

Part 1. Video Exposure Monitoring Techniques

I. Introduction

Occupational exposure to air contaminants is usually monitored by means of integrated sampling of the air a worker breathes. The air is drawn through a filter or other collection medium at a known flow rate by means of a small battery powered pump for a measured period of time. The collection medium is analyzed to determine the quantity of contaminant collected, and the average exposure during the sampling period is computed. These results indicate the extent of exposure, but integrated air sampling provides little insight into the specific causes of the worker's exposure. Recommendations for controlling the air contaminant exposures are often based upon an observer's judgment and can result in implementation of control measures that do not address the major worker air contaminant exposure sources. To help overcome this problem, direct reading instruments and data recording devices can be used as a part of a system for recording events and exposures in the workplace as a function of time. The data from such a system can be used to associate events and exposures and to promote more effective and focussed recommendations for controlling the air contaminant exposures.

Through studies conducted in a variety of industries, researchers with the National Institute for Occupational Safety and Health (NIOSH) have developed a systematic approach to help identify the sources of worker exposures and to provide an effective means for communicating the results to workers and management.^(1,2) This system employs:

- direct reading instruments and data recording devices to monitor and store data characterizing worker exposures,
- video cameras and recorders to document worker activities,
- task analyses to evaluate work activities,
- statistical techniques to develop predictive models and to summarize the results, and
- personal computers to perform analyses on the data and to combine the activity data and the exposure data into a presentable form.

The present system evolved from a series of studies conducted either to evaluate the effectiveness of engineering controls or to identify characteristics about the worker's exposure so that controls could be implemented. Direct reading instruments were used so that exposure changes over a short time interval (on the order of seconds) could be monitored. The output from these instruments was stored in an electronic recording device rather than on a stripchart recorder, so that the data would not require re-keying for statistical analysis. Worker's activities were documented by video recording systems to determine whether exposures were the result of particular work practices. Work activity data were combined with the real-time exposure data by determining both the exposure and the activity at any given time. Time series analysis of the combined real-time and work activity data set resulted in a model to predict worker exposures. After several studies, however, it became apparent that time series analysis could become a prohibitive task because of the tremendous amount of data that can be collected in a very short period of time. To ease this problem, several simplified analysis techniques were developed. Although these techniques are not as powerful as the time series analysis, in most

cases they can identify those activities that contribute the most to the worker's contaminant exposures.

As some of the initial studies were being completed, a need became obvious: a way to communicate the study results to workers and to management. The consensus among the individuals working on these studies was that a video recording of the work activity combined with a display of the real-time exposure measurement would be most effective. The exposure data could be presented in two forms: numerically, with the value of the exposure measure being displayed on the video screen, or graphically, by displaying a graphical representation of the exposure on the video screen. Both options were combined by displaying both the numerical exposure concentration and a bar representing the relative magnitude of the exposure. To place the bar and number on the video screen, a computer program was written to read the exposure data file and to generate and update the bar with time. The system required the use of consumer quality video and ordinary personal computer equipment; the only specialized equipment required was a special graphics card for the personal computer. The result was a video recording that graphically showed how exposure to a particular substance was affected by the activities of the worker.

This document describes various aspects of using direct reading monitors to evaluate occupational exposures. The discussion of the different techniques includes the equipment necessary for conducting this type of exposure assessment. Finally, several case studies illustrate the use and limitations of these techniques.

II. Video Equipment

Two types of video equipment are described in this report: conventional video equipment, used to document the worker's activities, and infrared video equipment used to visualize specific air contaminant plumes. The discussion of conventional equipment includes the system requirements for conducting video exposure monitoring; the discussion of infrared equipment includes theory and operation, and explains how it can be used with direct reading instruments to characterize workplace contaminant concentrations.

A. Conventional Video Equipment

The conventional video recording system consists of a video camera and a videotape recorder. For better portability, a camcorder, a video camera with built-in recorder, can be used. Mounting the video camera onto a tripod eliminates the need to hold the camera throughout the entire process. The tape format (Beta, VHS, 8-mm) is not important, and many consumer-quality video recording systems are suitable for video exposure monitoring. There are, however, two important requirements. First, the video system must have a National Television System Committee (NTSC) standard video output signal — a signal used by the video overlay system described elsewhere in this document. This standard is used by most home video equipment. Second, an on-screen clock or timer is needed — one that can be synchronized with the real-time clock of the data recording device. Synchronizing the data recording device with the video camera can be as simple as starting the timer in the camera at the same time the data logger is turned on. The clock or timer should have a resolution of at least 1 sec. The on-screen clock permits an exposure to be coordinated with an associated activity. The video recording of the work cycle or process can then be reviewed while simultaneously tracking the worker's exposure from a printout or plot of the real-time exposure data.

B. Infrared Video Equipment

Effective control of air contaminants depends on understanding of the characteristics of their release. Not only is concentration important but it is also necessary to know the source and path of the emission. Although some gasses and vapors are visible, most are not. Infrared imaging is a technique that can provide a real-time picture of some otherwise invisible emissions.

A schematic of such an infrared imaging system is presented in Figure 1. An infrared scanner (Thermovision 782)⁽³⁾ detects changes in absorption of infrared radiation by contaminant gases or vapors. Two versions of the scanner may be used depending on the range in which the gases absorb infrared radiation: a shortwave band (2 to 5.6 microns) and a longwave band (8 to 12 microns). The images received by the scanner are transmitted to a display unit and may be converted from the normal infrared gray scale image to a colored scale. This image is then simultaneously transmitted to a monitor and video recorder for real-time viewing and recording.

The system uses a flat, black panel as an infrared radiator. The panel is a square, 2-in. thick aluminum tank filled with water. A flat-sheet electrical heater is glued to the back surface of the tank; the front surface is painted black. An electronic temperature controller maintains the tank at a constant temperature. The water in the tank is circulated by a laboratory stirrer to inhibit the formation of a temperature gradient across the panel surface.

The radiant panel and the infrared scanner are positioned so that the emission source is between them. The scanner sees the panel as a constant temperature source, and it is displayed as a uniform image. As a contaminant gas passes between the scanner and the heat source, it absorbs some of the

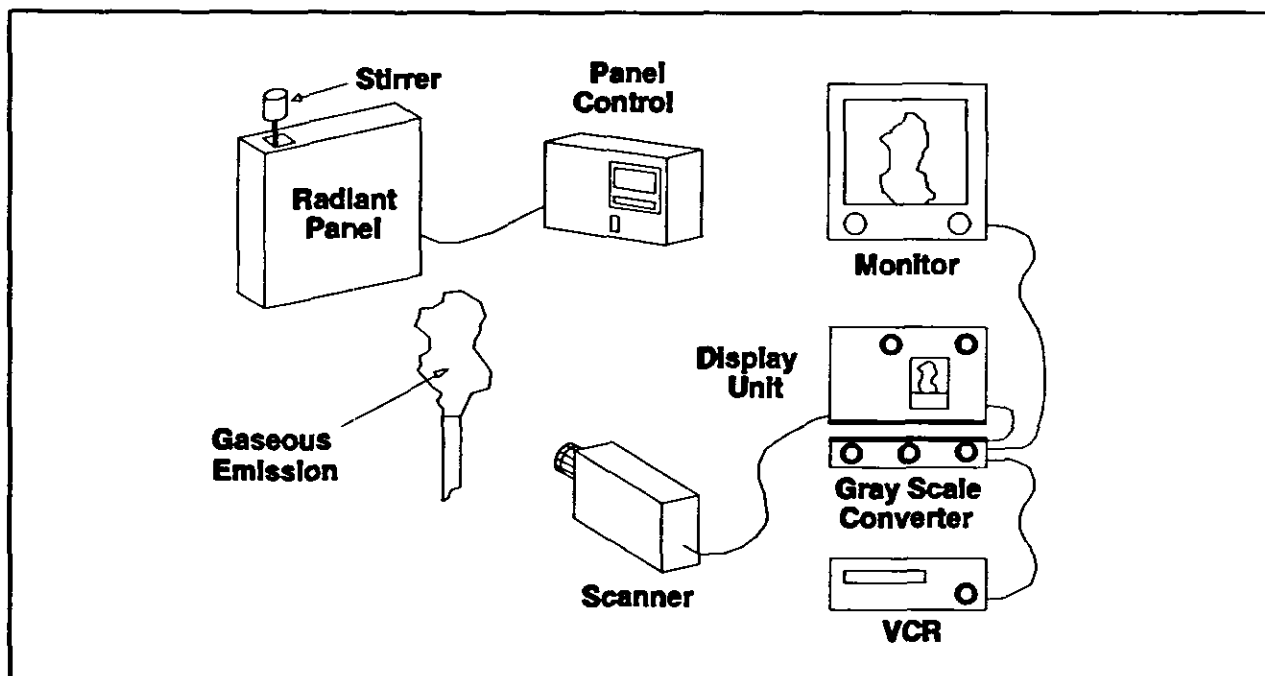


Figure 1. Infrared imaging system.

radiated infrared energy. The scanner detects this as a lower temperature, which is then displayed as a different color or shade of gray and recorded.

The system as described here is useful for detecting certain process emissions because it provides a real-time image that identifies both the source and path of the emissions. Medical processes, such as the release of nitrous oxide (N_2O) during dental surgery, as well as industrial processes can be monitored. Also, the infrared imaging system may be used in determining of flow patterns around exhaust openings with the use of a tracer gas. An advantage to this technique is that the effect of specific work activities or changes in control configuration can be determined immediately.

The most important limitation of this system is sensitivity. The absorption of the emission cloud is directly related to the concentration of the emission and the path length through the cloud. Thus, lower concentrations must be present in greater quantities to be visualized. For example, the sensitivity for N_2O is on the order of 200 ppm-meter, i.e., a cloud of nitrous oxide having a concentration of 200 ppm must be 1 m across to be detected. System sensitivity can be increased by the use of narrow band pass filters that filter out radiation outside the narrow band containing the absorption peak of the monitored contaminant. The high concentrations typically found at the generation point of an emission can generally be visualized using this system. Detection of contaminant levels in the range of occupational health standards is, however, limited. Another limitation of the system is lack of portability. Because the radiant panel is a water-filled tank, it is quite heavy and not easily positioned. Although this is not a severe limitation for laboratory use, it does make field operation difficult.

Some of these limitations are addressed by recent advances in thermal imaging technology. A system that uses a laser in combination with the infrared scanner to detect changes in energy is now available. The laser scans the viewed object, thus eliminating the need for a radiant panel, greatly increasing portability and making the system much more convenient for field use. This system also has a sensitivity in the range of one order of magnitude greater than the one previously described.

III. Monitoring Equipment

Any air contaminant monitoring instrument that can produce an output signal of the concentration measurements can potentially be used to conduct real-time assessments of a worker's exposure to an air contaminant. The usefulness of a specific instrument will vary with the situation. To evaluate the utility of an instrument, consider:

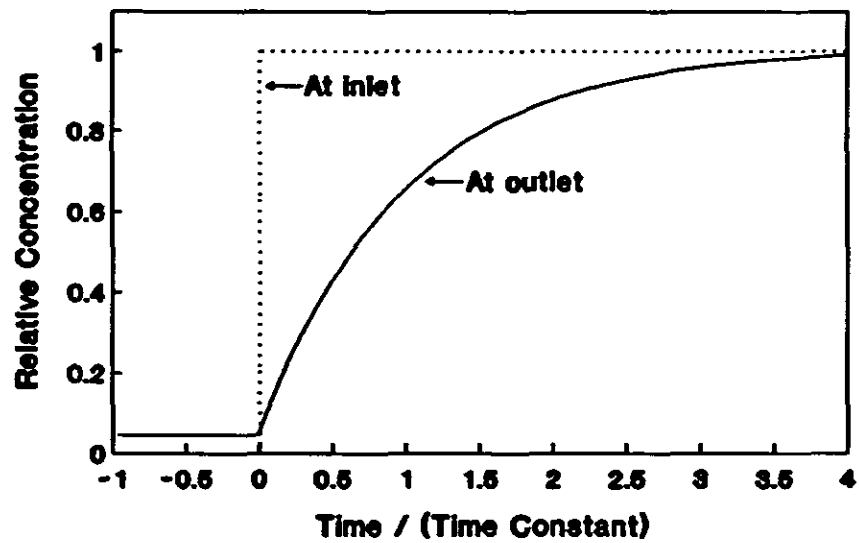
1. the nature of the analog or serial output,
2. the response time of the instrument,
3. specificity for the contaminant of interest, and
4. portability and size.

Output. Because real-time concentration data are generally used to evaluate the relationship between events in the workplace and air contaminant concentrations, the concentration measurements generally need to be recorded automatically. For a monitor to be useful, it should produce a digital or analog output. The analog output of many industrial hygiene instruments is a voltage that is proportional to concentration. Techniques for recording analog data are given in the "Data Acquisition" section of this document. Some instruments also provide a digital output that is periodically updated. The frequency of these concentration measurements is usually a function of the instrument and normally cannot be adjusted by the user.

Response Time. The total system response time (for the monitor and the setting being evaluated) can be defined as the sum of (a) the time required for the air contaminant to be transported to and to accumulate in the worker's breathing zone and (b) the time required for the instrument to respond to a change in concentration in the worker's breathing zone. To conduct video exposure monitoring studies of air contaminant concentrations, the total system response time must be less than that of the events of interest. As a result of the delays that make up the total system response, the instrument output lags behind work events in the workplace.

The time constant describes how an instrument responds to changes in concentration. An instrument responds to changes in concentration in the same way that the concentration in an ideal stirred mixing tank responds to changes in concentration of the incoming stream.⁽⁴⁾ The time constant of the tank is the time needed for the tank's volume to flow through the tank at a given flow rate. (The time constant equals the tank's volume [V] divided by the flow rate [Q]). The concentration in the mixing tank is the average concentration of each increment of fluid that is flowing through the tank. Some of these fluid increments flow in and out of the tank quickly, whereas others remain in the tank for some time. As a result, the average concentration in the tank does not immediately respond to changes in inlet concentration. Figure 2 illustrates the theoretical response of the concentration in an ideal stirred tank to changes in the inlet concentration. Figure 2A illustrates the effect of a step change in the inlet concentration upon the concentration in the tank. More than two time constants are needed for the concentration in the tank to complete 90% of its response to the change in concentration. Figure 2B illustrates the effect of a concentration pulse upon the concentration in the mixing tank. The width of the concentration pulse is one-fourth of the tank's time constant. Figure 2B, shows a distorted picture of the inlet concentration as measured by the concentration in the tank. The concentration in the tank reaches a maximum when the concentration pulse has completely passed into the tank. A period of several time constants is required to completely flush the concentration pulse out of the tank. Air monitoring instruments respond to changing concentrations in a manner similar to that of the stirred tank. Therefore, when changes in the inlet concentration occur faster than

(A)



(B)

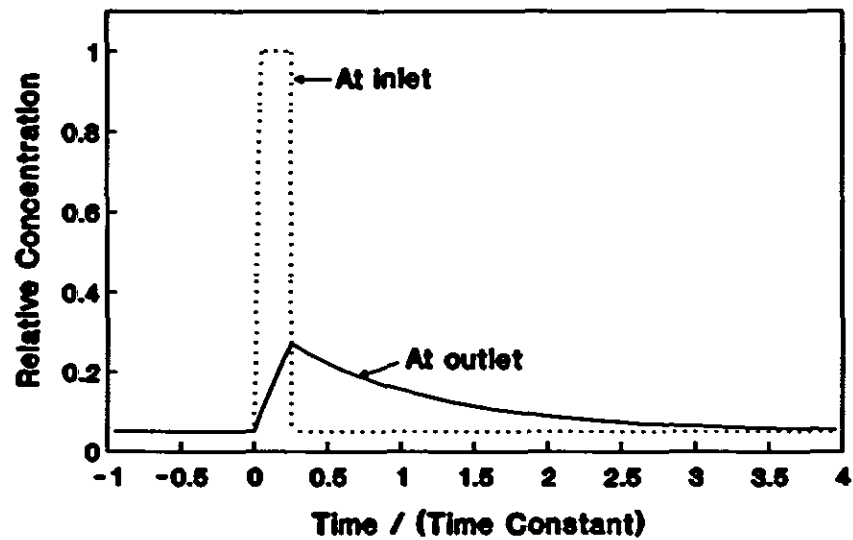


Figure 2. Ideal mixing tank concentration response to inlet concentration changes: (A) inlet concentration step change from 0.05 to 1.0, (B) concentration pulse of 25% of the tank's time constant.

the instrument's response, the measured concentration profile will be a distorted picture of the actual concentration profile. To limit this distortion, the instrument's time constant should be shorter than the events being studied.

Specificity. The air monitoring instruments used in industrial hygiene are usually not specific for a particular substance. These instruments are usually based upon the measurement of some parameter that is proportional to concentration. For example, aerosol photometers respond to any aerosol that scatters light. This limitation of the existing equipment requires either that the monitor be calibrated for the specific air contaminant or that the results be reported as a relative concentration.

Portability. To allow for worker acceptance, the monitoring equipment should be light enough to be worn comfortably by the worker. The equipment should be battery-operated, and should weigh as little as possible. If the equipment cannot be worn by the worker, tubing can be used to transport the air contaminant from the worker's breathing zone to the instrument. This, however, adds some extra complications. The monitoring system's response time will increase because of the time needed to transport the air contaminant through the tube to the monitor. In addition, the tubing might collect the air contaminants or might contribute to the instruments's signal; aerosols can be lost to the tubing walls and later be released if the tubing is struck or vibrated; and organic vapors can be adsorbed onto the tubing walls during periods of high concentration and desorbed during periods of low concentration.

Users need to consider the limitations and capabilities of the direct reading instruments to design and conduct studies that yield useful information about exposure sources. The instruments used in the case studies described in this document all have limit capabilities. In the case studies, three types of instruments were used: aerosol photometers, photoionization detectors, and portable infrared spectrometers. Background information on these instruments can be obtained from the NIOSH Manual of Analytical Methods (NMAM) and the American Conference of Governmental Industrial Hygienists' (ACGIH) Air Sampling Instruments.^{6,8} The following paragraphs discuss each of these instruments from the perspective of an occupational health professional who wishes to conduct video exposure monitoring.

A. Aerosol Photometers

Aerosol photometers, such as the Real-Time Aerosol Monitor (RAM®) (Mie Inc., Bedford, MA) or the Hand-held Aerosol Monitor (HAM) (PPM Inc., Knoxville, TN), provide a continuous signal (analog voltage and digital display) output that is proportional to concentration. Both instruments have user selectable time constants. As illustrated in Figure 3, such instruments are operated by continuously drawing the aerosol through an illuminated sensing volume and detecting the light scattered by all the particles in that volume. The amount of light scattered by the aerosol is a complex function of particle size, shape, and refractive index. Generally, as particle size increases above 1 μm , the mass sensitivity of these instruments decreases with increasing particle size.^{7,8} As a result, instrument calibration may vary dramatically between different materials and different samples of the same material. In using these instruments to conduct video exposure monitoring, the assumption is that the nature of the aerosol (particle size distribution, composition, etc.) remains constant so that the calibration of the instrument does not change while collecting data. This assumption can be verified by conducting integrated sampling to confirm that the response of the aerosol photometers correlates with the actual integrated exposure results.

For aerosol photometers to be useful for video exposure monitoring, the contaminant of interest must cause most of the scattered light. If studying the sources of exposure that are small in relation to the total background aerosol concentration, sampling with aerosol photometers may not yield useful information. The background concentration caused by ambient air pollution is about 0.03 mg/m³.

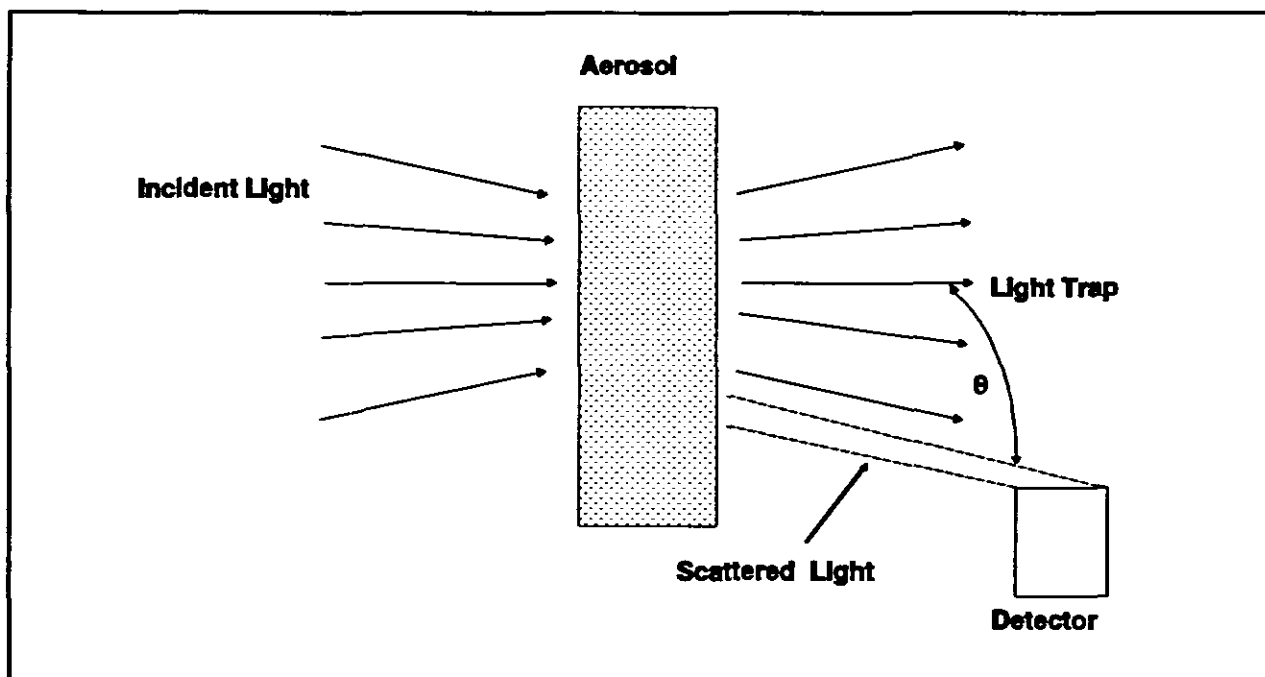


Figure 3. Schematic of aerosol photometer utilizing scattered light (from Reference 6).

Some commercially available aerosol photometers such as the HAM do not have pumps to draw air through the sensing volume. They are designed so that natural air currents transport the aerosol to the sensor. This adds to the lag between events and measured concentration. To minimize this lag, a personal sampling pump can be used to draw air through the instrument's sensing chamber.

B. Photoionization Detectors

Photoionization detectors operate by passing air through a sensing chamber that is illuminated by an ultraviolet (UV) lamp. The UV radiation from this lamp ionizes many of the contaminants that may be present in the air, and thus a current flows between negative and positive electrodes located in the sensing chamber. The measured current flowing between the negatively and positively charged electrodes in the sensing chamber is proportional to the concentration in the chamber. The lamps in these instruments produce photons with an energy of less than 11 eV. Therefore, these instruments respond to gases and vapors that have an ionization potential less than 11 eV. Because they do not respond well to gases and vapors that have ionization potentials much greater than the energy of the photons produced by the lamp,⁽⁶⁾ the common components of air such as oxygen, nitrogen, helium, carbon dioxide, and water vapor (all of which have higher ionization potentials) are not detected. Because many chemicals have an ionization potential that is less than 11 eV, photoionization detectors are not specific for a given air contaminant.

Commercially available photoionization detectors such as the HNu[®] model 101 (HNu Systems, Newton, MA) and TIP[®] II (Photovac Inc., Thornhill, Ontario, Canada) have relatively short response times. Both instruments have a time constant of approximately 1 sec. In these instruments, a small fan is used to draw air through the sensor. As a result, a small pressure loss in any sampling train can cause a reduction in the flow rate through the sensing volume and a subsequent increase in the instrument response time.

C. Infrared Analyzers

Unlike the aerosol photometers and the photoionization detectors, infrared (IR) analyzers can be used to analyze for a specific compound in the presence of interferences. A pump or fan draws air through tubing into the sampling chamber of the analyzer, and IR radiation is passed through the sampling chamber. Compounds absorb infrared radiation at specific wavelengths that are characteristic of the chemical bonds between the atoms of the compound. The IR wavelength is selected to maximize the radiation absorption of the compound of interest and to minimize the absorption of interfering compounds. The amount of infrared radiation adsorbed is described by the Beer-Lambert Law, which states that the radiation absorption is proportional to the molar concentration of the compound and the distance through which the radiation travels. This relationship is stated mathematically as:⁽¹⁰⁾

$$\log \left(\frac{I_0}{I} \right) = A = \epsilon CL \quad (1)$$

where:

- I = intensity of light transmitted by sample
- I_0 = intensity of incident light
- A = absorbance of sample
- ϵ = molar absorbtivity (l/mole/cm)
- C = concentration (moles/l)
- L = path length (cm)

To have adequate sensitivity, these instruments usually have path lengths on the order of meters. The long path lengths are achieved in small volumes by using mirrors and multiple reflections. A conceptual diagram of the mixing chamber is shown in Figure 4.

The response time of these portable infrared analyzers is frequently determined by the volume of the sampling chamber. The time constant usually can be calculated by dividing the volume of the sampling

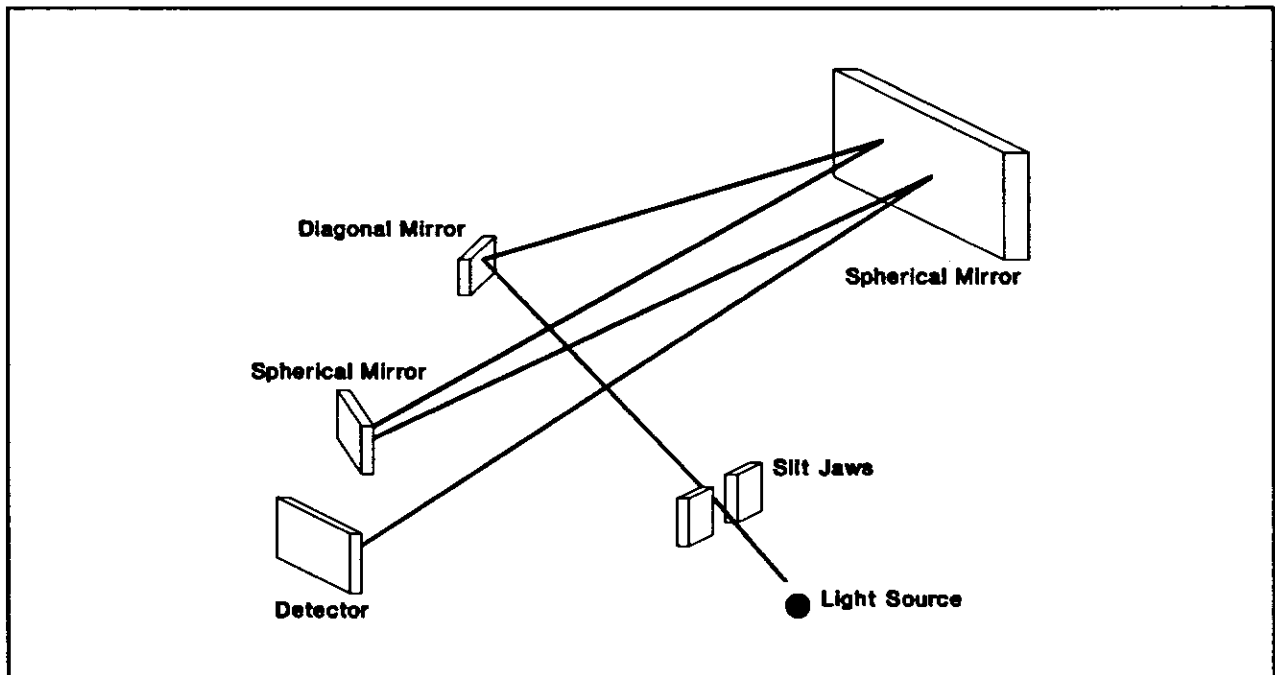


Figure 4. Infrared analyzer schematic.

chamber by the flow rate. For the MIRAN® 1A (Foxboro Instruments, Foxboro, MA), this time constant is about 17 sec based upon a mixing chamber volume of 5.6 l and a sampling rate of 20 lpm. The response time for portable infrared spectrometers will generally be longer than those for aerosol photometers and photoionization detectors.

To minimize the time constant, the flow rate through the sampling chamber can be increased by using an external pump to move air through the sampling chamber. This can, however, cause a significant pressure drop through sampling lines and in the sampling chamber, and, as a result, there may be a noticeable decrease in the absolute pressure in the chamber and in the moles per volume of analyte in the mixing chamber. The measured concentration can be corrected for the reduced chamber pressure by the following:

$$C_{act} = C_{red} \left(\frac{P_{atm}}{P_{atm} - P_{drop}} \right) \quad (2)$$

where:

C_{act}	=	Actual concentration
C_{red}	=	Concentration at reduced pressure
P_{atm}	=	Atmospheric Pressure
P_{drop}	=	Pressure drop

Although portable infrared analyzers can be carried from site to site, they are too heavy (10 to 20 kg) to be placed on a worker. A sampling line inlet can be mounted on the worker's lapel or very near the worker's breathing zone (see Case Study E), but this can present a number of complications. The total response time of the instrument is increased because of the long sampling line. Because the flow rate induced by the fan decreases rapidly with an increase in the static pressure, adding a sampling line may decrease the air sampling rate. Pressure losses through the sampling line can be minimized by using larger diameter tubing and by minimizing the number of bends and kinks in the tubing.

IV. Personal Computer Software

Several types of software may be used to collect and analyze real-time exposure data. Control software is used to operate an analog-to-digital converter card, and communications software is used to download portable data loggers. Spreadsheets are valuable for manipulating the real-time exposure data as well as for performing some simple analyses. For more sophisticated data analyses, full-function statistical analysis packages may be required. In addition, if the exposure data are to be combined with the work activity video recording, a specially written computer program can be used to generate a graphical representation of the worker's exposure.

Control software is used to operate the analog-to-digital converter that is either a card located in the computer or a stand-alone system with an interface to the computer. These software packages usually require special device drivers for the particular hardware system in use. Many of these control packages can process the real-time data as they are being collected, and some packages provide some limited data analysis capabilities. Besides collecting data from an analog source (a direct reading instrument for example), the control software can also instruct the computer to send out signals. Although the capability to function as a controller may be useful in the industrial or laboratory setting, it is not further described in this report.

Configuring the analog-to-digital system is normally done by menu-driven software. Many of the software packages will allow the readings to be displayed on the computer screen as the data are being collected. This display may be graphical or tabular. Once data collection is complete, the readings are stored in a data file. Some programs will link directly with a spreadsheet program making it possible to save the data in a spreadsheet file. For other programs, the data are stored in file formats that can be imported into the spreadsheet. There are several different control programs with many different functions and capabilities. Two specific packages are Labtech Notebook (Laboratory Technologies Corporation, Wilmington, MA) and ASYST (MacMillan Software Company, New York, NY). Both of these programs will work with a variety of analog-to-digital converter cards. Depending on the options purchased, the prices of these packages range from \$200 to \$2000.

If a portable data recording device (data logger) is used to record the real-time exposure data, control software is not needed. Instead, a program to download the data logger to a personal computer is required. Most data loggers either come complete with downloading software or have one available for an additional cost. After downloading the data logger, some of the programs may allow simple data analysis to be performed. Many of these programs store the data in a file that can then be imported into a spreadsheet program. In addition to the programs supplied with the data loggers, communications programs such as Crosstalk (Crosstalk Communications, Roswell, GA) and Procomm (Datastorm Technologies Inc., Columbia, MO) also can download some data loggers through the computer's asynchronous communications port. Using the communications programs may be a nonstandard procedure, since the format of the data from the data logger may vary with the device.

After the data have been collected and stored in a file, spreadsheet programs can be used for data manipulation and simple data analysis. Lotus 1-2-3 (Lotus Development Corporation, Cambridge, MA) and Microsoft Excel (Microsoft Corporation, Redmond, WA) are examples of two spreadsheet programs. If the data are to be analyzed by worker activity, a spreadsheet is useful for keying activities with the real-time exposure data: determine the time a particular reading was recorded and then observe the worker's activities for that time on the video recording of the work activity. Spreadsheets can be used not only to sort data and perform elementary statistical analysis but to

format data sets for analysis in a statistical analysis program or to combine the work activities and the real-time exposure data onto videotape. A detailed discussion on the use of the spreadsheet for more sophisticated data analysis is given in the Data Analysis section of this document.

To combine the real-time exposure data with the video recording of the worker's activities, NIOSH researchers have written a program for IBM compatible computers that generates a graphical representation of the worker's exposure. A listing of this program, written in BASIC, is given in Appendix A, and instructions for running the program are given in Appendix B. This IBM compatible program reads a real-time data file, generates a bar to represent the magnitude of the exposure, and then displays the bar on the screen. When this program is run through a video overlay system, a video recording graphically shows how a worker's exposure is influenced by the work activity. The video overlay system is discussed in the Personal Computer Hardware section of this report. The bar is updated at the same time interval as the readings in the data set. The program was written to allow either one or two bars to be displayed on the screen at one time. Two bars can be displayed if the exposures of two workers are to be compared or if one worker is monitored with two different instruments. To use the program, the real-time exposure data must be stored in a properly formatted ASCII file. For the program to display one bar, the format of the data file must have three columns of data: two columns for the time the reading was recorded (minutes and seconds) and one column for the exposure measurements. For the program to display two bars, then the data file format must have an additional column for the second exposure measurement. The first data set will be displayed on the left side of the screen while the second data set will be displayed on the right. The time interval between the readings must be constant. Figures 5A and 5B shows examples of the data file formats. The spreadsheet program can be used to arrange the data file into the proper format. The bar generated by this program is overlaid onto the work activity video recording through the use of a video overlay system.

The computer software packages discussed here are only a few examples of the programs that can be used in collecting, analyzing, and presenting real-time exposure data. The choice of the specific package depends upon the needs of the particular situation. The case studies presented in this document outline some specific uses of some of these packages.

(A)	Minutes	Seconds	Reading	(B)	Minutes	Seconds	Reading 1	Reading 2
	10	00	0.25		10	00	0.25	0.35
	10	01	0.30		10	01	0.30	0.33
	10	02	0.59		10	02	0.59	0.05
	10	03	1.20		10	03	1.20	0.65
	10	04	1.03		10	04	1.03	0.79
	10	05	0.74		10	05	0.74	1.13
	10	06	0.66		10	06	0.66	1.54
	10	07	0.88		10	07	0.88	1.44
	10	08	1.01		10	08	1.01	1.09
	10	09	0.54		10	09	0.54	0.76
	10	10	0.29		10	10	0.29	0.32

Figure 5. Overlay file format: (A) one bar (B) two bars. Do not include column headings in the file.

V. Personal Computer Hardware

The computer hardware required for collecting and presenting real-time data, as described in this document, is fairly basic. Specialized equipment is required only for combining the graphical exposure bars with the video recordings of the work activity or if a computer-based analog-to-digital converter system is to be used. The basic computer system used by NIOSH researchers is an IBM PC compatible personal computer. The computer that is used should have at least 640 KB of memory and, preferably, a hard-disk drive. Additional memory may be desirable if unusually large data sets are to be manipulated in a spreadsheet. If the real-time exposure data are not going to be combined with the video recording of the work activity, then the type of graphics card is not critical. If data loggers are to be down loaded to the computer, an asynchronous (serial) communications port is required (most computers are sold with this port as standard equipment).

Computer based analog-to-digital converters are special cards that fit into an expansion slot of the computer. Special software drivers and control programs may be required to operate this board. Control software packages were discussed in the Personal Computer Software section of this document and the Data Acquisition section contains more detailed descriptions of the analog-to-digital converter systems.

To overlay the real-time exposure data with the video recording of the work activity, the computer will need either an Enhanced Graphics Adapter (EGA) card and a video overlay board or a Variable Graphics Array (VGA) card with the overlay features built in. A monitor appropriate for the graphics card also is needed. Both VGA and EGA are high resolution color graphics adapters, with VGA having slightly higher resolution.

If an EGA card is used, it must be combined with a video overlay system. One such system, the Video Charley® (Progressive Image Technology, Folsom, CA), consists of a single computer card. The Video Charley requires the EGA card to have a standard Features Connector (most EGA cards do). The Features Connector links the video overlay board with the computer. The video overlay board will convert the computer's graphics signal to a National Television System Committee (NTSC) signal and overlay the graphics onto the activity video recording. Besides the Features Connector, most EGA cards also have a DB9-pin connector for the EGA monitor and two RCA-type connectors. Under normal circumstances (without the Video Charley), the two RCA connectors serve no function. With the Video Charley board installed, however, one RCA connector becomes the input for the activity video signal, and the other is used to output the video signal with computer graphics overlaid.

When overlaying computer graphics using the Video Charley, signal differences require the computer display system to operate at a resolution of 640x200, rather than at the typical EGA resolution of 640x350. To combine the activity video signal with the computer graphics signal, the two signals must have the same synchronization frequencies. In the case of the video signal, an NTSC signal, the horizontal sync frequency is 15.7 kHz and the vertical sync frequency is 60 Hz. In the 640x200 mode, the horizontal and vertical sync frequencies are also 15.7 kHz and 60 Hz, respectively. In the 640x350 mode, the vertical sync frequency is 60 Hz; however, the horizontal sync frequency is 21.8 kHz. To get both signals at the same horizontal sync frequency, the computer graphics card must operate at the lower resolution mode. Depending on the type of EGA card used, either software drivers or hardware switches can be used to set the resolution.

If the VGA option is chosen, an appropriate VGA card is required. Two such cards are the USVideo VGA/NTSC Recordable® graphics card with the Genlock Overlay Module (USVideo, Stamford, CT) and the Willow Peripherals VGA-TV GE/O® (Willow Peripherals, Bronx, NY). These two systems will allow computer graphics to be overlaid onto video images at a higher resolution than will the EGA system with the Video Charley. To do the overlay on VGA systems, only one setting needs to be changed to direct the card's output to the video monitor: on the USVideo card, this is done with a hardware switch; on the Willow Peripherals card, a software program is run. Both cards have two RCA-type ports, one for video in and one for video out. The cabling setup, shown in Figure 6, is the same for both the EGA/Video Charley and the VGA systems. Operation of the VGA overlay system is similar to the normal use of the computer, except that the video monitor (connected to the video out RCA-type port) is the primary monitor.

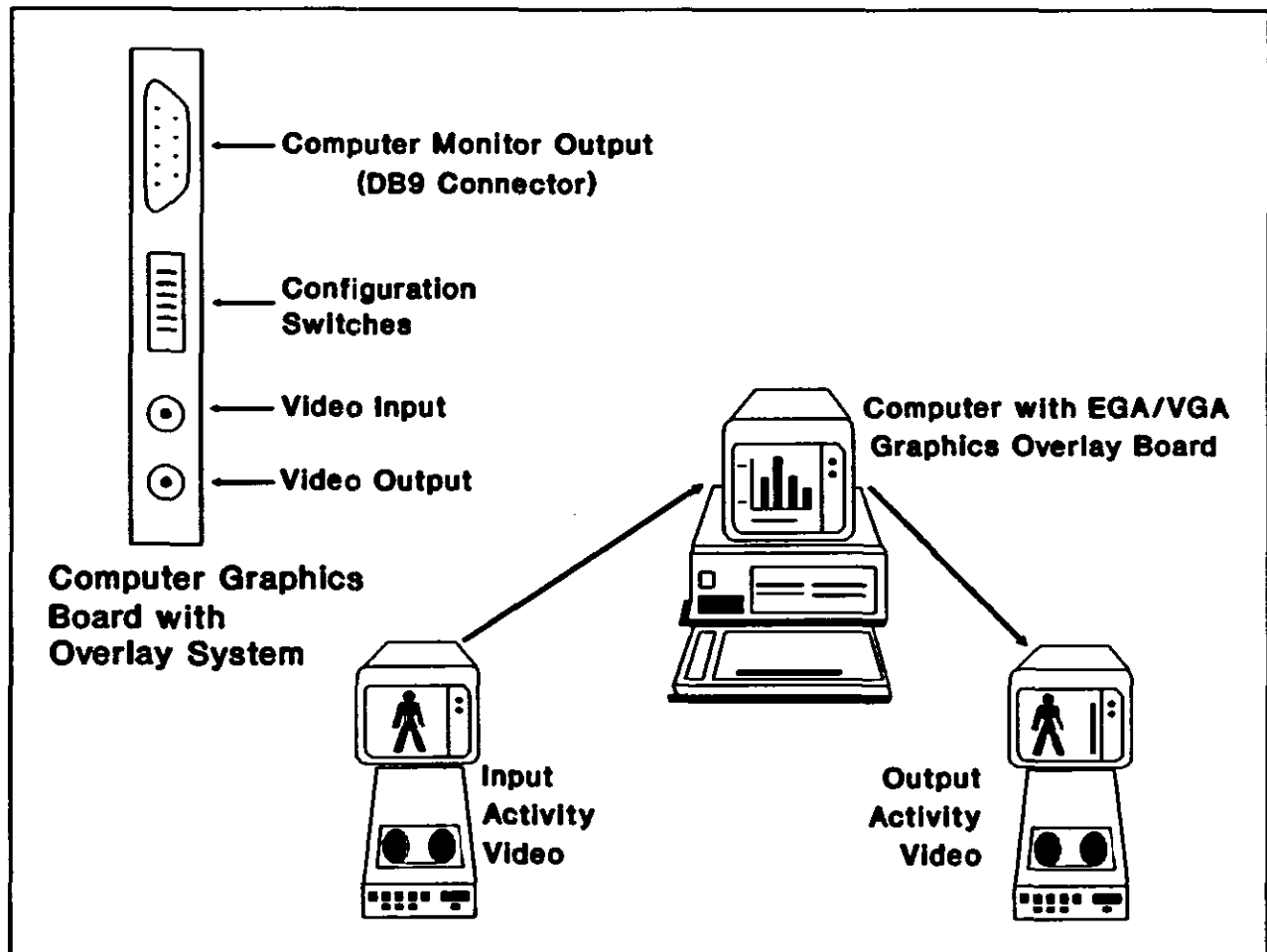


Figure 6. Diagram of the personal computer system's equipment and connections needed to overlay exposure data with work activities.

VI. Data Acquisition

Many direct reading monitors have analog output capabilities, usually in the form of a DC voltage signal, typically on the order of 1 to 10 v, full scale. Before the proliferation of the personal computer, this analog output was typically used to drive a strip chart recorder. At that time, to perform data analysis with a computer, the data from the strip chart was keyed into the computer, a tedious process. With advances in personal computers, the analog output from these monitors can now be stored digitally, allowing the data to be transferred to the computer with just a few easy steps.

Data recording devices generally fall into two categories: portable data loggers and computer based analog-to-digital (A/D) converter systems. Both types of devices have a limited resolution over their working voltage range. Depending on the type, the device will either have a fixed input voltage range (0 to 2 v for example), or the working range can be chosen with hardware switches or control software. This working range is then broken down into intervals. Resolution of a data recording device is usually given in bits. For example, an 8-bit data logger with a working range of 0 to 2 v, will break the 0 to 2 v range into 256 intervals. The number of intervals is determined as follows:

$$\text{Number of Intervals} = 2^{\text{Bits}} \quad (2)$$

The magnitude of these voltage intervals is calculated from

$$v_i = \frac{(v_U - v_L)}{N} \quad (3)$$

where, v_i = Interval, v
 v_U = Upper working range, v
 v_L = Lower working range, v
N = Number of intervals.

For the 8-bit, 0 to 2 v working range example, the difference must be at least 0.008 v for the data recording device to detect a difference between two voltage readings. In most instances, an 8-bit device should be sufficient. Data loggers are typically 8-bit devices whereas A/D converters range from 8 to 16 bits; 12-bit boards are very common.

Computer based systems store the data directly into the computer's memory or onto a disk drive. These systems require software programs to control the parameters. Depending on the program, the exposure measurements can be displayed on the computer screen as the data are being collected. In general, computer-based A/D converter systems are more flexible than are portable data loggers. The computer based system is usually more expensive; A/D boards can cost \$1000 or more and the control software can cost another \$1000.

Portable data loggers store the data in a built-in bank of memory. After data collection, the data logger must be down loaded to the computer, typically through the computer's communication port. A general communications program or a program written specifically for down loading a particular data logger can control the down loading procedure. Most data loggers have parameter setting programs built in and require no additional control software. Most data loggers only display limited amounts of data while recording, since the data logger is likely to be fastened to a worker, observing the data as it is being generated is not feasible. Portable data loggers can be purchased for as little as \$500 including down loading software.

A hybrid of the A/D systems and the portable data loggers is a telemetry system. Telemetry systems use a transmitter and receiver to transfer data from an instrument to a base unit for storage. The base unit may include a personal computer and may allow the data to be displayed as it is being generated. As with the portable data loggers, telemetry systems do not require a worker to be tethered to a computer. Unfortunately, most commercially available telemetry systems are expensive.⁽¹¹⁾ However, NIOSH researchers have developed a telemetry system that should be more cost effective for industrial hygiene applications.⁽¹²⁾

VII. Activity Analysis

Activity analysis is an important step in video exposure monitoring because such an analysis helps catalog work activities (and the elements composing the tasks) of interest. This analysis is a systematic method for breaking a complex job into its elements and subelements so they can be studied for improvements. More importantly, these elements can be sorted so those elements that contribute most to a worker's air contaminant exposure can be dealt with first.

The first phase of activity analysis can be a time and motion study. Analyzing work methods determines the work content of the job. A job is described as a set of tasks, with each task consisting of a series of steps or elements,⁽¹²⁾ that is, the fundamental movements or acts (reaching, grasping, moving, positioning, use, etc.) required to perform a job. Gilbreth suggested that formal element definitions were arbitrary in that one could increase or decrease detail as necessary.⁽¹³⁾ For example, "get" adequately describes the process of "reach-grasp-move," and "put" works well on "move-position-release." By observing the job or by observing slow-motion video recordings of the job, the elements are identified. Activities (also known as tasks) are groups of elements that are usually performed in the same sequence to accomplish a common end. Examples of tasks might include: "turn on machine," "operate machine," and "clean-up." For the purpose of this section, managers, supervisors, and workers can provide job descriptions and demonstrations from which to determine tasks; time-study and production records and timed observations provide the necessary interval data.

The second phase of activity analysis is an actual review of the job for recognized occupational risk factors that may cause excess exposure to air contaminants. If a trained investigator can record the risk factors as the worker is performing the job, this analysis can be done at the work site. A more thorough analysis can be done, however, by viewing the video recording of the worker's activities. The clock or timer in the video camera documents the time it takes the worker to perform the various activities. The clock or timer also coordinates the occurrence of activities with changes in the air contaminant exposure as measured by direct reading instruments. When evaluating air contaminant data, the job analysis need not be done with more detail than the real-time exposure data can reveal. For example, if the response time of the instrument measuring the air contaminant exposure is longer than the time required to complete the individual work activities being video recorded, then those individual activities are of little value and should be combined into a "principal" activity. This principal activity can then be associated with the air contaminant exposure. Examples of how to perform a task analysis in which work activities are matched with worker exposures are described in some of the case studies section of this document.

VIII. Data Analysis

To perform data analysis, worker exposure measurements and descriptions of events in the workplace are combined into a single data set. Descriptive statistics describe the contribution of workplace events to a worker's air contaminant exposure. In addition, statistical analysis evaluates whether workplace events significantly affect exposure. The findings of the data analyses can be used to focus control measures upon actual sources of worker air contaminant exposure.

A. Transportation Lag and Autocorrelation

As a prologue to data analysis, an appreciation is needed of how events in the workplace affect the concentration measured by an instrument. Consider a worker standing at a work station. Turbulence in front of the worker transports the air contaminant from a source at the work station to the worker's breathing zone. If it takes 2 sec for the air contaminants to travel from the source to the worker's breathing zone, the concentration in the worker's breathing zone does not start to change until 2 seconds after the event has occurred. In statistical terms, the concentration is said to lag behind the workplace events. This can be referred to as transportation lag. The actual magnitude of this lag can be estimated by observation and measurement, or it can be addressed in the selection of a statistical model and data analysis package.

After, the air contaminant has been transported to the worker's breathing zone, the direct reading monitor begins to respond to the changing concentration. As discussed in Chapter III, the monitor does not immediately respond to a change in concentration. A monitor with a time constant of 1 sec, would require 3 sec to complete 95% of the change in response to an abrupt change in concentration. Because of the dynamics of the monitor's response, the measured concentration at any moment in time is a function of the concentration in the preceding time intervals. This phenomena is called autocorrelation.

B. Assembling the Data Set

Concentration measurements from a direct reading instrument are recorded and stored by data logging devices. Because the software written for controlling or downloading data logging devices has limited data analysis capabilities, real-time concentration data can be imported into a spreadsheet program for manipulation and data analysis. Many of the downloading or control programs include utilities for storing the real-time concentration measurements in a "print file" that can be imported into the spreadsheet. (A print file is a text file in ASCII format that can be printed directly by the operating system's print command.) The interval between the concentration measurement readings is set either before the data are recorded by the data logging device or when the data are stored in the print file.

The real-time exposure data are loaded into the spreadsheet using the "import" command. (The name of this command may vary from program to program, but the command loads a print file into the spreadsheet.) The print file loaded into the spreadsheet may contain several columns of numbers depending on the type of data logging device used. These columns may include several time columns (elapsed time, clock time, etc.), event markers, and concentration measurements. The data can be manipulated in the spreadsheet to create a data set that includes only two columns, one for the real-time concentration measurement and one for the time the readings were recorded. This time reading can be elapsed time or clock time depending on how the data logging device was synchronized with the video camera's clock or timer.

After the time and concentration readings have been isolated, work activity variables can be added to the spreadsheet. The video recording of the work activities can be viewed while tracking the worker's exposure in the data set. From this recording, the worker's activities can be defined in two different ways: so that only one activity can occur at any given time or so that any one of several activities can occur at any given time. For each concentration measurement, the activity can be coded into the data set in one of several ways, depending on how the activities were defined and the type of data analysis to be conducted. Two methods frequently used are: (1) entering the activity as a single variable with a different value for each activity, or 2) entering each activity as a separate variable, with one value if the activity occurs and another value if it does not occur ("1" and "0" for example). If the activities are defined such that only one activity can occur at a time, the single variable method would usually be more appropriate since it will result in a smaller data set than if each activity were entered as a separate variable. If, however, several activities can occur at a time or if data analysis involves using a spreadsheet program to perform multiple regression, then each activity is usually entered as a separate variable. If the activities were entered using the single variable method in these cases, a different value would be needed for every combination of activities.

As discussed earlier, the air contaminant concentration lags the causal activities because of the time required to transport the air contaminant from the source to the monitor. The magnitude of the transportation lag can be determined either through knowledge of the process (estimating the lag by observing the activities and the exposure data) or through the selection of a statistical model (the lag is incorporated into the model by the data analysis package). If the transportation lag will not be addressed by the statistical analysis package, the air contaminant concentration measurements can be "slipped" with respect to the worker activity variables, after estimating the magnitude of the lag. This matches the worker's activities with the associated air contaminant concentration measurements. At this time, the data set (a time series) is now ready to be analyzed.

C. Data Analysis Techniques

After assembling the data set as a time series, it can be analyzed to determine the effect of workplace activities on the changes in worker air contaminant exposures. Autocorrelation considerably complicates any statistical analysis that is done to model worker exposures and to examine whether the worker's activities are affecting the air contaminant exposures. In general, when conducting statistical analysis, the extent of the changes in exposure attributed to worker's activities are compared with the variability of the exposure data. When the changes in exposure are large in respect to the exposure data variability, the conclusion is that the activities significantly affect the exposure. Autocorrelation can cause the variability of the exposure data to be underestimated during regression analysis and analysis of variance. Thus, autocorrelation can cause these two data analysis techniques to overstate the level of confidence for concluding that the workplace events affect the worker's exposure. Special techniques, called time-series analysis, have been devised to deal with autocorrelated data.

A variety of techniques are available to analyze real-time data and deal with autocorrelation (Table 1), but because of the time and complexity required to deal with autocorrelation, descriptive statistics are commonly used. For a quantitative evaluation of whether activities are causing air contaminant exposures, autocorrelation in the data can be addressed either by censoring the data to remove autocorrelation or by performing time-series analysis. In case study A, time-series analysis is used to remove autocorrelation from the data set without censoring. Case study F illustrates how the data set was censored to remove autocorrelation before conducting statistical analysis. The techniques given in Table 1 are discussed in the following paragraphs.

Table 1. Approaches to analyzing real-time data

Approach	Knowledge of Statistics	Comments
Descriptive statistics; graphing and annotating	Simple	Ignores problem caused by autocorrelation. Summary statistics can present the fraction of the worker's exposure caused by different activities. User must exercise caution in evaluating the data.
Censor data to remove autocorrelation	Regression analysis	In censoring the data some information may be lost. Still, this allows the investigator to use routine regression analysis and analysis of variance techniques that can be done on a spread sheet or by a standard statistical analysis package.
Time-series analysis	Sophisticated	This involves modeling the structure of the experimental noise.

1. Descriptive Statistics

In some cases, worker exposure is plotted as a function of time and the activities contributing to the exposure are noted on the plot. Plotting or tabulating average worker exposure as a function of activity also may be useful. Frequently, plots and tables are prepared to illustrate the fraction of the worker's total time-weighted average exposure or dose (the product of exposure concentration and length of exposure) caused by the various activities. Such results are used to indicate which activities need to be controlled in order to reduce worker air contaminant exposures. If activities appear to be causing more than an order-of-magnitude change in the worker's average exposure, it probably can be concluded that activity affects exposure. Statistical analysis can be used to quantitatively evaluate the uncertainty in making this conclusion.

2. Data Censoring Using a Spreadsheet

Spreadsheet programs can be used to perform multiple regression to determine which workplace events are causing changes in air contaminant concentrations. Multiple regression determines if the dependent variable is a function of the explanatory variables. Typically, the dependent variable (the Y-range in a spreadsheet) is the concentration of the contaminant, but it also may be a function of concentration such as a difference. The explanatory or independent variables (the X-range) are the workplace activities. In regression analysis, the data are fitted to a model of the following form:

$$\text{Exposure Concentration} = (\beta_0 \times 1) + (\beta_1 \times X_1) + (\beta_2 \times X_2) + \dots + (\beta_n \times X_n) + \epsilon \quad (4)$$

where:

- β_0 = constant or intercept of regression line
- $\beta_1 \dots \beta_n$ = coefficients of regression
- $X_1 \dots X_n$ = explanatory or independent variables
- ϵ = the difference between the measured and predicted concentration (also called the residual); it has a mean value of zero and is assumed to be normally distributed

For example, the spreadsheet in Figure 7 illustrates the application of regression analysis to real-time data. This spreadsheet contains an abbreviated listing of exposure data for a worker who uses two different tools (A & B). The measured concentration is the dependent variable "exposure," and the explanatory variable is the qualitative variable "tool." To compute the standard error for the intercept, the spreadsheet's intercept option is set at "zero" and a column of 1's is added, labeled "intercept."

	A	B	C	D	E	F
1						
2	One worker uses two tools (A&B) to perform his job.					
3	Which tool causes the greater exposure?					
4						
5	Measured		Intercept		Predicted	
6	Time	Concentration	Tool	Constant	Concentration	Residual
7		(Y)	(X ₁)			
8	0.0	1.0	0.0	1.0	1.1	-0.1
9	1.0	1.0	0.0	1.0	1.1	-0.1
10	2.0	1.2	0.0	1.0	1.1	0.1
11	3.0	1.3	0.0	1.0	1.1	0.2
12	4.0	1.0	0.0	1.0	1.1	-0.1
13	5.0	4.0	1.0	1.0	3.6	0.4
14	6.0	4.0	1.0	1.0	3.6	0.4
15	7.0	3.0	1.0	1.0	3.6	-0.6
16	8.0	2.0	1.0	1.0	3.6	-1.6
17	9.0	5.0	1.0	1.0	3.6	1.4
18						
19	MODEL	$Y = \beta_1 * X_1 + \beta_0$				
20		Regression Output				
21		Regression Output				
22	Constant	0.0 <--Forced through 0				
23	Std Err of Y Est	0.81				
24	R Squared	0.75				
25	No. of Observations	10				
26	Degrees of Freedom	8				
27						
28			Tool	Intercept		
29	Regression Coefficient(s)		2.5	1.1		
30	Std Err of Coef.		0.51	0.36		
31						
32		$Exposure = 2.5 * TOOL + 1.1$				
33		Exposure when using tool "A" For "A", TOOL=0				
34		$EXPOSURE(A) = 2.5 * 0 + 1.1$				
35		$EXPOSURE(A) = 1.1$				
36		Exposure when using tool "B" For "B", TOOL=1				
37		$EXPOSURE(B) = 2.5 * 1 + 1.1$				
38		$EXPOSURE(B) = 3.6$				
39		Coefficient β_1 :				
40		$\beta_1 = EXPOSURE(B) - EXPOSURE(A)$				
41		$\beta_1 = 2.5$				
42						
43						
44						
45						

Figure 7. An example of regression analysis on a spreadsheet.

In the column labeled tool, a value of 0 is entered when tool A is in use and a value of 1 is entered when tool B is used. The regression function in the spreadsheet was used to fit the data to the model described in line 20 of Figure 7. As a result of the coding scheme (0 for tool A and 1 for tool B) and the form of the model, the regression coefficient β_1 for the variable tool is the difference in exposure between tools A and B. The regression coefficient β_0 is the Y-intercept. The results of the regression analysis are presented in lines 23 to 32. To evaluate whether the variable tool affected the worker's exposure, the 95% confidence limit for the regression coefficient β_1 is computed. If this confidence interval does not contain 0, then the explanatory variable is said to have a significant effect upon exposure. The confidence interval for a regression coefficient is computed by multiplying the coefficient's standard error by the appropriate value of the t-statistic and adding/subtracting the result to the coefficient. To compute the 95% confidence interval for β_1 , a value of 2.3 is obtained from tables of the t-statistic and the 95% confidence interval about β_1 is 2.5 ± 2.3 .⁽¹⁴⁾ Thus, the variable tool is said to significantly affect exposure.

In many cases, real-time data may be autocorrelated. To determine the degree of autocorrelation, the regression equation is used to calculate a predicted value of the dependent variable (e.g., dust exposure). The predicted value minus the observed or measured value yields the residual (ϵ in equation 4). If the real-time data are independent, each residual value should be independent of the others. To test for time dependence, the residuals can be copied to an empty section of the spreadsheet and then recopied to adjoining columns but offset by one, two, and three readings corresponding to delays of 1, 2, and 3 time intervals. In statistical terminology, these copied residuals are called the residuals at lags of 1, 2, and 3. Regression analyses are done to determine whether the residual is a function of the residuals at lags of 1, 2, and 3. If this analysis demonstrates that each residual is dependent only on the residual preceding it, the autocorrelation can be removed from the original data set by eliminating every other data point and then performing a regression (as described above) on the reduced, time independent data set. Similar data censoring can be done if a time dependence exists for readings separated by 2 or 3 time intervals. For 2 time intervals, every third reading is used for the regression, and for 3 time intervals, every fourth reading is used.

3. Time-Series Analysis

At times, too much information is lost when the data are censored to remove autocorrelation. When this occurs, time-series analysis methods can evaluate the relationship between the worker's activities and air contaminant concentrations without censoring the data set.^(15,16) Because time-series analysis can be very complicated, the assistance of a statistician may be needed. This section provides an overview of the complexities that arise when time-series techniques are applied to real-time data.

The objective for time-series analysis in video exposure monitoring is to remove the serial dependence (autocorrelation) among concentration measurements so that the effects of a worker's activity on air contaminant exposures can be evaluated. Time-series analysis frequently involves several iterations of a two-step process:

1. Development of an explanatory model that relates exposure to the worker's activities. This model is of the form of equation (4).
2. Development of a time-series model, using the residuals obtained from step 1, to describe the relationship between sequential exposure measurements.

The time-series model transforms the original data set, eliminating autocorrelation, and regression analysis is then done on the transformed data set. Because the time-series model is developed with the use of residuals from a regression model that may not adequately fit the data, the estimate of the variability of the concentration data may be distorted, and the resulting estimate of the transformation

required to achieve independence may be poor. Therefore, the time-series step can be repeated, the data set transformed with the revised time-series model, and the regression analysis performed again on this new data set. This iterative cycle might be repeated several times until the changes in the models become negligible.

The explanatory model developed during the first step includes explanatory variables that describe worker activities at the time of the exposure measurement. In addition, the model can contain explanatory variables that describe worker activities in one or more earlier intervals. These explanatory variables are said to be lagged, and they are included in the model because a change in exposure, caused by some work activity, may be delayed. (As mentioned earlier, such delays occur because of instrument response, transportation delays, or the nature of the process under study.) Determining how many time intervals to lag is a difficulty that may be resolved either by knowing the process or by developing the explanatory model.

The time and expense for performing the iterative cycle described in the preceding paragraphs may not produce commensurate benefits. A less rigorous and less time-consuming alternative is to include lagged values of the worker's exposure as independent variables in the model and to omit the time-series analysis step completely. This may sufficiently adjust the model for the autocorrelation that can occur in the exposure data. After obtaining a model that fits the data, the results may be used cautiously to obtain insight about those variables that affect a worker's exposure to air contaminants.

D. Summary of Data Analysis

Descriptive statistics can be used to conduct exploratory data analysis. In such an analysis, the identity of workplace activities causing differences in the worker's exposure is investigated. If there are no differences or if the differences are greater than an order of magnitude, conclusions can usually be based on the findings of the descriptive statistics. However, when the observed differences in concentration are less than an order of magnitude, statistical analysis should be performed. In conducting statistical analysis, the effect of autocorrelation on the analysis must be evaluated. If too much data are lost by censoring, time-series analysis may be required.

Real-time data are frequently analyzed to evaluate whether specific workplace activities affect worker exposures. When a workplace activity occurs and the worker's exposure increases, the activity is concluded to have contributed to the exposure. Because many activities can occur simultaneously in the industrial environment, some unrecognized activity may possibly cause the change in the worker's exposure. Thus, judgment must be exercised when interpreting the results of the data analysis. After analyzing the real-time data, control measures can be focussed on actual exposure sources.

IX. Dilution Ventilation and Material Balances

By applying a simple material balance to real-time exposure data, the generation rate of a vapor or gas can be estimated and the room mixing factor can be determined. By using these data, a dilution ventilation system can be sized to reduce the contaminant to a level below a given occupational exposure limit or a need can be demonstrated for better control at the point of contaminant generation. The concentration of a contaminant at any time can be expressed as a differential material balance. When integrated over a sampling period, this material balance will provide a rational basis for relating ventilation rate to the generation and removal of a contaminant in a room.⁽¹⁷⁾

$$\text{ACCUMULATION RATE} = \text{GENERATION RATE} - \text{REMOVAL RATE}$$

$$V \frac{dC}{dt} = G - \frac{QC}{K} \tag{5}$$

where:

- V = volume of room or enclosure (m³)
- C = concentration of contaminant at time t (mg/m³)
- G = rate of generation of contaminant (mg/hr)
- t = time (hr)
- Q = rate of ventilation (m³/hr)
- K = design distribution constant or mixing factor

Assuming that the volume of the room (V), the rate of generation of the gas or vapor (G), the rate of ventilation of the room (Q), and the mixing factor (K) are constant during the period of interest, equation (5) can be rearranged and integrated as follows:

$$\int_{C_1}^{C_2} \frac{dC}{G - \frac{QC}{K}} = \frac{1}{V} \int_{t_1}^{t_2} dt \tag{6}$$

where:

- C₁ = concentration at time t₁
- C₂ = concentration at time t₂

Solving this definite integral yields the following:

$$\ln \left[\frac{G - \frac{QC_2}{K}}{G - \frac{QC_1}{K}} \right] = \frac{-Q}{KV} (t_2 - t_1) \tag{7}$$

Equation (7) is transformed by taking the exponential of each side of the material balance.

$$\frac{G - \frac{QC_2}{K}}{G - \frac{QC_1}{K}} = e^{\left(\frac{-Q}{KV}(t_2 - t_1)\right)} \quad (8)$$

Solving equation (8) for c_2 yields the following generalized equation:

$$C_2 = \frac{KG}{Q} \left[1 - e^{\left(\frac{-Q}{KV}(t_2 - t_1)\right)} \right] + C_1 e^{\left(\frac{-Q}{KV}(t_2 - t_1)\right)} \quad (9)$$

Air changes per hour (Q/V) is the ratio of the ventilation flow rate of the room (Q) to the volume of the room (V). The exponential term in equation (9) contains not only Q/V but also the exponential of the inverse of the mixing factor (K). This mixing factor adjusts for incomplete mixing of the ventilation air in the room. Over the years, the term "air changes per hour" has been employed incorrectly more often than correctly.⁽¹⁸⁾ Inspection of equation (9) reveals that Q/V has no effect on the equilibrium (when $(t_2 - t_1) \gg Q/KV$ or when $Q/KV \gg 1$) concentration but affects only the rate at which that concentration is reached. When applied to meeting rooms, offices, and similar spaces where the purpose of ventilation is simply the control of odor, temperature, or humidity, and the only contamination of the air is from the activity of people, the use of air changes per hour (Q/V) may be appropriate.⁽¹⁷⁾ For contaminant control, however, there is no sound basis for designing dilution ventilation based on the number of air changes per hour. Like the ratio Q/V, K affects the rate at which an equilibrium concentration is reached. Unlike Q/V, K also appears in equation (9) as a multiplier, affecting the equilibrium concentration. Dilution ventilation requirements should be expressed as some absolute unit of air flow (e.g., m³/hr).

Where no gas or vapor is generated (i.e., $G = 0$), equation (9) reduces to an exponential decay of the initial concentration. The mixing factor (K) can be estimated by solving the following equation for K:

$$C_2 = C_1 e^{\left[\frac{-Q}{KV}(t_2 - t_1)\right]} \quad (10)$$

K is specific to the room, the location within the room, and other environmental conditions at the time of sampling.⁽¹⁷⁾ If some contaminant remains in the room and none is being generated, the decay of the contaminant in the room would be similar to that shown in Figure 8. The K factor can be estimated by performing a least squares fit of the data to equation (10). Figure 9 shows the effect of varying K. If K doubles, the effective ventilation rate is decreased by a factor of two, and the decay of the contaminant is much slower. If K is halved, indicating "better" exhaust locations, the effective ventilation rate is doubled, and the decay is much faster. ACGIH illustrates examples of mixing factors for several inlet and exhaust locations (Figure 2-1, page 2-4).⁽¹⁸⁾

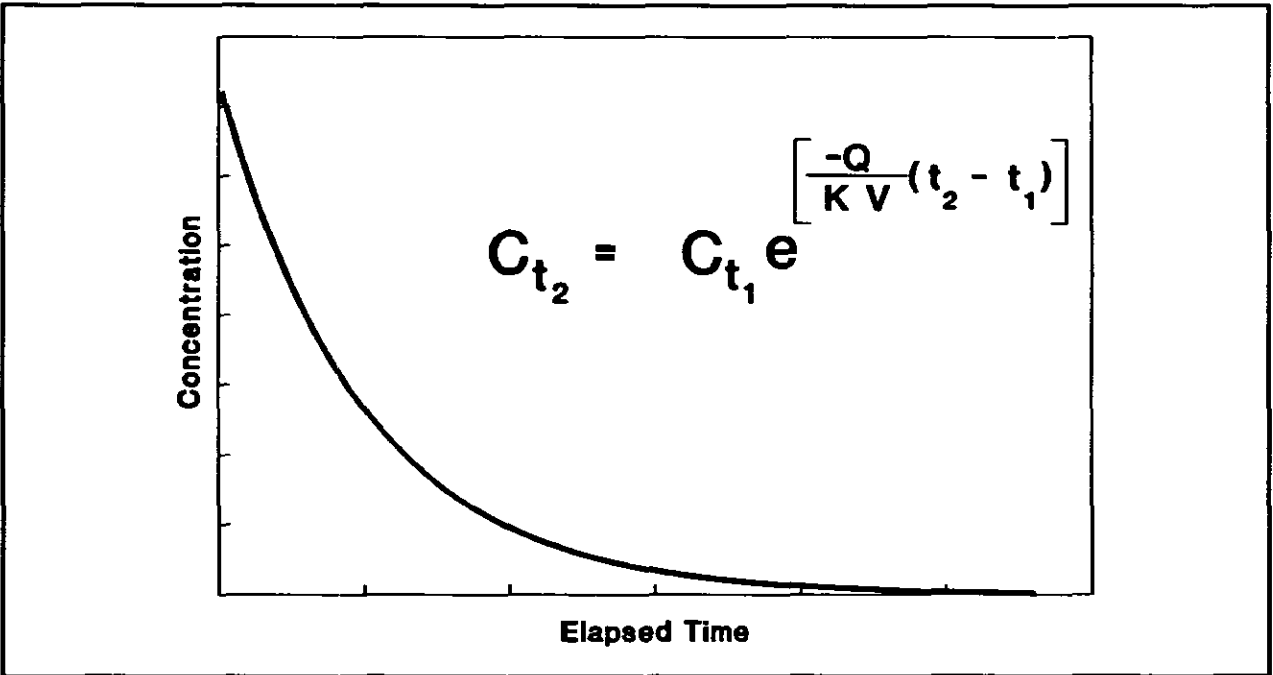


Figure 8. Room concentration decay curve.

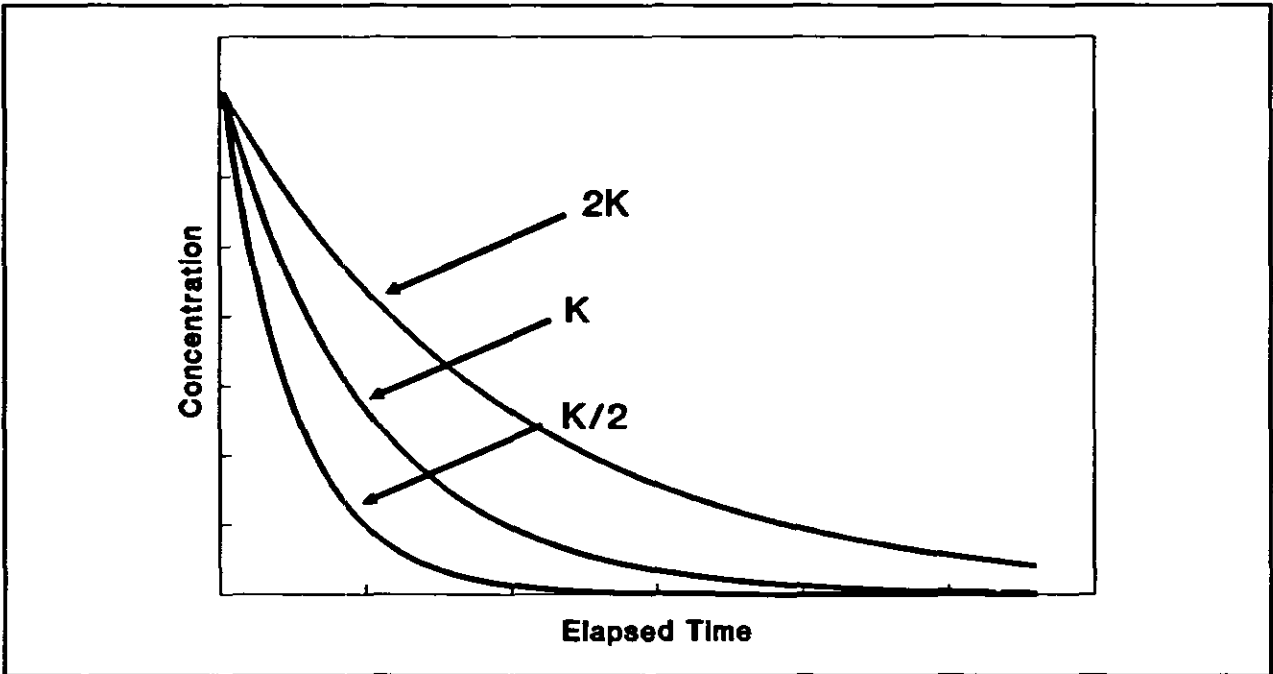


Figure 9. Effects of mixing factor on room concentration decay curve.

Another use for a material balance is to illustrate the buildup of contaminant and to estimate the equilibrium air contaminant concentration maintained by dilution ventilation. With the same assumptions used to develop equation (6), at equilibrium, equation (9) reduces to the following:

$$C_{t_2} = \frac{K G}{Q} \quad (11)$$

If there were no changes in the generation or exhaust rates of the contaminants in the air, the concentration in the room would increase to a level equal to C_{t_2} , as is shown in Figure 10. As Figure 11 shows, doubling K reduces the effective ventilation rate by 50%. The contaminant buildup within the room will initially be faster and the equilibrium concentration will be double; it will take much longer to reach the equilibrium concentration. The opposite is true if K is halved. The contaminant buildup within the room will initially be slower, the equilibrium concentration will be halved, and the equilibrium concentration will be reached in less time.

The buildup and decay of the contaminant in the room air as well as the location of the worker in relation to the source of the contaminant affect the concentration of contaminant in the breathing zone of the worker and, thus, the real-time exposure data. In two recent studies, NIOSH researchers applied this material balance approach to real-time exposure data to estimate the generation rate of the contaminant as well as the effect of the room ventilation. Details of these studies are given in Case Studies D and E.

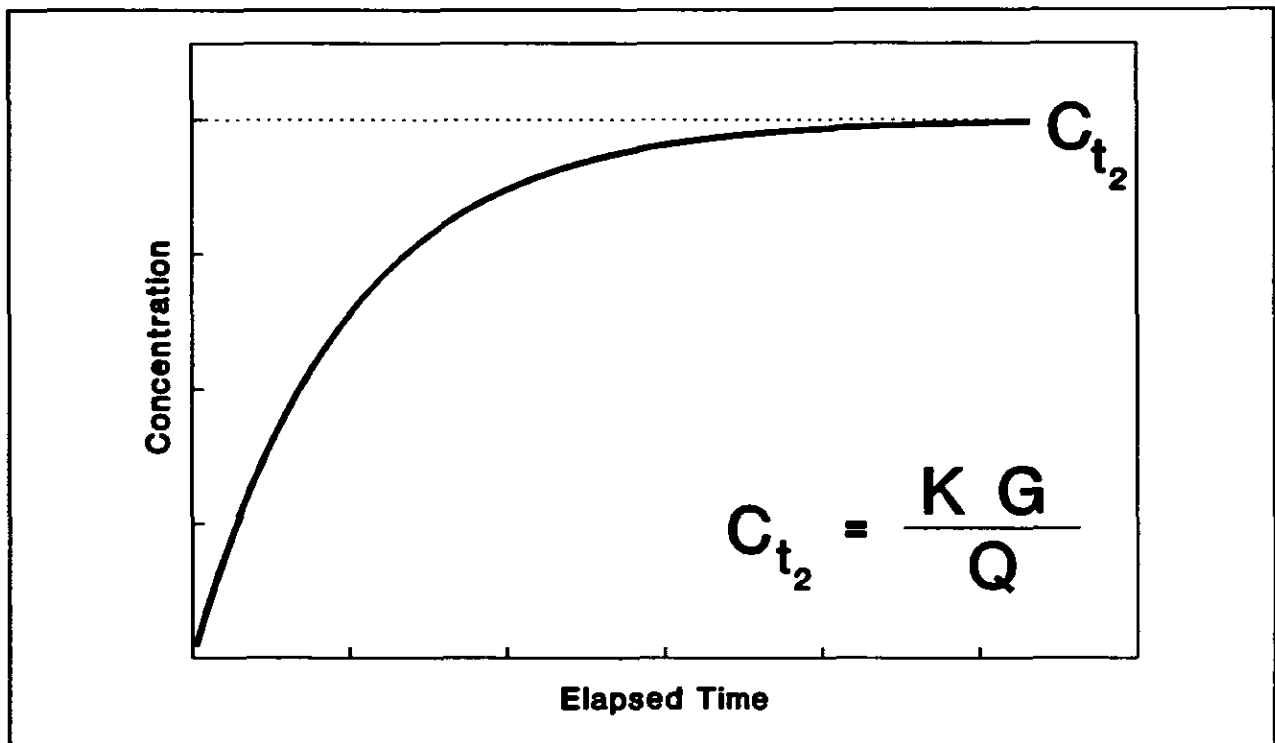


Figure 10. Room concentration buildup curve.

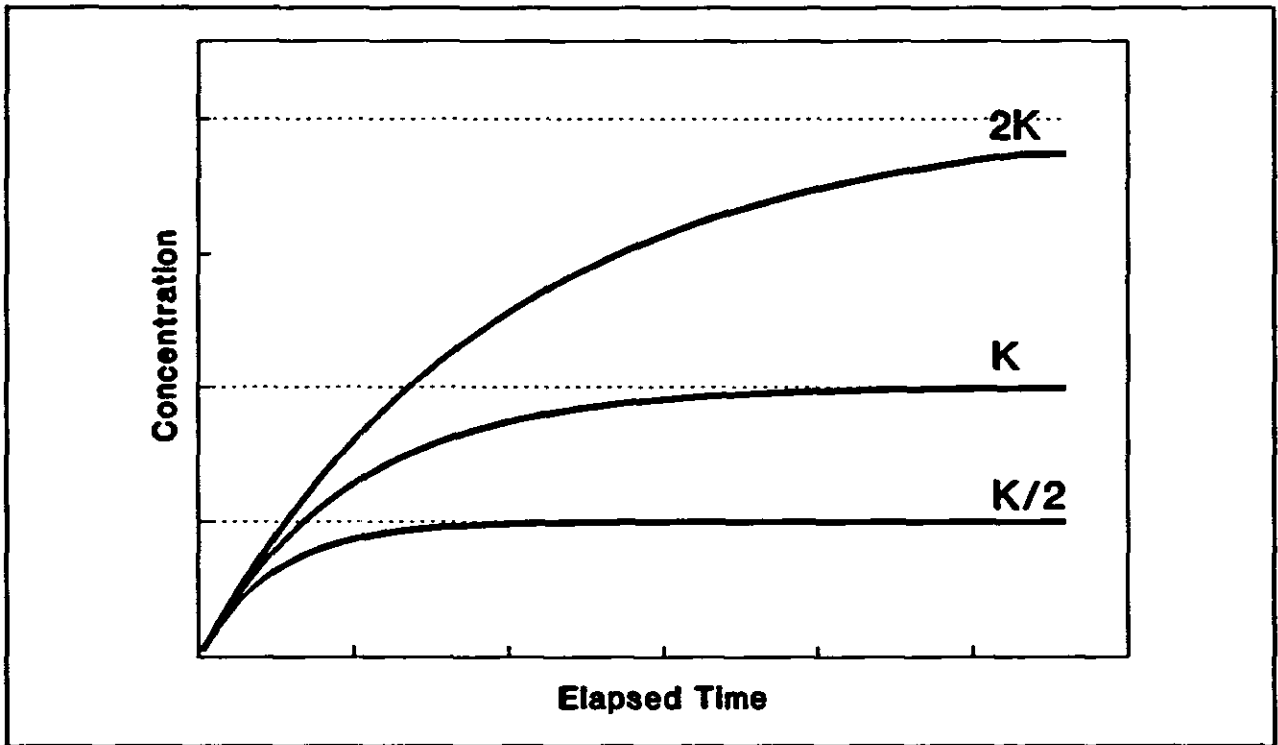


Figure 11. Effects of mixing factor on room concentration buildup curve.

X. Practical Application of Video Exposure Monitoring

All the ideas presented in the other sections are gathered here to show how video exposure monitoring can be conducted. Video exposure monitoring is effective for identifying those specific activities that most contribute to a worker's exposure to an air contaminant. Some integrated monitoring, such as sorbet tube or filter sampling, is normally conducted to determine the extent of the worker's exposure (averaged over the sampling period) before conducting video exposure monitoring. After determining the extent of the exposures, the techniques for video exposure monitoring can be applied as outlined in this document. A typical video exposure monitoring evaluation might proceed in the following manner.

1. With the process of interest and contaminant of concern identified, the appropriate direct reading monitor must be chosen (Section III). The monitor should be appropriate for the contaminant, e.g., an aerosol photometer to monitor for aerosols. The monitor should have a minimal time constant so that activities of short duration can be evaluated and should be as portable as possible. The monitor should be zeroed and calibrated according to the manufacturer's instructions.
2. In addition to the direct reading monitor, an IR video system (Section II, Part B) may prove useful, depending upon the contaminant being sampled. Such a video system, if applicable, can visualize air contaminant plumes, identify contaminant sources, and identify work practices that may contribute to a worker's exposures.
3. The output of the direct reading instrument should be recorded by a data acquisition system (Section VI). Setup of this system consists either of programming the data logger or of running the control software of the analog to digital converter system. The clock on the video camera (Section II, Part A) and the data recording device should also be synchronized at this point.
4. Data collection begins by starting the data recording device and the video camera. Data collection continues for a period judged to be representative of the process being studied. After the data collection period, the data must be stored in a data file. If a data logger was used, it must be down loaded to a computer for storage to a file.
5. After data collection and filing, the data are imported into a spreadsheet program. Work activity analysis (Section VII) is conducted, with the use of the video recording of the work activities. The activity variables are entered into the spreadsheet to accompany the air contaminant exposure data (Section VIII, Part A). Data analysis (Section VIII, Part B) can be conducted with the spreadsheet or by statistical analysis programs. The spreadsheet analyses can consist of simple descriptive statistics or of regression analysis. The statistical analysis programs are used for more sophisticated analyses, such as time-series analysis.
6. If the exposure data are to be overlaid onto the video recording of the work activities, the video overlay system (Section V) must be assembled and the exposure data stored in a specifically formatted ASCII file for use by the bar generating program (Section IV). To overlay the exposure data onto the video recording of the work activities, the bar generating program is set up (inputs entered); the work activity videotape then is played back. When the time on the video image reaches the time of the initial reading from the data file, the program's display is started. This

synchronizes the exposure data with the video recording. The overlaid signal can be displayed on a video monitor and recorded on a second video recorder.

7. In some situations, the real-time concentration data can be used to evaluate dilution ventilation systems and determine the contaminant generation rate for the process (Section IX). In these instances, the spreadsheet's regression function or a statistical analysis program can be used to determine the room's mixing factor. With this factor, the generation rate for the process can be estimated, and the dilution ventilation system can be further evaluated.

Video exposure monitoring is a set of flexible techniques that can be used to determine the specific sources of a worker's exposure to air contaminants. All the steps outlined above need not be used to evaluate worker's exposure. It may be possible to determine the source of a worker's exposure by simply performing summary statistics on the real-time exposure data set, without overlaying the exposure data onto the video recording of the work activities. Conversely, the overlay of the exposure data on the recording of the work activities may be the only product desired. Regardless of how many of the techniques are applied, users should find video exposure monitoring to be a valuable tool for identifying and reducing a worker's air contaminant exposure.

XI. References

1. Gressel, M.G.; Heitbrink, W.A.; McGlothlin, J.D.; and Fischbach, T.J.: Advantages of Real-Time Data Acquisition for Exposure Assessment. *Applied Industrial Hygiene* 3(11):316-320 (1988).
2. Gressel, M.G.; Deye, G.J.; Heitbrink, W.A.; and McGlothlin, J.D.: Graphical Exposure Demonstration: Computers and Video Link Together. Presented at the American Industrial Hygiene Conference, St. Louis, MO, May 21-26 1989.
3. Operating Manual, Thermovision®782. AGA Infrared Systems AB. Secaucus, NJ (1984).
4. Coughanowr, D.; and Koppel, L.: *Process Systems Analysis and Control*. McGraw-Hill, New York (1966).
5. American Conference of Governmental Industrial Hygienist: *Air Sampling Instruments for Evaluation of Atmospheric Conditions*, 7th ed. ACGIH, Cincinnati, OH (1990)
6. Eller, P. (Ed.): *NIOSH Manual of Analytical Methods (NMAM)*, 3rd Ed. USDHHS (NIOSH) Pub. No. 84-100, (1984); 85-117 (1985); 87-117 (1987); 89-127 (1989); and 90-121 (1990). NIOSH, Cincinnati, OH
7. Marple, V.; and Liu, B.: *Aerosols in the Mining and Industrial Work Environments, Volume 3, Instrumentation*. Ann Arbor Science, Ann Arbor, MI (1983).
8. Marple, V.; and Rubow, K.: *Respirable Dust Measurements*, Report for U.S. Bureau of Mines, Contract No. J0113042. NTIS No. PB-85-245843. National Technical Information Service, Springfield VA (1984).
9. Operating Manual, MicroTIP HL-200. Photovac, Inc. Thornhill, Ontario, Canada (1990).
10. Skoog, D.; and West, D.: *Principles of Instrument Analysis*. Holt, Rinehart and Winston, New York (1971).
11. Price Catalog #110190D. Robotic Guard Systems Inc. Denton TX (1991).
12. Barnes, R.M.: *Motion and Time Study, Design and Measurement of Work*, 7th ed. John Wiley and Sons, New York (1980).
13. Gilbreth, F.B.: *Motion Study*. Van Nostand, Princeton, NJ (1911).
14. Draper, N.R.; and Smith, H.: *Applied Regression Analysis*. Wiley, New York (1981).
15. Box, G.; and Jenkins, G.: *Time Series Analysis: Forecasting and Control*. Holding-Day, San Francisco (1981).
16. Berenson, M.; Levine, D.; and Goldstein, M.: *Intermediate Statistical Methods and Applications*. Prentice-Hall, Englewood Cliffs, NJ (1983).

17. **National Institute for Occupational Safety and Health: The Industrial Environment - Its Evaluation and Control. NIOSH, Cincinnati, OH (1973).**
18. **American Conference of Governmental Industrial Hygienist: Industrial Ventilation: A Manual of Recommended Practice, 20th ed. ACGIH, Cincinnati, OH (1988).**