracy	± 5.0% FS
Response Time	± 2 min.

Typical System Components:

Extractive system with back-purged in-stack filter, heated
sampling line, mechanical pump, sample conditioner, auto-
matic cal gas system, continuous O_2 monitor and two sepa-
rate NDIR analyzers and a multi-range backup unit, PC
type data acquisition for historical trend analysis and
proportional process control.

Cost Estimates:

Sampling System	$ 7,800
Analyzer	$34,760
Data Recording/Processing	$15,000
System Installation	$15,150
Performance Testing	$13,200
Total Installed Cost	$ 85,910

SECTION 4

REVIEW OF MONITORING SYSTEMS

INTRODUCTION

The RCRA regulations specify that the Part B application contain a trial burn plan which includes "..a detailed engineering description of the incinerator, including: ... stack gas monitoring and pollution control monitoring system" (270.62(b)(2)(ii)(G)), and " a detailed description of sampling and monitoring procedures, including sampling and monitoring locations in the system, the equipment to be used, sampling and monitoring frequency, ..." (270.62(b)(2)(iii). This section provides some guidelines for reviewing (and preparing) the CO monitoring aspects of a Part B permit application.

The review of the CO CEMS is a three-step process: (1) evaluate the system design and operating specifications; (2) conduct the performance test to verify that the "as-built" system performs as intended, and; (3) establish permit conditions from trial burn CO data. For interim-status facilities with operational CO CEMS, there may be advantages to conducting the performance tests without spending a great deal of effort reviewing the system design if a cursory review suggests that the system will likely meet the specifications. Conversely, thorough design review of a new system can avoid or at least minimize future difficulties with the acceptability of a system.

SYSTEM DESIGN REVIEW

Review of a proposed CO monitoring system consists mainly of comparing design specifications with the performance specifications of Appendix D to this manual.

Sampling Location

Section 3 described the general considerations for a suitable monitor location. The primary objectives are that the sample location point(s) or path represent the entirety of a flue gas stream and that the flue gas stream represents the combustion status of the incinerator. The stack is generally the best place to locate the sample interface, whether it is an extraction probe or a cross-stack installation. Problems of conditioning, stratification, and inleakage are minimized, access is usually acceptable, and the results reflect what is discharged to the atmosphere. If the

proposed location is on the discharge stack or duct leading to the stack, the review needs only consist of verifying a few items:

- Is the location within the distance-from-disturbance criteria?

- Does the sample interface include the central 50% of the cross-sectional area (path for cross-stack units, points for extractive)?

- Are all potential sources of inleakage more than 8 duct diameters upstream of the location?

If the answers are yes, then the site is acceptable. If not then additional review must be done.

There are valid reasons for locating a monitor at a position other than the stack and the relative importance of conflicting objectives will determine whether a particular location is acceptable. No one set of standards can be universally applicable and some judgement is required.

When considering a representative location for gaseous pollutant monitoring, the major concern is potential stratification of the gas stream. Stratification, meaning the presence of a definite change in concentration with respect to position in the duct cross section, usually results from insufficient turbulence or mixing of flue gases after inleakage of a gas with different composition or from localized chemical phenomenon such as reaction or sorption. One of the advantages of cross-stack monitors is that the instruments provide an average value over the path length and thus lessen the effect of stratification. They do not, however, measure the average in two dimensions so the result does not necessarily reflect the average of the entire gas stream. If the proposed location is not near any source of inleakage, the disturbance criteria will suffice to ensure a representative sample. Concentration changes from inleakage most often results from ambient air being drawn into the ductwork in the upstream, or negative-pressure side of the fan. Typical sources of inleakage are joints and seals between fixed and movable part, vibration isolation joints and seals, and thermal expansion joints. Engineering drawings for the facility layout should be reviewed to determine the nearness of these potential leak sources. Fan seals seldom result in stratification because of the turbulence in the fan housing, but leaks here add to dilution of the flue gas. For a number of reasons, dilution air is intentionally or unavoidably added which may create stratification. Many incinerator designs add quench or tempering air to cool the flue gas and minimize insulation requirements and temperature stress to the ductwork. The fabric filter collectors (baghouses) used for particle removal often use ambient air to clean the bags (seldom creates stratified gas stream, but adds dilution air) and baghouse operating temperature limits often require the addition of cooling air near the inlet (often creates stratified gas stream).

Stratified gas streams caused by reaction are less common than leak-related causes, but the drawings should be reviewed to determine if stratification might exist. Sampling locations near the flame will exhibit stratification because of the ongoing combustion process and should gen-

erally be avoided. The discharge of acid gas scrubbers can be stratified due to the combination of low design velocity (no mixing) and localized variation in removal efficiency (concentration difference). This stratification usually occurs with the less soluble gases like SO_2 and in large scrubbers as are used in power plants, but it can occur in HWIs. Wet scrubbers used on HWIs seldom remove CO but other gases, like SO_2 and HCl, can be affected.

If there is a potential for stratification, alternative locations should be investigated. As discussed in Section 3, the flow disturbance criteria are intended to apply to velocity-related issues of representative sampling and these issues are not as important for gaseous pollutant sampling as for particle sampling. In fact, if the gas stream shows smooth velocity profiles or low velocities (<-1200 feet/min), additional distance from any source of concentration change is needed because less mixing occurs at these conditions. Use of the 2/0.5 distance criteria of the CEM Guidelines is limited to cases where no stratification is expected.

If no other location is suitable and there is a probability of stratification, a stratification test (described in Appendix D) of the proposed sampling should be performed. Obviously, this test can only be done on an operating facility. For units not yet operating, use of an alternative location is peferable to changing the system after installation. Using a stratified location should be a last resort due to the intrinsic difficulty of obtaining a quantitatively accurate sample. If a cross-stack instrument is used to analyze a stratified gas stream, the instrument should be placed so the measurement path is oriented perpendicular to any concentration gradient. The path should represent the overall gas stream so that the linear average provided by the long-path measurement is equivalent to the calculated average for the entire gas stream. For extractive systems, a single sample point should be located at a point of average CO concentration and this point should be within the inner 50% area of the duct. If a multiple point sampling probe is used, the sample points should be located in the central 50% of the area so the sample point average equals the duct average.

In addition to stratification, inleakage can dilute the flue gas stream and mask combustion-related changes in the gas composition. This masking is not a common problem, but should be considered if the facility is designed to use quench or tempering air. The effects of dilution cause more problems for O_2 monitoring than for CO or CO_2 monitoring. For example, quench air is added to cool the flue gas from 1500°F to 500°F. The O_2 concentration of the gas prior to the point of dilution is 7% and the O_2 concentration after dilution would be -16.8%. If the combustion condition changed such that the pre-dilution O_2 level was 5% (a change of 2 volume percent O_2), the post-dilution concentration would only change by 0.6 volume % (from -16.8% to 16.2%). In this case, there is a good reason to measure oxygen prior to dilution and it may then be desireable to measure CO at the same location, even though the location is less than desireable for other reasons (dust and temperature). Changes in CO concentration are less masked by the dilution because there is no CO in the dilution air. For the same dilution and operating scenario as above, the CO changes

would appear as undiluted concentrations of 500 ppm/750 ppm and as diluted concentrations of 150/220 ppm. Thus, the CO monitor would need a lower operating range to detect the changes but the proportional difference would remain the same. This type of evaluation should be performed to ensure that the pre-dilution sampling location is warranted.

Sample Interface

The general considerations for the sample interface, which includes all elements of the system from the duct to the analyzer measurement section, relate to materials of construction and selection of appropriate conditioning equipment. Because of the variety of systems which can be employed, it is virtually impossible to define the specific hardware which comprises an acceptable interface. This section presents some general guidelines as to the factors to be considered.

Cross-Stack Analyzers --

The cross-stack analyzers have minimal sample interface requirements other than those already discussed regarding selection of a monitoring site. Two units bolt to flanges on opposite sides of the stack and special optical windows are the only components in contact with the gas stream. The units, the source or source/detector module and the detector or reflector module need to be placed in the same horizontal and vertical planes perpendicular to the duct walls. The instruments can be adjusted, within limits, to achieve and maintain proper optical alignment. The specific location on the stack or duct should be as free from vibration as possible. Generally, this requires some form of isolation of the sample location duct segment from fans and motors. Many HWIs have a free-standing stack on a concrete base with the induced-draft (ID) fan on the same pad. The fan motor can cause stack vibration if the components are not isolated by separate pads or vibration dampers. Because most of the measurement system is mounted on the stack, it is important to provide good access to the instrument housings.

Extractive Systems-Conditioning --

Nearly all analyzers which require the sample to be conveyed to the measurement section need some form of conditioning to ensure that the sample is relatively free from interfering components and physically compatible (temperature, pressure, etc.) with the sensor and/or detector. The integrity of the extracted sample needs to be maintained. The recommendations for materials and for conditioning are based on a stack location following a wet scrubber so the flue gas is expected to exhibit the following characteristics:

- low-to-moderate amounts of HCl, generally less than 50 ppmv,

- low particle concentration (less than 0.08 gr/dscf) but with a size distribution with a predominance of fine particles,(i.e. less than 5 μm,

- saturated moisture content (12-32% by volume), with temperatures in the range of 125°F to 160°F,

• gas composition of 5-15% CO_2, 15-5% O_2, 0-2000 ppm CO, 0-200 ppm SO_2.

The reviewer will need a schematic (like one presented in Appendix C) for the system, which identifies the major components of the sampling train, and a description of the operating characteristics and materials of construction. An engineering drawing of the stack and duct system showing monitor location is also necessary.

Probe. The sample probe is exposed to more extreme conditions than any other part of the sample interface so materials of construction are very important. The probe material needs to withstand the stack gas environment without significantly reacting with the extracted sample. Teflon•, Hastelloy•, and Incoloy• are good choices for nearly any application; the metal alloys have higher temperature limits. Teflon• can be used up to about 450°F and is virtually inert; Hastelloy• is an expensive nickel/-chromium/molybdenum alloy useful for high temperatures and corrosive environments; Incoloy• is another trade name for a high nickel/chromium steel alloy useful for high temperatures and corrosive environments. Teflon• probes need to be relatively short, especially for higher temperatures, because it is a thermoplastic material and will soften and deform. Some operators have achieved some success with PVC, although this would not be advisable for units with high-sulfur feeds. Special ceramic materials are often required for combustion-zone sampling and cooled-jacket probes are often necessary for temperatures above about 1800°F. The discharge end of the probe should be equipped with valves and fittings so that calibration gases can be flowed through the entire system. The piping and valving for calibration gases can be very simple or very complex; simple systems generally require much more manual attention in the form of connecting gas cylinders and switching valves than the more expensive multiple-line solenoid valve systems. The more complex systems offer the ability to automate calibrations and eliminate some of the need for operator attention. The probe is sometimes built with integral coarse particle filters (at the probe tip in the stack) and moisture receivers and should be provided with some means of back-flushing to minimize downtime for cleaning.

Particle Filters. Particle filtration is usually divided into coarse and fine removal. Coarse filters are more important for sampling locations upstream of air pollution control devices and are usually exposed to more severe operating environments. Most of the particulate matter has been removed by the time the gases reach the stack so stack locations require only fine particle filters; coarse filters may be used as added protection for the rest of the system.

Coarse filtration for particles larger than about 10 microns is provided by sintered stainless steel filters or sometimes porous ceramic elements. Most coarse filters are in-line and replaceable only with some difficulty so a blow-back system is used to clean the filter medium. They are usually heated (by the stack gas if inside the stack or by a heating element if external to the stack) to avoid condensation and corrosion from condensing

acid gases. Some systems, especially those using educted samples, use a flow-through/bypass (or slipstream) filter for coarse filtration. The educted sample is drawn through the center of a tubular filter at a high velocity and vented either back into the stack or to the atmosphere. A second sample line is attached to the annulus between the outside of the tubular filter and the filter holder tube and a portion of the bypass sample is caused to flow through the tubular filter medium by placing the annulus under vacuum. The source of the vacuum is often the same eductor used for the bypass sample flow, but it can be a sample pump. The high velocity in the tube center prevents clogging of the filter face and permits effective filtration with little pressure drop.

For extractive analyzers, virtually all particles greater than 1 μm diameter must be removed. Fine filtration is accomplished with depth filters using porous, disposable media which remove particles effectively without creating excessive pressure drops. Most fine filter media are disposable because they are not easily cleaned. Materials successfully used for fine filters include spun glass fibers and polypropylene fibers. A number of commercially available conditioning systems use a coalescing filter as a fine filter/condensate trap with a final particle filter at the analyzer inlet. The coalescing filter agglomerates liquid particles, including water, often acting as condenser and also removes fine particles at a low pressure drop.

Moisture Removal. Some analyzers, particularly flame ionization units for hydrocarbon analysis, benefit from a high temperature sample gas, and others, like NDUVs, can tolerate relatively high temperatures (>250°F). A heated sample line is used to keep the sample gas above the boiling point of water and particle removal is all that is required. If the CO unit is to use the same sample line, the moisture removal section will need to be placed between the THC and the CO analyzers. NDIR analyzers require drying of the sample to avoid interference problems from water vapor and nearly all extractive system CO analyzers require a liquid-free gas sample gas. Most current-generation NDIR analyzers, whether GFC or conventional, are equipped with optical filters and signal processing to avoid significant interference problems (<1% of instrument full scale) with water vapor concentrations up to 3 vol. % for a measurement range of 250 ppm. This requires a sample gas with a dew point lower than 115°F. Most extractive systems will use an air- or water-cooled condenser to reduce the stack gas temperature, and condense and remove most of the flue gas water (to less than 2-3%). Additional moisture removal is obtained with desiccant dryers, permeation dryers, or refrigeration condenser/dryers. The permeation dryer is probably the easiest to maintain and does an effective job at reasonable operating costs. The sample gas is simply passed through a bundle of tubes made of inert semi-permeable membrane material which allows water vapor (not droplets) to pass from the sample gas to the purge gas flowing over the tube bundle. The operating limit for most permeation dryers is about 125°F; if the sample gas exceeds the temperature limit, the dryer will be permanently damaged. Refrigeration dryers are very effective, but they are expensive to install and maintain and generally used only when a large volume (like plant instrument air) of sample gas is being processed; most analyzers do not need sample gas as dry as can

be obtained with a refrigeration unit. Desiccant units also yield a very dry gas by passing the sample gas through a packed bed of calcium sulfate or other solid desiccant. Desiccant beds are seldom used for CEMS because the sorbent capacity is limited and some desiccants will also react with flue gas components.

Interferent Removal. As a general practice, one should not attempt to remove interferents in a sample conditioning system. There are too many unknowns involving the operation of the interferent removal device to operate a conditioning system with any reasonable assurance that the interfering component, and only the interfering component, is being removed. Further, most analyzers are designed to eliminate the effects of most of the common interferences. If it is necessary, the most common way is to use a solid sorbent for insoluble gases or a scrubber for soluble ones. Chemical oxidizing scrubbers are also used to convert one compound into a non-interfering one. No specific recommendations are given for interferent removal.

Temperature, Pressure, Flow Rate Conditioning. Generally, a particular analyzer has a limited operating range for these parameters and most systems will be designed to operate within these limits. The flow rate through the sampling system should be more than required by the instruments and the excess sample vented. The pump should be as close to the probe as possible so most of the sample system is pressurized and any leaks will be out rather than in. Temperature control is obtained by the moisture removal system and it is a good idea to reheat the sample after final drying as an added precaution against condensation in the analyzer. Pressure regulators may be required if the analyzer does not contain internal sample gas pressure control or if the overall sample line is operated at a high pressure (>20 psi). If an aspirator or eductor pump is used, it has to be placed at the end of the sample line and will place the entire system under vacuum with the highest vacuum occurring at the analyzer; many analyzers are built to withstand pressure but not vacuum. The manufacturers' specifications should be checked against the system design. Most NDIR analyzers are not very susceptible to small changes in flow rate, so precise regulation of sample rate is not required.

Pump and Sample Line. The pump can be either mechanical or fluidic. Mechanical pumps can be used in either pressure or vacuum service; fluidic pumps like aspirators and ejectors can only be used as vacuum sources. Many systems will use a combination of both. Fluidic pumps require a large volume of steam, compressed air, or water; but are very simple to operate. For most applications, the mechanical pump will be used. If the pump is located at the end of the system (vacuum service), consideration of the materials of construction is focused on pump reliability because the sample has been analyzed when it reaches the pump. Pump surfaces in contact with the unanalyzed sample gas should be coated with or made form an inert material. Teflon* has proven to be the best all-purpose material for most applications, but stainless steels can be used after the conditioning system. The discharge should be vented away from the workplace.

The sample line should be Teflon® or stainless steel, although polypropylene can be used if only CO and O_2 are being analyzed. Sample line size depends on the number of analyzers and required flow rates, but lines smaller than 3/16 in. I.D. create high flow resistance for the length of line likely to be required.

Analyzer Performance Review

This task is relatively straightforward and consists of comparing the analyzer operating specifications as reported by the manufacturer with the limitations in Appendix D. The instrument must be able to measure CO continuously as defined in Appendix D and must meet the standards for the range, response time, precision, linearity and span drift limits. The zero drift should also be compared against the operating guide. If the reported values are within the limits, the system should be acceptable and will probably pass the performance tests. The comparisons should reflect the actual instrument being proposed including the specific ranges to be used. The one area where there may be some difficulty is where a single analyzer with range switching is being considered for both sets of specifications. In this case, the review should address the capability of the unit to meet both the high and low range specifications without intermediate calibration, (i.e. that performance is maintained in each range regardless of which range was used for calibration).

Data Handling System Review

At the minimum, the data system needs to have a continuous output meter, so the concentration at any time can be visually observed, and a chart recorder which records the meter output over time. The performance specifications permit the output reading to be updated at a maximum of 30 second intervals. This minimum system could consist of a display meter and a recorder which recorded a value every 30 seconds. At the other extreme, a sophisticated and completely automated data system would:

- record the analyzer output over time;

- calculate and report the data in the desired format;

- calibrate the system and record the results;

- generate malfunction and scheduled maintenance reports;

- generate the desired combustion controller input signals; and

- summarize emission and activity data formatted for submittal to the regulatory agency.

A real system will fall somewhere between these two extremes.

There are two types of data to be recorded; emission data and system operating data. A sophisticated system can handle most of this data. Most systems will process at least the emission data and maybe the calibration

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ANALYZER MAKE AND MODEL _____

OWNER/OPERATOR _____

SYSTEM DESCRIPTION _____

REVIEW CRITERIA

ANALYZER PARAMTER	ALLOWABLE LIMITS		THIS INSTRUMENT	
	Low Range	High Range	Low Range	High Range
Range	200 ppm, max	1000 ppm, min		
Response Time	·1.0 min. to 95% FS			
Precision, the lesser of	5.0% FS	2.0% FS		
or	10 ppm	20 ppm		
Linearity, the lesser of	10.0%	5.0%		
or	20 ppm	50 ppm		
Span Drift, Maximum	20 ppm, 24-hour max	50 ppm, 2-hour max		
	SUGGESTED LIMITS		THIS INSTRUMENT	
Zero Drift	10 ppm	20 ppm		
Accuracy	2% FS	2% FS		
Comments				

PERFORMANCE TEST RESULTS

TEST PARAMETER	NUMBER OF TESTS		ANALYZER PERFORMANCE	
	REQUIRED	COMPLETED	SPECIFICATION	ACHIEVED
Response Time, Upscale	3		·1 min	
Response Time, Downscale	3		·1 min	
Span Drift, 2-hour mean	6		20/50 ppm	
Span Drift, 2-hour max	1 test			
Span Drift, 24-hour mean	6			
Span Drift, 24-hour max	1 test			
Span Gas Concentration			80-100% FS	
			80-100% of Standard	
Precision, average	6		5.0%FS/20 ppm or 2.0%/50 ppm	
Linearity, average	6		10.0% FS/20 ppm	
			5.0% FS/50 ppm	

Figure 4. Performance Review Checklist

data; the operating data will be left to plant operating personnel. The data processing system, regardless of complexity, should provide records of compliance with the CO limits and cut-off requirements. Typical reports would not summarize emission levels over time; they would tend to be incident reports, describing the frequency and magnitude of CO emissions which necessitated waste cut-off, duration of cut-off periods, and tabulating highest averages if no cut-offs occurred.

Perhaps the most significant aspect of the data handling system is the procedure for correcting the CO concentration to 7% oxygen on dry basis. If correction is done "on the fly", some form of automation is a virtual necessity. A programmed microprocessor would read the output from both CO and O_2 analyzers and calculate a corrected value continuously. The recorded data should include all three parameters for each data point, i.e. stack gas CO, stack gas O_2, and corrected CO. The stack gas CO values are not used for any control action, but should be recorded as verification of proper operation of the system. The permit will specify limits based on oxygen-corrected values, so the O_2 corrected values are used for the cut-off system operation.

SYSTEM PERFORMANCE TEST

After the system has been installed, a performance test is required to verify that the installed CEMS meets specifications of Appendix D. This performance test needs to be conducted before the trial burn to ensure that the CO data generated during the trial burn is accurate. A written test protocol should be prepared, as a portion of the Part B or the trial burn plan, describing conduct of the system performance test. The protocol should contain descriptions of all elements of the test, including:

- test procedures, description of the type of calibration standards to be used, method of introducing the standards into the measurement system, number of repetitions of the drift, precision, and linearity tests,

- the test schedule, including the recommended conditioning period, a detailed schedule for the specification tests, and the schedule for data reduction and evaluation,

- a test report format, including description of the procedures for calculations, data handling and data reduction, and the forms used for recording results and operations.

Test Procedures

The basic procedures to be used for a performance test are described in Appendix D. Each individual system will require some specific methods and procedures for performing the various tests; these site-specific procedures should be included in the performance test protocol. For example, one system may be built so an operator pushes a button, while another requires an operator to manually connect a new gas cylinder to the line and open and close the proper valves. The quality and source of

calibration standards for the test and for the routine operation should be described.

The performance specifications also describe the number and type of particular tests required to demonstrate compliance with the specifications. There may be occasions where more tests are required, or where modifications to the sequence are necessary and these types of deviations and the reasons therefore should be discussed. Manufacturers of calibration standards can provide documentation of the precision and accuracy of their standards. In general, calibration standards should be manufacturer-certified to ± 2% analytical accuracy, which means that the reported or tag value (nominal value) is within 2% of the actual value. These standards are suitable for day-to-day operation and calibrations, but use of reference standards such as "NBS-traceable" or "certified reference materials" (CRMs) is recommended for the performance test. The reference standard is used as a transfer standard to check the manufacturer-certified value of a secondary standard. The system would be calibrated using CRMs and then used to analyze the secondary standard. If analysis of this secondary standard agrees with the nominal value the nominal value is used. If the difference between the reference standard and the secondard standard is greater than manufacturer's allowance for the secondary standard, the value obtained from the calibrated CEM is used.

Test Schedule

The test schedule description should be compared against the performance specification to ensure that the proper time intervals and number of repetitions are correct. While it is not always practical, the schedule should allow enough time between conditioning and the performance test and between the performance test and the trial burn to fix any problems that are identified.

A schedule in a daily appointment-like format is suggested to depict the sequence of individual test measurements. This aids in test conduct and permits identification of conflicts and overlaps. While not part of the monitor performance evaluation, testing of the waste feed cut-off system can be scheduled to occur during the CEMS tests. Most operators will test and debug the process controllers independently, but setting up a test program for the combined CEMS and cut-off system during the CEMS performance tests can eliminate problems commonly encountered in the trial burn. The cut-off system is often deactivated for the trial burn.

Data Reduction and Test Report Format

Reduction of data from the performance tests is relatively straight-forward. If a programmable or computerized data processing system is to be used, it needs to be programmed to provide the appropriate results for use in the comparisons. Some operators will prefer to use a temporary system (e.g. strip-chart recorder) for recording the performance test data because it is often simpler to record and analyze the data manually than to program or reprogram a microprocessor system. In any event, the test

protocol should provide a report format sufficiently detailed so the final report amounts to filling in the blanks.

TRIAL BURN PLAN

Although additional effort is required to review the monitoring system, the proposed CO limits for HWIs have simplified the task of establishing permit conditions based on trial burn test results. In the past, trial burn conditions were set to yield a "worst-case" operation so acceptable performance of the incinerator could be reasonably assured under the most difficult conditions. This remains the case for most operational variables but not for CO concentrations. Waste cut-offs during a DRE test run are highly undesirable. A cut-off during a DRE test run complicates completing a valid run or invalidates the run. Thus, the trial burn test conditions should be established to avoid waste cut-off during a test run. The trial burn plan should identify the CO concentrations expected during the trial burn and data and cut-off systems should be configured for the expected CO concentrations.

Monitoring during Trial Burn

The CO CEMS in use during the trial burn must be in compliance with the performance specifications, and the routine calibrations should show continued compliance during the trial burn. Both the CEMS and waste feed cut-off system need to be operating during the trial burn and the activation levels and logic for cutting off waste feed should be established in such a manner that the CO limits are not exceeded. The impact of oxygen correction of stack gas CO also needs to be considered. It will not be sufficient to measure the average O_2 level and assume that it will remain constant over the course of the trial burn.

If a cross-stack instrument is used, the moisture content of the flue gases at the point of CO monitoring needs to be measured during the trial burn and the CO concentration corrected to a dry basis. The moisture content of the flue gas will be relatively constant and a single correction factor, developed during the trial burn, can be used for subsequent corrections.

Data Reduction and Reporting

The trial burn plan should include detailed descriptions of the data recording system. If the system is largely manual, the description can consist mostly of data forms and equations. If an automated data system will be used for most of the data evaluations, the trial burn plan needs to contain a fairly detailed explanation of the hardware, software, and interfaces for the system. In many situations, the data system isn't finished until the the monitors are operational.

SECTION 5

REVIEW OF TRIAL BURN REPORT

INTRODUCTION

The trial burn is the focal point for many technical issues that have not been resolved in earlier stages of the permitting process. Thus, the results of the trial burn are usually expected to provide answers to many questions of technical feasibility and performance of equipment and these answers become the basis for making deferred decisions. However, the primary purpose of the trial burn is to demonstrate the incinerator's capability to destroy hazardous waste and to document certain operating conditions as representative of incinerator performance. The values for these operating parameters are incorporated in the final permit, if issued, to assure compliance with the performance standards during continued operation. The concentration of carbon monoxide in the combustion gas measured during the trial burn is an important parameter as is evidenced by the requirement that waste feed be discontinued if the CO level(s) is exceeded. This section discusses review of the trial burn report with respect to CO emissions and establishing permit conditions.

The permit writer's task is to ensure that the hazardous waste is being destroyed in compliance with the regulations. In order to provide this assurance, the data used to set conditions must be accurate. The CO data generated during the actual DRE testing portion of the trial burn forms the basis for the permit conditions and it is incumbent on all concerned to see that the data were collected and analyzed properly. The last part of this section suggests methods to review and analyze this data.

CO MONITOR PERFORMANCE TEST REVIEW

Review of a report on monitor performance testing is fairly straightforward and requires verification that the system was installed as expected, that all the required tests were conducted, that the data were reduced and calculated correctly, and finally that the data show compliance with the specifications.

Monitor Location

In most cases, the monitor location will have been agreed to in advance and should not be an issue. In some cases, however, a precise location

may not have been established. In any event, the report should include a drawing of the "as-built" CEMS location, for the probe if an extractive system, or the instrument if an in-situ. The "as-built" structure is usually somewhat different than the design arrangement and most review and approvals are based on design drawings. Often, design drawings are not updated when the facility is finished. These construction/design variances are not particularly significant if the only construction is the monitoring system (as for an interim status facility without a CO monitor) but they can be significant for a new facility.

Test Procedures

The report should contain a description of the procedures used to conduct the test and these procedures should match those required in Appendix D. There are four separate test parameters to be evaluated: range, span drift, precision, and linearity. The zero drift may also be included. Appendix D describes specific numbers of repetitions and the sequence of the tests. There are also some requirements for intervening measurements, i.e. switching to another gas between precision measurements. The order of the tests may vary, but all must be present. The test procedure description should discuss the quality of the calibration standards and the method of introducing the standards into the measurement path. This method used should include the entire sample train from stack to analyzer. The report should include a description of any automatic internal analyzer calibrations used during the tests in sufficient detail that subsequent inspections or tests can duplicate the conditions. These conditions should be included in the permit to ensure that the system operation is consistent with the performance tests.

Test Completion

All the required tests should be completed and Table 8 presents an example checklist to verify completion of the required tests. This type of checklist also serves to identify that the procedures were conducted as intended. If the raw test data are presented on strip-charts, completion of the checklist is easy; if the raw data are printouts of a data processing system, completion of the checklist is likely to be more difficult but also more necessary for ensuring that all the data are present. This table can easily be modified to include provisions for summarizing the test results and calculating the required values, in a form similar to the calculation forms of Appendix D.

Calculations

Appendix D describes the equations and procedures to be used in determining whether a system meets the performance requirements. The data are treated statistically by applying a confidence interval to the measurement sets so that some consideration is given to inherent variances in the measurement process and to the possibility of infrequent occurrences of measurements exceeding some established limit. The calculations presented in the report should at least be audited by independent calculation of results for one test parameter and not much additional effort is required

to check all of them. The basic statistical equations can easily be done on most calculators and many calculators are pre-programmed with mean and standard deviation routines. Table 8 can easily be adapted to include provisions for data entry and calculation.

TABLE 8. MONITOR PERFORMANCE TEST COMPLETION CHECKLIST

Test Parameter	Initial	Measurement Number 1	2	3	4	5	6	Final
Span Drift Tests								
Required	Y	Y	Y	Y	Y	Y	Y	N
Completed								
Zero Drift Tests								
Required	Y	N	N	N	N	N	N	Y
Completed								
Precision Tests								
Required	Y	Y	Y	Y	Y	Y	Y	N
Completed								
Linearity Tests								
Required	Y	Y	Y	Y	Y	Y	Y	N
Completed								

*   Y - Required
     N - Not required

Test Acceptance

The final step in performance test review is comparison of the test results with the specifications. If the system meets the test specification for all parameters, the system is acceptable and the trial burn data can be used for combustion evaluation and permit conditions. If the zero drift is greater than the guideline, the system is conditionally acceptable

and the trial burn data should be examined closely to ensure that calibration was maintained during the DRE tests. If the system fails to meet any of the other specifications, the data for the trial burn are not valid and should not be used for permit purposes.

EVALUATION OF TRIAL BURN RESULTS FOR CARBON MONOXIDE

The proposed CO limits should simplify the process of setting permit conditions for CO from the trial burn. If the CO emissions during the trial burn exceed the proposed limits and DRE is maintained, the limits will stand. If the CO levels are less than the proposed limits, then the permit conditions should reflect the lower levels. Further, the monitor performance specifications provide a yes/no test for the acceptability of the CO data thus relieving the reviewer of some of the burden of evaluating questionable data. The reviewer must, nonetheless, evaluate the CO data generated during the trial burn carefully and needs to consider some other aspects of CO emissions related to combustion stability.

Test Procedures

Having established the performance characteristics of the CEMS, the quality of the CO data is presumed acceptable and the actual monitoring procedures need minimal review. The reviewer needs to verify that the CEMS was operated in the same manner as during the performance testing. Section 6 lists daily inspection/observation parameters which can serve as evidence of continued proper operation. Recording these parameters during the trial burn and the performance testing is recommended.

It is suggested that the CEMS operating data be recorded more frequently than daily during the test burn. In the event that the monitoring system experiences some malfunction, a data record of the operation may avoid the undesirable situation of having to reject the DRE test results for an entire day or more. Repeating one test run is preferable to repeating a complete trial burn test series. It is also important to verify that internal analyzer calibrations and/or other system checks performed without operator intervention are maintained at the same frequency and intensity as they were during the monitor performance testing.

The last item regarding the trial burn testing is whether or not CO data exists for all the DRE tests. If the data are absent from one or more test runs or for a complete burn condition, that DRE data will probably not be acceptable for permit condition use. There are some cases when exceptions should be considered (discussed in the following sections) and some cases where absence of the CO data is immaterial or not particularly significant such as a test burn conducted with high excess oxygen (and correspondingly low CO) to demonstrate scrubber particle removal efficiency.

Data Review

There are a number of aspects of the trial burn CO results that need to be reviewed for determining appropriate permit conditions. These aspects

encompass the time bases for averaging, correction of stack gas CO concentrations to 7% O_2 and dry basis, dealing with the rolling average requirement, and dealing with anomalous or missing data.

The evaluation of CO levels should be related to the DRE of the unit. The only DRE data comes from the emission tests. A VOST test run may be as short as 20 minutes and a modified Method 5 run may last as long as several hours. It is desirable to match the CO data to the DRE test data. The rolling average requirement of the proposed CO limits dictates that the average concentration for the test run not be used; rather the CO data must consist of several 10- and 60-minute averages. The number of values to be used will depend on the length of the test runs and the integration/update interval of the data processing system. By definition, continuous CO monitoring requires an analytical update at least once every 30 seconds. If we assume a 60-minute test run and 30-second updates, there will be one 60 minute average and 111 10-minute average values. The 10-minute values are based on no average value until 10 minutes have elapsed and one updated 10-minute rolling average every 30 seconds thereafter. If the test run lasted 70 minutes, there would be 21 values for 60-minute averages and 131 values for 10-minute averages.

In the above example, the 30-second update by the data processing system has already integrated the measured concentration for that time interval. While the CO is being measured continuously, by the definition in Appendix D, the concentration is being reported at time intervals deemed often enough to represent the combustion status of the incinerator. The displayed value may be updated as often as the detector output changes, but the recorded value or the value processed by the data system may be different. The data system could be designed to update the average values as often as the display is updated, even though the guidelines do not require it.

Correction of the stack gas concentration to 7% O_2 is subject to the same data processing concerns as described above for CO and there are some other considerations as well. The performance specification for oxygen monitors requires the same maximum response time as the CO analyzer. However, the response time for the analyzers can be different. The recommended approach is to correct the CO values to 7% O_2 as they are included in the 10- and 60-minute average calculations. This does not address whether the value used for O_2 correction represents the same time base as the CO value. If the oxygen monitor has a slower response than the CO analyzer, the CO values need to be "held up" in the data system or vice versa if the oxygen analyzer responds more rapidly. Another alternative would be independent calculation of oxygen concentrations and correction the rolling-average CO concentrations with rolling average oxygen concentrations.

A relatively common occurrence is the appearance of one or two very high values, compared to the rest of the data. To determine whether these data points should be included in the data set used for establishing permit conditions, a statistical test should be applied to the data.

There are a number of techniques for evaluating whether a seemingly anomalous value is beyond the range of reasonable probability and these techniques are described in most statistics references. One technique commonly used is the Grubbs' "t" test for outliers. In general, disregarding these outliers is the more conservative approach because it tends to eliminate extraordinarily high values which result in higher permit levels than normal operation would indicate.

Another common concern is whether a test is valid if some of the data are missing. With short-term testing as is done during trial burns, 90% valid data collection is considered acceptable. For CO continuous monitoring, this means that valid data should exist for 90% of the time during which DRE testing was being done. Data completeness as low as 75% is often considered acceptable where the data do not exhibit much variation (standard deviation less than 10% of the mean). The trial burn plan should include objectives for data completeness.

The proposed limits define stable combustion, after an upset, as a 10-minute average value less than the 60-minute standard. If permit limits lower than the proposed limits are being considered, the trial burn 10-minute averages can be used to establish a corresponding definition of stable combustion.

PERMIT CONDITIONS AND WASTE FEED CUT-OFF SYSTEM

The currently proposed CO limits state that waste is not burned if the CO concentrations are above certain limits (with limited exceptions); this would not prevent CO levels from exceeding these limits. If the CO concentrations during the trial burn exceed the proposed values, the permitted waste feed cut-off trigger levels will be 100 and 500 ppm for the 60- and 10-minute averages, respectively. If, however, the trial burn data show that the unit has the capability to operate at lower levels and meet the DRE and other standards, then the permitted waste cut-off levels should be lower than the proposed levels. The trial burn report should contain documentation of the cut-off actions and operation during the testing so proper operation can be verified.

The suggested procedure for determining appropriate levels for the waste feed cut-off is to determine the means and arithmetic standard deviations for each of the runs and for each test run series for both the 10 and 60 minute averages. The waste cut-off levels should then be set as the sum of the mean and 2 times the standard deviation for the highest test run which met the DRE standards unless this value (2s + mean) is greater than the applicable limit. If this sum is greater than the limiting values, then whatever limits exist are to be used.

The trial burn data should be reviewed to determine if the CO values for restarting waste feed after a cut-off were consistent with the proposed emission limits, or whether some other value(s) is appropriate. Following this review, the permit should include either the regulatory limit or a lower one, if the data justify a lower value.

SECTION 6

OPERATING AND MAINTENANCE PROCEDURES

INTRODUCTION

In order for the data generated by the system to be useful to the agencies and the operators, the CEMS must operate successfully on a continuing basis. Successful operation requires periodic checks of system performance and maintenance of records to document both the data generated and the activities performed to maintain the quality of that data. Certain inspection/verification procedures, primarily for the waste feed cut-off system, are required by the regulations to prevent malfunctions which might result in avoidable releases of hazardous materials to the atmosphere. This section provides some guidelines for routine CEMS operation to ensure continued compliance with the established standards.

The basic purpose of these QA procedures is to prevent a system malfunction from going undetected for an extended period of time and to minimize the magnitude of such a situation. Most units will occasionally go out-of-specification and these procedures will detect this occurrence. If a system starts going "off spec" frequently or regularly, there is cause for concern. Keeping records permits the operator and the agency to evaluate the significance of a particular case.

Most industrial facilities are accustomed to using written standard operating and maintenance (O & M) procedures to maintain process operations within established limits. For this manual, the types of activities involved in an O & M program are divided into three categories: 1) observation and inspection; 2) testing and verification; and 3) corrective action. All activities require recordkeeping for historical and analytical purposes. The following sections discuss, in general terms, the application of these O & M procedures to the monitoring system and, to a lesser extent, the waste feed cut-off system.

EMISSION MONITORING SYSTEM

The basic O & M program for a CEMS consists of calibration, audit, and preventive maintenance activities. The performance frequency of these activities is divided among "as required", daily, weekly, monthly, and annually or semi-annually. The level of attention or detail increases with decreasing frequency of performance.

Daily

Two system checks should be performed daily: a system inspection to confirm operating status of all elements, and; a calibration check of the instrument zero and span.

System Inspection --
The daily system inspection consists of visual observations of system operating conditions and evaluation of the status against "pass/fail" criteria. Each system will be unique and a site-specific checklist is suggested to ensure that all pertinent items are checked. Typical parameters to be checked in an extractive system include:

- system pressure drops, (e.g. overall, across filters, or across the analyzer);

- sample flow rates;

- verification of flow through permeation dryers and air-cooled condensers;

- sample gas temperatures at appropriate points in the sample line, (e.g. stack exit, condenser outlet, reheater outlet and measurement chamber);

- operation of sample mover, (e.g pump noise or vacuum or ejector operation);

- operation of strip chart recorders (verifying times and dates, chart advance, pen response);

Where appropriate, a check value or range of normal values should be established which define acceptable or normal operations. The performance test can provide the baseline values for proper operation.

Calibration Checks --
The daily calibration checks do not need to duplicate those conducted during the performance tests as the performance tests demonstrated the ability for the system to hold its calibration for 6 days. Any internal electronic calibration check routine used during the performance tests should be maintained. Some analyzers (particularly the GFC-type NDIRs) are equipped with an adjustable automatic calibration cycle which places a CO calibration standard in the measurement path and recalibrates the analyzer automatically. Other units have similarly named routines (automatic calibration) which check internal electrical signal levels but do not truly check the measurement section of the instrument. In either of these cases, the "calibration" frequency should be maintained as during the performance tests. The basic distinction between the two types is whether the entire system is checked or only the analyzer or a portion of the analyzer. If the system does not have provisions for automatic calibration checks, the daily checks should place zero and calibration standards in the measurement path for evaluation of instrument response. In the case

of the electrical signal check, a zero/span calibration should be performed
weekly. If the span value deviates from the calibration by more than the
specified drift limits, the system requires a full calibration and the
precision and linearity tests should be conducted. Otherwise, readjustment
of the span is adequate. The incinerator can remain on-line (with waste
feed) during these calibration checks as long as the calibration cycle is
shorter than 10 minutes. A daily full-system calibration check is only
required for those systems which do not use some form of automatic cali-
bration.

Weekly

The RCRA regulations require weekly (unless specifically permitted
less frequently) testing and verification of the waste feed cut-off system.
Many analyzers have a provision for preventing a false control signal
during calibration periods and most units used for HWI monitoring will
probably be equipped with this feature. During this weekly test (or other
frequency if permitted), the CEMS should be calibrated with a standard
value near the permit limits so that the operation of the hardware and
software responsible for the cut-off signal can verified. The specific
procedure for testing the system will depend on the how the controllers
and the CEMS are related. Normally, an instrument span would be higher
than the allowable CO limits and would cause a cut-off signal if continued
long enough to exceed the time-averaged setpoints. The data system would
normally prevent this false signal. If this signal block can be deacti-
vated, then a calibration cycle can be used to test the hardware and
software for the cut-off. If not, an alternative method should be devised.

If automatic electronic calibration checks are used for the daily
checks, then a weekly test of the measurement system is needed. This
weekly test is only required for those systems where the automatic internal
calibration checks only the electrical circuitry and does not include the
measurement path. If the auto-cal places calibration standards (gases or
cells or filters) in the analytical chamber or path, then the weekly
check is not required. The net result of the daily and weekly calibration
checks should be that the complete system is checked at least once per
week.

Quarterly

The precision and linearity tests of Sections 4.5 and 4.6 of Appendix
D should be repeated quarterly to ensure continued compliance with the
performance specifications. This is, in effect, a multiple-point recali-
bration compared to the single-point checks done daily or weekly, and is
a more thorough evaluation of system performance.

Annually

Regardless of the operating history, the performance specification
tests should be repeated every two years. The operating history should
be reviewed annually and the performance test repeated if the history
suggests a decline in performance.

WASTE FEED CUT-OFF SYSTEM

The proposed limits require that waste feed be discontinued if CO emissions exceed either rolling-average limits or not-to-be-exceeded limits. The rolling-average limits require some rudimentary data processing system; the time/concentration limits only require a timer for cut-off purposes, but some signal processing is required for the O_2 (and moisture, if required) corrections.

For the not-to-be-exceeded standards, some form of programmable process controller is required to read the CO and O_2 values, correct the CO concentration, and generate an output signal to the timer. If the corrected CO value exceeds the setpoint(s) the timer needs to be the accumulating type with an automatic reset every hour so it will accumulate the total time above the standard, cut-off waste if the time limit is exceeded, and set the counter to zero every hour. A second process controller (or channel) is required to cut-off waste if the instantaneous limit is exceeded.

If rolling-average limits are used, each facility operator will be required to develop a control logic scheme that will discontinue waste if one or both of the limits are exceeded and prevent feed until stable conditions are reestablished. Description of appropriate testing of the number of potential process control systems which perform the task would occupy a volume at least the size of this manual. The basic elements of testing such a system are:

- analog-to-digital signal conversion precision and accuracy

- digital signal integration accuracy

- verification of the mathematical processing and calculation algorithms (hardware or software or both)

- testing the corresponding output (control) signals

Much of this testing is only done during the debugging phase. After testing and debugging, the hardware and software tend to perform consistently unless a catastrophic failure occurs.

DATA REDUCTION AND REPORTING

There are two basic types of data records that should be kept for the CO monitoring system: operating logs and emission records. The operating logs serve as documentation that the CO emission data are valid. No specific reporting requirements have been established, although some permittees are required to submit periodic reports to state air quality agencies and sometimes to regional EPA offices. The records are required to be kept on file and be made available for inspection. No specific report submittal is suggested but all CEMS records should be retained.

The regulations specifically address recording whether the waste feed was discontinued when the emission levels exceeded permit limits. Thus,

the data records need to show, at a minimum, each occurrence of CO emissions above the standards and the corresponding action regarding waste feed. Some facility operators may elect to include other data regarding trends, process feeds, long or short-term averages or other statistical summaries of the CO levels in the system records.

The data records can be used in a number of ways, some of which are identified below:

- Using the regular inspection program to identify problem areas and repair or replacement before catastrophic failure occurs.

- Maintaining a record of inspections, repairs, calibrations, and CEMS operating logs encourages attention to system operations and provides a basis for diagnosing problems and prevention of reoccurrence.

EQUIPMENT REPLACEMENT AND REPAIR

The many possible configurations for CEMS makes recommendations for specific maintenance practices nearly impossible. In general, the manufacturers provide recommended preventive maintenance procedures tailored to their instruments and these procedures are a sound starting point for development of site-specific O & M manuals. The quality of the vendors O & M manuals varies and experience with a particular system is often the best way to generate a useful O & M manual. Most manuals also provide a recommended spare parts inventory, which often amount to a spare analyzer in pieces.

There are some general guidelines to be considered for maintaining parts and supplies. However, the decisions about the level of back-up equipment and supplies is best left to the operator. A minimal spare-parts list is presented below:

- Consumable materials (60 day supply is adequate for most purposes)

  - recorder pens and chart paper
  - sample line filters
  - calibration gases

- Spare parts inventory

  - fuses
  - lamps for analyzers
  - pump repair parts, like diaphragms, vanes, motors, or complete replacement pumps
  - valve repair parts like packing, valve stems, solenoids, or complete replacement valves
  - sample lines and fittings
  - condenser coils

- pressure and vacuum gauges
- flowmeters
- most any item subject to destruction or corrosion by
  contact with sample gas.

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APPENDICES

APPENDIX A

MANUFACTURER'S REPORTED SPECIFICATIONS

FOR CO ANALYZERS

Manufacturer: ANARAD, Inc.

    Model: AR-xxx

    Type: Extractive NDIR

    Ranges Available: 500 ppm to 100%

    Precision: ± 1% FS*

    Accuracy: ± 1% FS

    Drift: ± 1% FS, 24 hours

    Response Time: 5 seconds to 90% FS

    Linearity: ± 2% FS

    Comments: Manufactured in several models depending on sophistication and use

Manufacturer: AMETEK, Inc.

    Model: E1-10

    Type: Cross stack NDIR-GFC

    Ranges Available: 1000 ppm

    Precision: Not specified

    Accuracy: ± 3% FS

    Drift: Not specified

    Response Time: 3 seconds to 90% FS

    Linearity: Not specified

* FS - Full Scale

Manufacturer: AMETEK, Inc.

Model: WDG-111C

Type: Extractive catalytic oxidation

Ranges Available: 2000 ppm, 1%

Precision: Not specified

Accuracy: ± 5% FS

Drift: Not specified

Response Time: 11 seconds to 90% FS

Linearity: Not specified

Interferences: H2, other combustibles

Comments: Combustion control analyzer

Manufacturer: Bailey

Model: OL 230 with OL 231 Auto Cal

Type: Extractive catalytic oxidation

Ranges Available: 1000 ppm, 5000 ppm, 1%, 2%

Precision: ± 0.5% FS

Accuracy: ± 1% FS

Drift: ± 2% FS, 30 day

Response Time: 2 seconds to 63% FS

Linearity: ± 1% FS

Interferences: Other combustibles

Comments: Not true CO analyzer, analyzer for combustion
control

Manufacturer: CEA Instruments

Make: RIKEN

Model: RI-200 Series

Type: Extractive NDIR

Ranges Available: 1000 ppm to 50%

Precision: ± 2% FS

Accuracy: Not specified

Drift: ± 2%, 30 day

Response Time: 25 seconds to 90% FS

Linearity: Not specified, (Linearizer optional)

Manufacturer: Dynatron

Model: 3100M

Type: Cross-stack GFC

Ranges Available: Depends on path lengths

Precision: ± 1% FS

Accuracy: ± 10 ppm or ± 2.5% FS Whichever greater

Drift: Not specified

Response Time: Adj. 1-250 seconds

Linearity: ± 1% FS

Comments: Single-pass

Manufacturer: Horiba
    Make: PIR

    Model: 2000

    Type: Extractive NDIR

    Ranges Available: 500 ppm - 100%

    Precision: ± 0.5% FS

    Accuracy: ± 1.0% FS

    Drift: ± 1.0% FS, 24 hours

    Response Time: Adj. 0.5, 1, 2, 3, 5 seconds to 90%

    Linearity: ± 1% FS with optional linearizer

-   Comments: Multiple range options

Manufacturer: Horiba

    Make: VIA

    Model: 500

    Type: Extractive NDIR

    Ranges Available: 50 ppm to 1000 ppm

    Precision: ± 1% FS

    Accuracy: Not specified

    Drift: ± 2%, 24 hours

    Response Time: Adj. 0.5-16 seconds

    Linearity: Not specified

    Interferences: Interference rejection ratios specified
                   for many gases

    Comments: Dual range with range ratios of 1:2 or 1:2 5

Manufacturer: Infared Industries

Model: IR-760

Type: Extractive NDIR

Ranges Available: 100 to 5000 ppm

Precision: ± 0.5% FS

Accuracy: Not specified

Drift: ± 2% FS, 7 days

Response Time: 20 seconds to 90%

Linearity: ± 2% FS

Comments: Other models (higher ranges) available. Dual
range models available.

Manufacturer: Land

Model: Land CO

Type: Cross-stack GFC

Ranges Available: Depends on path length

Precision: ± 1% FS

Accuracy: ± 4% FS

Drift: Not specified

Response Time: Not specified

Linearity: Not specified

Comments: Single pass

Manufacturer: MSA

    Model: Mini-CO

    Type: Portable extractive electrochemical

    Ranges Available: 2000 ppm

    Precision: Not specified

    Accuracy: Not specified

    Drift: Span ± 2% FS, zero ± 1% FS, 24 hours

    Response Time: 30 seconds to 90% FS

    Linearity: ± 2% FS

Manufacturer: Syconex

    Model: 6000

    Type: Cross-stack GFC

    Ranges Available: Depends on path length

    Precision: ± 1% FS

    Accuracy: ± 2% FS

    Drift: ± 1% FS, 30 days

    Response Time: Adj. 5 seconds to 95% typical

    Linearity: ± 1% FS

    Comments: Double pass

Manufacturer: Teledyne Analytical Instruments

    Model: 9300

    Type: Extractive NDIR,

    Ranges Available: 500 ppm up to %

    Precision: ± 1% FS

    Accuracy: ± 2% FS at constant temp, ± 5% over operating
                temperature limits

    Drift: Not specified

    Response Time: 5 seconds to 90% FS

    Linearity: ± 1% FS

Manufacturer: Teledyne Analytical Instruments

    Model: MAX 5, Portable

    Type: Extractive electro-chemical

    Ranges Available: 1000 ppm

    Precision: ± 1% FS

    Accuracy: ± 2% FS

    Drift: Not specified

    Response Time: <30 seconds to 90% FS

    Linearity: Not specified

Manufacturer: Whittaker

Model: P 310

Type: Extractive electro-chemical

Ranges Available: up to 150,000 ppm (15%)

Precision: ± 1% FS

Accuracy: ± 2% FS

Drift: ± 2% FS, 24 hours

Response Time: 2 minutes to 90% FS

Linearity: ± 1% FS

APPENDIX B

INSTRUMENT MANUFACTURERS LIST

ANARAD, Inc.
534 E. Ortega Street
Santa Barbara, CA 93103
(805) 963-6583

Extractive NDIR
Other-O2, CO2, NOx
  THC, H2S

AMETEK, Inc. Thermox Instruments Div.
150 Freeport Road
Pittsburgh, PA 15238
(412) 828-9040

Extractive NDIR, Cross-stack
GFC (NDIR
Other-O2

Bailey Controls Co.
29801 Euclid Avenue
Wickliffe, OH 44092
(216) 585-8500

Extractive catalytic
 oxidation
Other-O2, combustibles

Beckman Industrial Corp.
600 S. Harbor Blvd.
La Habra, CA 90631
(213) 690-7600

Extractive NDIR

CEA Instruments
16 Chesnut Street
P. O. Box 303
Emerson, NJ 07630
(201) 967-5660

Extractive NDIR
Other-CO2, CH4

Dynatron, Inc.
P. O. Box 745
Wallingford, CT 06492
(203) 265-7121

Cross-stack GFC (NDIR)
Other-Opacity, SO2

Esterline-Angus Instrument Corp.
P.O. Box 24000
Indianapolis, IN 46224
(317) 244-7611

Extractive NDIR

Horiba Instruments, Inc.
1021 Duryea Avenue
Irvine, CA 92714
(714) 250-4811

Extractive NDIR
Other-CO2, SO2, CH4,
  C3H8, C6H14, NH3

Infrared Industries, Inc.
P. O. Box 989
Santa Barbara, CA 93102
(805) 684-4181

Extractive NDIR
Other-O2, NOx, SO2, CH4

Interscan Corp. 21700 Nordhoff P. O. Box 2496 Chatsworth, CA 91311 (818) 882-2331	Polarographic (extractive)
Land Combustion, Inc. 3392 Progress Drive Suite E Bensalem, PA 19020 (215) 244-1100	Cross-stack GFC (NDIR)
MSA 600 Penn Center Blvd. Pittsburgh, PA 15235 (412) 273-5000	Extractive NDIR
Process Analytics Combustion Engineering, Inc. P. O. Drawer 831 Lewisburg, WE 24901 (304) 647-4358 (Formerly Bendix Process Instruments)	Extractive NDIR
Syconex Corp. 1504 Highland Avenue Duarte, CA 91010-2831 (818) 359-6648	Cross-stack GFC (NDIR) Other-CO2, HC, SO2, H2O, HCl
Teledyne Analytical 16830 Chesnut Street P. O. Box 1580 City of Industry, CA 91749-1580 (213) 283-7181 (818) 961-9221	Extractive NDIR Extractive electro-chemical Other-O2, CO2, H2S, THC
Thermo Electron Instruments 108 South Street Hopkinton, MA 01748 (617) 435-5321	Extractive GFC (NDIR) Cross-stack GFC Other-SO2, NO, CO2, H2O, Opacity
Western Precipitation (Joy Division) 4565 Colorado Blvd. Los Angeles, CA 90039 (818) 240-2300	Polargraphic (extractive)

Western Research and Development   Extractive NDIR
#3 1313 44th Avenue, N.E.
Calgary, Alberta, Canada T2E 6L5
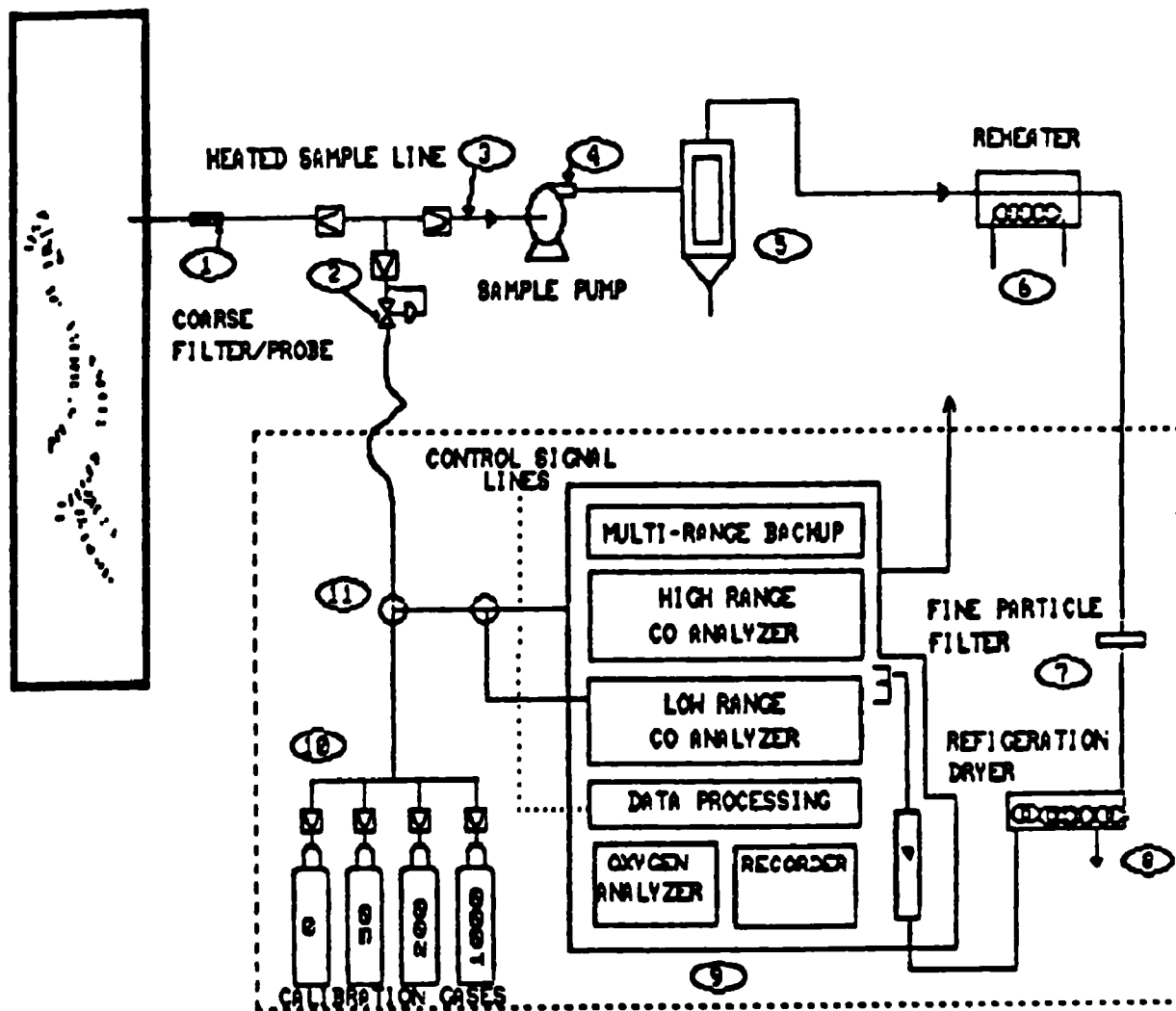(403) 276-8806

Westinghouse Electric   Cross-stack GFC (NDIR)
Combustion Control Division   Other-O2, combustibles
P. O. Box 901
Orrville, OH 44667-0901
(216) 682-9010

Whittaker Corp.   Extractive electro-chemical
12626 Raymer Street   Other-SO2, NOx, O2
North Hollywood, CA 91605-4307
(818) 765-6622

APPENDIX C

EXAMPLE MONITORING SYSTEMS AND COMPONENT LISTS

SYSTEM COMPONENT LIST

ITEM NO.	DESCRIPTION
1	INCONEL PROBE WITH DISPOSABLE FILTERS
2	PRESSURE-REGULATING VALVE
3	3/8" ID TEFLON TUBING WITH TEMP. CONTROL HEATED JACKET
4	DUAL-DIAPHRAGM PUMP, TEFLON-LINED, 110 V
5	COALESCING FILTER- COMBINATION MIST/PARTICLE REMOVAL
6	110 VOLT HEATED COMPARTMENT WITH STAINLESS STEEL SAMPLE LINE
7	TEFLON FILTER HOLDER FOR MEMBRANE FILTER
8	THERMOELECTRIC COOLER
9	CUSTOM-BUILT TEMP CONTROLLED INTEGRATED SAMPLING CABINET
10	CERTIFIED ANALYSIS CALIBRATION GASES IN ALUMINUM CYLINDERS
11	MANUAL 3-WAY VALUES
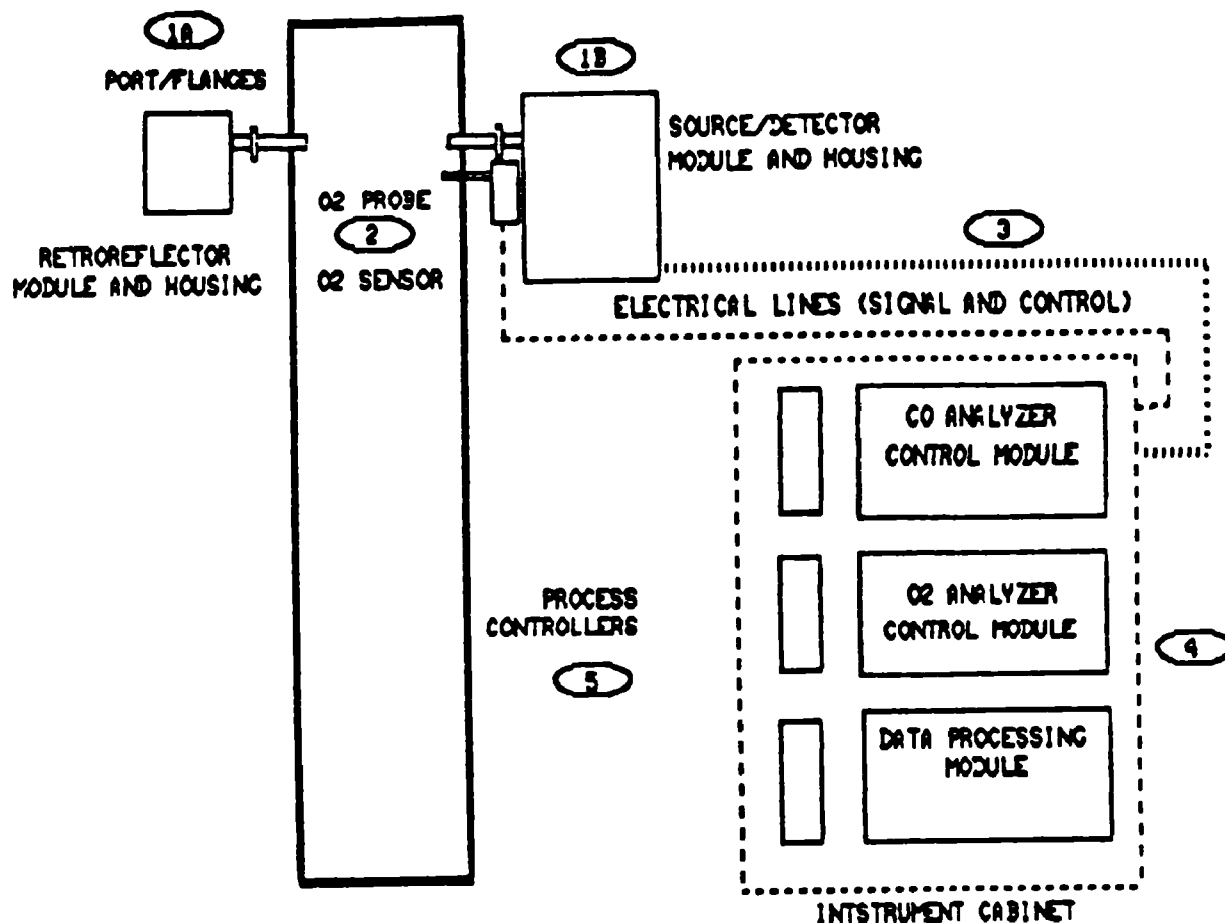
SYSTEM COMPONENT LIST

ITEM NO.	DESCRIPTION
1A	RETROREFLECTOR IN BOLT-ON WEATHERPROOF HOUSING
1B	CO ANALYZER SOURCE DETECTOR MODULE IN BOLT-ON WTHRPROOF HOUSING
2	O2 ANALYZER IN-SITU PROBE/SENSOR UNIT
3	UMBILICAL LINE WITH POWER, CONTROL, AND OUTPUT CONDUCTORS
4	RACK-TYPE INTEGRATED INSTRUMENT CABINET
5	FUEL, AIR, AND WASTE-FEED CUT-OFF PROCESS CONTROLLERS

APPENDIX D

QUALITY ASSURANCE AND PERFORMANCE SPECIFICATIONS

FOR CONTINUOUS MONITORING OF CARBON MONOXIDE

AT HAZARDOUS WASTE INCINERATORS

1. Introduction

According to the RCRA regulations (40 CFR Part 264.346(a)(2)), carbon monoxide "must be monitored on a continuous basis at a point in the incinerator downstream of the combustion zone and prior to release to the atmosphere". Another part of the rule (264.345(b)(1)) states that the permit will contain a limit for the CO level in the stack exhaust gas. These two requirements were adopted to provide the agency with some means of evaluating the combustion efficiency of an operating hazardous waste incinerator (HWI) at any point in time. The regulation do not define what constitutes continuous monitoring, nor do they define what instrumentation is acceptable for determining compliance with the rules. Owners and operators of HWIs and the regulatory personnel (EPA regional office and state) have not had any specific guidelines for assessing the adequacy of monitoring systems.

In order to ensure that the regulatory intent is observed, there must be some consistency to the application of continuous monitoring requirements. This set of specifications and procedures attempts to provide this consistency. The technical objectives are to ensure that CO monitoring data are of known quality and that the monitoring system is representing the operation of the incinerator.

These guidelines provide a set of performance standards for the monitoring systems, describe procedures for comparing the systems to the standards, and suggest procedures to maintain the performance level during continued operation. A glossary and a set of definitions are provided to convey the technical foundation for the performance specifications so the

reader can apply the principles if a specific case warrants deviation from the prescribed procedures. For example, several of the terms used in the performance specifications are also used by the manufacturers to report equipment performance. Sometimes test conditions are specified but the reported or test conditions differ from company to company.

There are three basic sections to this guideline which correspond to three phases of evaluating a monitoring system. The first of these is a set of equipment specifications and criteria which can be used for a "paper" evaluation of analyzers and other components of the proposed or considered monitoring system; the second is the performance verification phase where actual tests are conducted to verify that the operating monitoring system does what it is supposed to do; the third section deals with maintaining the system and regularly checking one or more "indicator" parameters to ensure that it continues to perform as intended.

2. Definitions and Glossary

2.1. Continuous Emission Monitoring System (CEMS). The CEMS is considered to be all the equipment used to generate data and includes the sample extraction and transport hardware, the analyzer(s), and the data recording/processing hardware (and software).

2.2. Continuous. A continuous monitor is one in which the sample to be analyzed passes the measurement section of the analyzer without interruption, and, which evaluates the detector response to the sample at least once each 5 seconds and provides an output signal to the data recorder or meter at least once each 30 seconds.

2.3. **Monitoring system types**. There are three basic types of monitoring systems--extractive, cross-stack and in-situ. Cross-stack and in-situ systems perform the analysis without removing a sample from the stack and an extractive system withdraws a sample from the stack for remote analysis.

2.3.1. **Extractive**. Extractive systems use a pump or other mechanical, pneumatic, or hydraulic means to draw a small portion of the stack or flue gas and convey it to the remotely-located analyzer.

2.3.2. **Cross-stack**. Cross-stack analyzers measure the parameter of interest by placing a source beam on one side of the stack and either the detector (in single-pass instruments) or a retro-reflector (in double-pass instruments) on the other side and measuring the parameter of interest (SO2, NOx, opacity, etc.) by the attenuation of the beam by the gas in its path.

2.3.3. **In-situ**. In-situ analyzers place the sensing or detecting element directly in the flue gas stream.

2.4. **Span**. Span or span value is the upscale or positive instrument reading at or near but not exceeding the full-scale reading of an instrument.

2.5. **Calibration Standards**. Calibration standards are quantities of materials with known and relatively unchanging values for the measurement parameter of interest. The values for the parameter are known with a specified degree of accuracy and precision.

2.5.1. **Gases**. A calibration gas contains a specific concentration of the analyte gas (e.g. CO or O2) in an appropriate diluent gas (e.g. N2 or air), usually supplied in high-pressure cylinders. The diluent is chosen so as not to interfere with the analytical technique and the gases are

available in a wide range of concentrations and différent quality grades.

2.5.2. Gas Cells and Optical Filters. These are calibration devices for optical measurement paths which when placed between the source and the detector produce a predictable response which is or can be correlated to a specific analyte concentration. Gas cells are usually sealed chambers filled with a calibration gas, although there are flow-through cells. Optical filters are solid materials designed to transmit (or absorb) electromagnetic energy of a specific wavelength or spectral composition.

2.5.3. Standard Reference Materials (SRMs). This term is used to describe a particular class of calibration standards which has been certified by the National Bureau of Standards as to the properties of interest.

2.5.4. Other. There are several ancillary standard materials that may be used in system evaluations. These include audit samples used to test analyst proficiency or analyzer performance, electronic signal generators to test certain aspects of instrument response, pressure and vacuum gauges, and temperature measuring standards.

2.6. Instrument Range. The maximum and minimum concentration that can be measured by a specific instrument. The minimum is often stated or assumed to be 0 and the range expressed only as the maximum. If a single analyzer is used, either manually or automatically, on multiple ranges, the performance standards expressed as a percentage of full scale applies to all ranges.

2.7. Drift (Zero or Span). Drift is change in the response or output of an instrument from a set or calibrated value over time. Drift is measured by comparing the response to a calibration standard over time with no adjustment of instrument settings.

2.8. Response Time. The response time of a system or part of a system is the amount of time between a step change in the system input (e.g. change of calibration gas) until the data recorder displays 95% of the final value.

2.9. Precision. Precision is the agreement among individual measurements of the same property, usually under prescribed similar conditions and is usually expressed as the standard deviation of a group of measurements. The units, for this specification, are % of full scale. Repeatability, reproducibility, and replicability are terms used to describe precision, depending on the descriptive statistic used.

2.10. Accuracy. Accuracy is a measure of agreement between a measured value and an accepted, or true, value and is usually expressed as the percentage difference between the true and measured values relative to the true value. For this specification, accuracy is measures by the linearity test, i.e. accuracy at 1 particular measurement value.

2.11. Linearity. Linearity is a measure of the deviation of a measured value from a value predicted by a straight line drawn between the zero calibration and full-scale or span calibration points when calibration value and analyzer response are plotted on rectangular coordinates. For this specification, linearity is measured at mid-scale and is a measure of accuracy at this level.

2.12. _Interferent_. An interferent is a component of a gas stream which, when present, yields an instrument response when the desired effect is no response.

3. Monitoring System Performance and Equipment Specifications

This section describes the characteristics of monitoring system performance that are consistent with the regulations and with sound engineering judgment. The specifications are attainable with systems and components available from a number of commercial vendors of emission monitors and permit the use of different analyzer types. Table 3.1 summarizes the standards and each of items are discussed in the following paragraphs. Two sets of standards are given-one for low range measurement and one for high range measurement. The high range standards relate to measurement and quantification of short-duration high-concentration peaks and the low range standards relate to the overall average operating condition of the incinerator. The dual-range specification may require the use of dual analyzers or at least dual range units as most commercial units do not appear to have the capability of meeting both standards with a single unit.

3.1. Measurement Range. In order to measure both the high and low concentrations specified in the draft CO limits with the same or similar degree of accuracy, it is necessary to establish specifications appropriate to the concentration values and the time averaging periods. The ranges are the full-scale measurement range of the instrument. With this approach, time-weighted averages can be calculated and status relative to the limits determined with assurance.

Table 3.1

Summary of CO Monitoring Systems

Performance Specifications

Parameter	Specifications
	Low range High range
Measurement Range, ppmv	0-200 max 0-1000 min
Monitor Location	No numerical standard
System Response Time	$\leq$ 1.5 minutes to 95% FS
Drift, Zero (as operating)* (guide only)	$\leq$ 10 ppmv,$\leq$ 20 ppmv, 24 hour 2 hour
Drift, Span*	$\leq$ 20 ppmv,$\leq$ 50 ppmv, 24 hour 2 hour
Precision*	the lesser of the lesser of 5.0% FS or 2.0% FS or 10 ppmv 20 ppmv
Linearity*	the lesser of the lesser of 10.0% FS or 5.0% FS or 20 ppmv 50 ppmv

* expressed as the sum of the mean absolute value plus the 95% confidence interval of a series of measurements

3.2. Monitor Location. The recommended location for the CO analyzer, if in-situ or cross-stack, or for the sample extraction probe for extractive systems is in the exhaust stack at least 2 equivalent duct diameters downstream from any source of dilution or in-leakage.

3.3. Response Time. The specification for response time is based on providing at least 6 distinct periods (or values) to comprise the ten-minute average. Six ten-minute values can then be used to determine the 60-minute average.

3.4. Drift. The drift specifications also reflect consideration of the averaging times. The long-term (24 hour) calibration and zero drifts are not particularly important to peak measurements; thus the 24-hour drift limits are proportionally less restrictive than the 2-hour limits. Each set of drift tests, as described in the next section, requires several repetitions of the test and permits one failure to meet the specification. The zero drift values are presented as a guide to operational performance; a monitoring system which does not meet the guideline during the performance test should not be rejected for this reason only. The regulations are not concerned with precise measurements near zero; the concern is for elevated levels of CO. If the instrument exhibits excessive zero drift but maintains performance at the upper levels, the operation is acceptable. This is more likely to occur with systems with non-linear response but inmost cases, zero drift causes a corresponding span drift.

3.5. Precision. All of the performance specifications involving comparison of one measurement value with another are interrelated. An analyzer with a drifting span or calibration will be neither very precise nor very

accurate. The precision specification presented here is repeatability and is defined as the variability among measurements of the same sample with the same analyzer at different times and is calculated as described in 5.3. The precision limits are different for the different ranges, both in the relative and the absolute senses, reflecting the intent of the CO limits and averaging times, and they are consistent with the drift specification. Thus, the analyzer system is permitted to exhibit a certain amount of variation about some central value whether this variation is a result of drift or random changes in the instrument response.

3.6. Linearity. The linearity specification evaluates the accuracy at the mid-point of the measurement range. The common procedure for analyzer calibration is to set a zero response with a zero gas and a full-scale response with a span gas(or cell or filter), adjusting the display or meter reading to the known concentration of the span value. The linearity tests in Section 4 evaluate the accuracy of the system at the mid-point of the measurement range by determining the difference between the measured value and the expected value at this point.

4. Quality Assurance-Monitoring System Performance Tests

4.1. General. This section describes the procedures to be used in evaluation of CO monitoring systems at hazardous waste incinerators. The procedures are adapted, for the most part, from Gaseous Continuous Emission Monitoring Systems - Performance Specification Guidelines for SO2, NOx, CO2, O2, and TRS, EPA Publication No. 450/3-82-026, October 1982, with modification deemed necessary to apply the general procedures to HWIs.

4.2. Location. The best or optimum location of the sample interface for the monitoring system is determined by a number of factors, including ease of access for calibration and maintenance, the degree to which it represents total emissions, and the degree to which it represents the combustion situation in the firebox. As previously mentioned, the location should be as free from in-leakage influences as possible and reasonably free from severe flow disturbances. The sample location should be at least 2 equivalent duct diameter downstream from the nearest control device, point of pollutant generation, or other point at which a change in the pollutant concentration or emission rate occurs and at least 0.5 diameters upstream from the exhaust or control device. The equivalent duct diameter is calculated by Equation 5.1.

The sample path (for cross-stack monitors) or sample point(s) (for extractive or in-situ monitors) should include the concentric inner 50% of the stack or duct cross section. For circular ducts, this is .707 x diameter and a single-point probe, therefore, should be located between .141*diameter and .839*diameter from the stack wall and a multiple-point probe should have sample inlets in this region. A location which meets both the diameter and the cross-section criteria will be acceptable.

If these criteria are not achievable or if the location is otherwise less then optimum, the possibility of stratification should be investigated. To check for stratification, the concentration of CO should be measured at several points in the duct at the potential location. The concentration of O2 or CO2 should also be measured as verification of diluent leakage. For rectangular ducts, at least nine sample points located at the centroids of similarly-shaped, equal area divisions of the cross

section should be used. For circular ducts, twelve sample points (i.e., six points on each of the two perpendicular diameters) should be used, locating the points as described in 40 CFR 60, Appendix A, Method 1. Calculate the mean value for all sample points and select the point(s) or path that provides a value equivalent to the mean. For these purposes, if no single value is more than 15% different from the mean and if no two single values are different from each other by more than 20% of the mean, then the gas can be assumed homogeneous and can be sampled anywhere. The point(s) or path should be within the inner 50% of the area.

4.3. Response Time. The response time tests as here described apply to all types of monitors, but will generally have significance only for extractive systems. The entire system is checked with this procedure including sample extraction and transport (if applicable), sample conditioning (if applicable), gas analyzer, and the data recorder.

Introduce zero gas (or zero cell or filter) into the system. For extractive systems, the calibration gases should be introduced at the probe as near to the stack as possible. If any form of "multiplexing" is being used, the response time tests should be performed for each path in the system. For in-situ systems, introduce the zero cell at the sample interface so all components active in the analysis are tested. When the system output has stabilized (no change greater than 1% of full-scale for 30 seconds), switch to monitor stack effluent and wait for a stable value. Record the time (upscale response time) required to reach 95% of the final stable value on a data form like Figure 4. Next, introduce a high level calibration gas (or cell or filter) and repeat the above procedure (stable, switch to stack, stable, record). Repeat the entire procedure

three times and determine the mean upscale and downscale response times. The slower or longer of the two is the system response time.

4.4. Zero and Span Drift. The purpose of the drift checks is to determine the ability of the CEMS to maintain its calibration over a specified period of time. The performance specifications establish a drift standard related to span drift for the two analyzer ranges and suggest operating values for zero drift. The long-term averaging (1 hour) corresponds to the 24-hour drift and the 10-minute averages correspond to the 2 hour drift. Each drift test is conducted several times and the system(s) are allowed to exceed the limit once during the test. The monitoring system should be operated for some time before attempting drift checks because most systems need a period of equilibration and adjustment before the performance is reasonably stable. At least one week (168 hours) of continuous operation is recommended before attempting drift tests.

Drift checks and precision and linearity checks should all be conducted using the entire monitoring system. For extractive and in-situ systems using calibration gases, this would include all sample conditioning equipment, including external filters and moisture traps. For cross-stack systems using calibration cells or optical filters, the measurement path should be as nearly the same as the stack path as possible and include lenses, optical filters, mirrors, beam splitters, etc., and the electrical and electronic signal processing and control circuitry, including pressure and temperature and other compensation circuits. During the drift tests, no adjustment of the system is permitted except those automatic internal adjustments which are part of the automatic compensation circuits integral

to the analyzer. Subsequent CEM operation must include the same configur-ation as used during the performance testing.

4.4.1. Two-hour drift. Select a span gas with a CO concentration between 80 and 100% of the full-scale range of the analyzer. However,if a range higher than 200 ppm is used, the span gas should be 160-200 ppmv CO. The zero gas should have less than 1 ppm CO. At the beginning of the test, zero and span the analyzer using the selected gases (or cells or filters). After two hours and at two-hour intervals thereafter, alternately introduce both zero and span gases, wait until a stable reading (Sec. 4.3) is obtained and record the values reported by the system. Repeat this procedure for 12 hours, obtaining six values of zero and span gas measurements. The procedure may use more than 12 hours and the two-hour periods need not be consecutive but may not overlap. The difference between the established or reference value for the span and the measured value may not exceed the specifications in Table 3.1 more than once and the mean of the absolute values of the differences plus the 95% C.I.(confidence interval) must be less than the limit of Table 3.1. Calculate the results according to Eqs. 5.2.n. The zero drift should, but is not required to, be within the limits of Table 3.1

4.4.2. Twenty four-hour drift. The procedure for determining compliance with the 24-hour drift limits is essentially the same as the 2-hour test, except that the time intervals are 24 hours instead of 2 hours. The system is calibrated initially and at least 24 hours later, and at subsequent 24-hour intervals, zero and span gases (or cells or filters) are consecutively introduced into the measurement path. The 24-

hour periods may not overlap but may extend longer than 24 hours. Determination of compliance follows the same procedures and one of the six values may exceed the performance specification but the average must not.

4.5. Precision. The precision test (one aspect of a calibration error test) is much like the span drift tests, except that the instrument is presumed to be at a steady-state condition. The test consists of repeated analysis of the span gas (or cell or filter) with intervening changes in the measurement input. The precision and linearity tests (Section 4.6) can be conducted simultaneously by using a mid-scale calibration standard as the intervening input change. The analyzer is calibrated with zero and span standards. After the introduction of the span standard, a lower concentration standard is introduced to the measurement section, and then the span standard is reintroduced. This process (mid, span) is repeated 6 times, recording the instrument response to the span value. The average deviation (Eq. 5.3) must be less than the precision limits of Table 3.1. If the linearity test (Section 4.6) is performed at the same time, there are additional requirements.

4.6. Linearity. The performance specifications are not intended to eliminate instruments which do not have a linear response, but rather to set limits on the allowed deviation between the actual value and the predicted value. The basic procedure for testing linearity (or calibration) error is to set the instrument zero and span with the appropriate standards and then repeatedly measure a standard in the middle of the range. In order to minimize bias from previous analyses, the sequence of standard introduction should alternate between high and low standards prior to the mid-level standard (e.g. high, mid, low, mid, high, mid, low, mid, etc.)

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until 6 analyses of the mid-level standard are obtained, with three values obtained from upscale approach and three values obtained from downscale approach. If the precision and linearity tests are conducted at the same time, additional high standard measurements need to be made and they can be preceded by either low or mid-scale standards. Calculation of deviation from linear response is done with Eq 5.4. If the system response is intended to be non-linear, a multiple-point calibration is usually performed to generate a calibration curve. The manufacturer most often provides either an instrument-specific calibration curve or a recommended procedure to generate one. Depending on the nature of the response of the instrument, a 50% standard may yield a low response (e.g. 30 % of full-scale) or a high response (i.e. 70 % of full-scale) and the calibration points are concentrated in the region of the greatest rate of change. In these cases the calibration error test standard should be greater than 45 % of the instrument range and between the manufacturer's recommended span and intermediate calibration standards.

5. Equations

5.1. Equivalent Duct Diameter. To determine the round duct equivalent diameter of a rectangular duct

$$D_c = \frac{2 * L * W}{(L \pm W)}$$

where D_c = equivalent diameter, L = length and W = width

5.2. Drift Calculation. Use the following equations to calculate system drift for comparison to the performance specifications

$$di = | MVi - RV |$$

where di = absolute value of individual drift measurements, MVi = individual measured values of standard, and RV = reference value of standard

$$\bar{d} = \frac{1}{n} \cdot \sum_{i=1}^{n} d_i$$

where $\bar{d}$ = arithmetic mean of the absolute values of the drifts and

n = number of measurements (usually 6)

$$S_d = \left[\frac{\sum_{i=1}^{n} d_i^2 - \frac{1}{n} (\sum_{i=1}^{n} d_i)^2}{n - 1} \right]^{1/2}$$

where S_d = standard deviation of the d_i values

$$95\ \%\ C.I. = t_{.975} \cdot \frac{S_d}{\sqrt{n}}$$

where 95% C.I. = the confidence interval for the data at a probability of 2.5% (two-tailed) and t values are the critical t values for the Student's "t" test. Some t values are presented below.

n*	t
3	4.303
6	2.571
12	2.201

* n values are number of samples; t values are corrected
  for number of degrees of freedom

Drift = $\bar{d}$ ± 95 % C.I.   (ppm)

5.3. Precision Deviation. Use the same approach for calculating precision as for drift, using the individual differences between the measured values and the reference value as the data points.

5.4. Linearity Deviation. The same calculations are also used for the linearity checks, using the differences between the measured instrument output and expected output for the reference standard as the data points.

6. References

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6.5. Ferguson, B.B., R.E. Lester, and W.J. Mitchell, Field Evaluation of carbon Monoxide and Hydrogen Sulfide Continuous Emission Monitors at an Oil Refinery, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 27711, EPA-600/4-82-054, August 1982.