Video Exposure Monitoring—A Means of Studying Sources of Occupational Air Contaminant Exposure, Part I—Video Exposure Monitoring Techniques

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Conventional sampling with pumps and sampling media can be used to determine whether exposures to air contaminants are excessive. Unfortunately, such results provide few insights into the reasons for the excessive exposures. However, Video Exposure Monitoring can be used to identify the sources causing these excessive exposures. Any movable instrument that has an analog or digital output can potentially be used for Video Exposure Monitoring. The instrument should be light enough to mount on a worker, be specific for the chemical interest, and have a short time constant. Although most existing direct-reading instruments do not simultaneously meet all these requirements, currently available instruments, such as aerosol photometers, photoionization detectors, and portable infrared analyzers have been used effectively. The analog or digital output from direct-reading instruments can be recorded by data-logging devices. The data-logging devices transfer the exposure data to a personal computer for storage and statistical analysis. In addition to statistical analysis of the data, the personal computer, outfitted with a video overlay system, can also be used to overlay the exposure data onto a video recording of worker activities. The worker's exposure is displayed as a moving bar proportional in height to the air contaminant concentration. The work activity video image with the overlaid exposure data can be recorded on a second video tape. By replaying the overlaid video recording, this technique shows how worker exposures are related to work activities, permitting industrial hygienists to make recommendations for control measures focusing on actual exposure sources. Furthermore, these video recordings can be used to train workers to avoid work practices that cause elevated air contaminant exposures. Gressel, M.G.; Heitbrink, W.A.; Jensen, P.A.: Video Exposure Monitoring—A Means of Studying Sources of Occupational Air Contaminant Exposure, Part 1—Video Exposure Monitoring Techniques. Appl. Occup. Environ. Hyg. 8(4):334–338; 1993.

Introduction

Occupational exposure to air contaminants is usually monitored by drawing a known volume of air through a filter or other collection medium for a given period of time. The collection media then are analyzed to determine the quantity of contaminant collected and the average exposure during the sampling period is computed. Although these results indicate the extent of exposure, they provide little insight into the specific causes of the exposure. Because recommendations for air contaminant control are often based upon an observer's judgment, control measures may not adequately address the major exposure sources. To overcome this problem the Video Exposure Monitoring technique was developed to characterize workplace exposures as a function of time. During Video Exposure Monitoring, the direct-reading instrument output is stored by a recording device, while a video recording system documents worker activities. The resulting data can be used to study the association between workplace events and air contaminant levels, allowing for more effective control recommendations.

Video Exposure Monitoring evolved from several studies conducted either to evaluate the effectiveness of engineering controls or to characterize the worker's exposure so that controls could be developed.[1,2] As these studies were completed, a convincing means for communicating the results of the studies to workers and employers became obvious. A method for displaying the real-time exposure measurements on the video recording of the work activities was devised. A computer program was written to generate a moving bar that was a graphical representation of the worker's exposure. This graphical representation was combined with the video recording of the work activities by running the bar-generating program on a computer with a video overlay system. The resulting video recording graph-

ically showed how the worker's exposure was affected by workplace activities.

This article describes the various aspects of the Video Exposure Monitoring technique. This discussion includes the selection, setup, and operation of the necessary equipment. Details concerning the analysis techniques for evaluating real-time exposure data are discussed in Part II.

Data Collection

Any air monitoring instrument with provisions for producing an output signal of the concentration measurements can potentially be used for Video Exposure Monitoring. The utility of an instrument depends upon its output signal, response time, specificity for the contaminant of interest, and size and portability.

In Video Exposure Monitoring, the output of the instrument lags behind the workplace events. This delay is due to the total response time of the monitoring system, defined as the sum of the time required to transport the air contaminant to the inlet of the monitor (usually in the worker's breathing zone) and the time required for the instrument to respond to the changing concentration. For Video Exposure Monitoring studies, the total response time should be shorter than the events of interest.

A time constant describes the instrument response to concentration changes. When an instrument's response is described by a time constant, the instrument responds to concentration changes in the same way that the concentration in a stirred mixing tank responds to concentration changes in the incoming stream.[3] 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 (tank volume divided by flow rate). The mixing tank concentration is the average concentration of each fluid increment flowing through the tank. Because some of these fluid increments flow through the tank quickly while others remain for some time, the average tank concentration does not immediately respond to inlet concentration changes.

Figure 1A 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 tank concentration to complete 90 percent of its response. Figure 1B illustrates the effect of a concentration pulse upon the concentration in the mixing tank. The measured mixing tank concentration shows a distorted picture of the inlet concentration. 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 flush the concentration pulse completely out of the tank.

Air monitoring instruments respond to changing concentrations in a manner similar to that of the stirred tank. Inlet concentration changes occurring faster than the instrument's response result in a measured profile that is a distorted picture of the actual concentration. The distortion is the same as for the stirred tank. To limit the distortion, the instrument's time constant should be shorter than
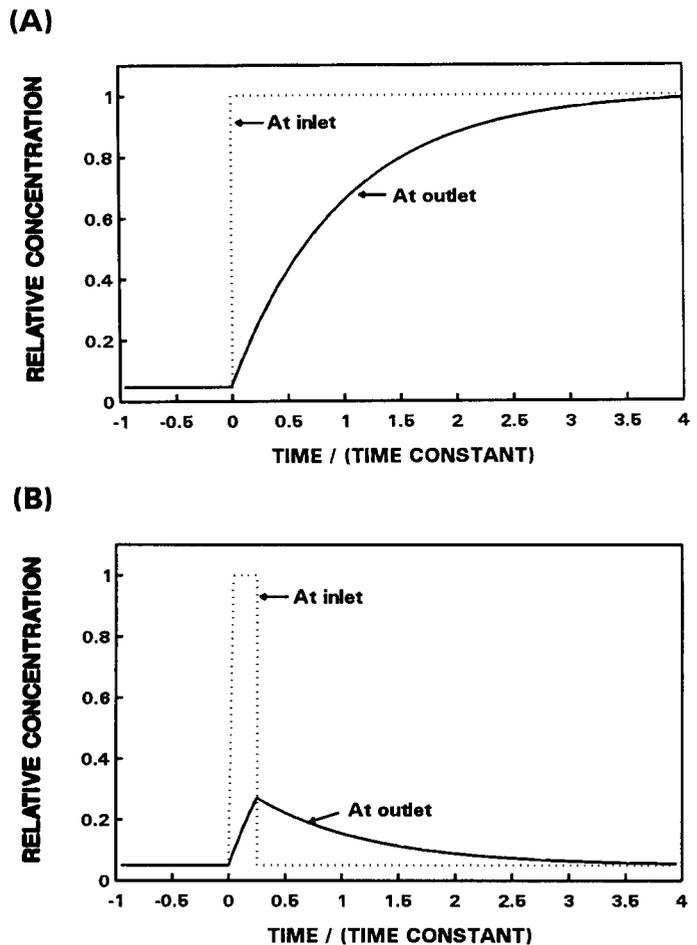
(A)

(B)

FIGURE 1. Ideal mixing tank concentration response to inlet concentration changes: (A) inlet concentration step change from 0.05 to 1.0, (B) inlet concentration pulse equivalent to 25 percent of the tank's time constant.

the events studied. For example, the time constant for some aerosol photometers can be set to 1 sec.

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 a parameter that is proportional to concentration. For example, aerosol photometers respond to any aerosol that scatters light.[4] This limitation of the existing equipment requires that the monitor be calibrated for the specific air contaminant or that the results be reported as a relative concentration.

The monitoring equipment used for Video Exposure Monitoring should be battery operated and light enough to be worn by the worker. If the worker cannot wear the equipment, then tubing can be used to transport the air contaminant from the worker's breathing zone to the monitor. This adds complications because the total response time will increase as a result of the transportation of the contaminant through the tube to the monitor. The tubing also can absorb and later release the air contaminants.

The limitations and capabilities of the direct-reading instruments should be considered in the design and conduct

of Video Exposure Monitoring studies. The National Institute for Occupational Safety and Health (NIOSH) *Manual of Analytical Methods* (NMAM)[4] and *Air Sampling Instruments*, published by the American Conference of Governmental Industrial Hygienists[5] contain information on a variety of direct-reading monitors.

Because real-time concentration data are generally used to evaluate the relationship between workplace events and air contaminant exposures, the concentration measurements generally should be recorded automatically. Many industrial hygiene instruments provide an output voltage proportional to concentration. This signal is usually on the order of 1–10 VDC, full scale. Prior to the proliferation of the personal computer, the output signal typically was output to a strip chart recorder. With advances in personal computers, the analog output from the monitors can be stored digitally, allowing the data to be easily transferred to the computer. Many instruments now include built-in data-logging capabilities. However, with many of these monitors, the storage capacity and recording rate are not adequate for use in Video Exposure Monitoring.

Data-recording devices generally fall into two categories: portable data loggers and computer-based analog-to-digital (A/D) converter systems. Depending on the type, the device will have either a fixed input voltage range or a variable range set by hardware switches or software. This working range then is divided into intervals. Resolution of a data-recording device is usually given in bits. For example, an 8-bit data logger will break the working range into 256 intervals (2^8). A 12-bit data logger will break the range into 4096 intervals (2^{12}). For a data logger to detect a difference between two readings from a monitor, the readings must lie in different intervals. For an 8-bit data logger with a 0–2 VDC working range, the difference between two readings must be at least 0.008 VDC (working range divided by number of intervals). Data loggers are typically 8-bit devices while A/D converters range from 8 bits to 16 bits.

A/D converter systems store the data directly into the computer's memory or onto a disk drive. These systems require software for control and configuration. Depending on the nature of this software, the exposure measurements can be displayed on the computer screen as the data are being collected. Because of the capabilities of control software, computer-based A/D converter systems are more flexible than portable data loggers.

Portable data loggers store data in a built-in bank of memory. After data collection, the data logger is downloaded to the computer, typically through the computer's communication port. A communications program or special downloading program is used for this procedure. Most data loggers have configuration programs built in, requiring no additional control software. Data loggers display only limited amounts of data while recording. However, because the data logger is likely to be fastened to a worker, observing the data as they are generated is not feasible.

The video recording system, consisting of a camcorder or a video camera and recorder, documents the activities of the worker being monitored by the direct-reading instrument. Many consumer-quality video systems are suitable for Video Exposure Monitoring. There are, however, two important requirements. First, the system must have a National Television System Committee (NTSC) standard output signal (typical for most home video systems). This signal is used by the video overlay system described later in this article. Second, the camera should have an on-screen clock or timer with a resolution of at least 1 sec. The clock or timer is synchronized with the data-recording device's clock. The video recording of the work activities then can be reviewed while simultaneously tracking the worker's exposure from a printout or plot of the real-time exposure data.

Assembling the Data

Several types of software can collect and analyze real-time exposure data. Special programs operate A/D converter cards, while other packages download portable data loggers. Spreadsheets are valuable for manipulating the raw exposure data and performing some simple analyses. In addition, if the exposure data are to be combined with the work activity video recording, a special computer program generates a graphical representation of the worker's exposure.

Control software is used to operate A/D converters. These software packages usually require device drivers (programs accessing hardware or software) for the specific hardware used. Many packages can process the data as they are being collected; others provide limited data-analysis capabilities. Control software may display readings on the computer screen in either graphical or tabular form as the data are collected. Some programs will link directly with a spreadsheet program, allowing the data to be saved in a spreadsheet file. Other programs store the data in file formats that can be imported into a spreadsheet.

When portable data loggers record the real-time exposure data, special software is used to download the data logger to a personal computer. Most data loggers either come complete with downloading software, or have one available at additional cost. Some downloading software may have simple data-analysis capabilities and may store the data in a file that can be imported into a spreadsheet program.

Producing the Overlay Video Recording

To combine the real-time exposure data with the video recording of the worker's activities, NIOSH researchers have written a program that generates a graphical representation of the worker's exposure. This IBM-compatible program reads a real-time data file, then generates and displays a bar to represent the magnitude of the exposure. When the program runs through a video overlay system, a video recording is produced, graphically showing how a worker's exposure is influenced by the work activities. To run the program, the real-time exposure data must be stored in a properly formatted American Standard Code for

Information Exchange (ASCII) file. There should be separate columns for the time the reading was recorded (minutes and seconds) and the exposure measurements; the interval between the readings must be constant. The data can be adjusted for the instrument lag before overlaying by shifting the exposure data with respect to the time readings (this is discussed further in Part II). A spreadsheet program makes this formatting convenient. The spreadsheet can then export the data to an ASCII file.

The basic computer system used by NIOSH researchers to conduct Video Exposure Monitoring is an IBM AT-compatible personal computer with at least 640 kilobytes (KB) random access memory (RAM) and a hard disk drive. Additional memory may be needed if large data sets are managed in the spreadsheet. If data loggers are downloaded to the computer, an asynchronous (serial) communications port is required. An A/D converter can also be placed into an expansion slot of the computer.

To overlay the real-time exposure data with the video recording of the work activity, the personal computer should have a video overlay system installed. One video overlay system used in conjunction with an Enhanced Graphics Adapter (EGA) card is the Video Charley® (Progressive Image Technology, Folsom, California). Video Charley is a card that interfaces with the EGA card through the Features Connector, standard on most EGA cards. The video overlay board converts the computer's graphics signal to an NTSC signal and overlays it onto the activity video recording. Most EGA cards have two RCA-type connectors. With the Video Charley board installed, one RCA connector becomes the input for the activity video signal, while the other is used to output the computer graphics overlaid video signal. Because of signal differences, the EGA system must operate at a screen resolution of 640 × 200, instead of the typical EGA resolution of 640 × 350, when using the Video Charley.

Several Variable Graphics Array (VGA) cards have built-in overlay options. Two cards include the USVideo VGA/NTSC Recordable® graphics card with the Genlock Overlay Module (USVideo, Stamford, Connecticut) and the Willow Peripherals VGA-TV GE/O® (Willow Peripherals, Bronx,

New York). These systems allow computer graphics to be overlaid onto video images at higher resolutions than the EGA/Video Charley system. Both VGA cards have two RCA ports, one for video in and one for video out. The cabling setup, shown in Figure 2, is the same for both the EGA/Video Charley and the VGA systems. The VGA overlay system operation is similar to normal computer use, except that the video display (connected to the video out port) is the primary display.

To synchronize the exposure data (the moving bar) with the video recording of the work activity, the bar generating program is first set up. The program reads and displays the time of the first reading in the data set. Next, the video recording of the work activity is started. When the time on the video's clock reaches the time of the first reading in the data set, the bar generating program is started. With practice, this will synchronize the exposure data and the video recording of the work activity to within less than a second, sufficient for most applications.

Conclusions and Recommendations

Video Exposure Monitoring can be a highly effective technique for identifying the sources of worker exposure. In the studies using this technique, information on the exposure sources has allowed engineering controls to be implemented, addressing the primary sources of the worker's exposure. While this technique has proven to be extremely valuable, there can be some improvements, primarily in the available air monitoring equipment. The response of many monitors is too slow to be adequate for Video Exposure Monitoring. Other monitors, while fast enough for use in this technique, would also benefit from an increase in their response. The monitors also need to be smaller and more portable. Many of the currently available monitors are too heavy for workers to wear for any extended period. While many manufacturers are incorporating data-logging capabilities into their monitors, they need to be more flexible in the way they record and report the data. The monitors should be capable of storing readings in at least 1-second
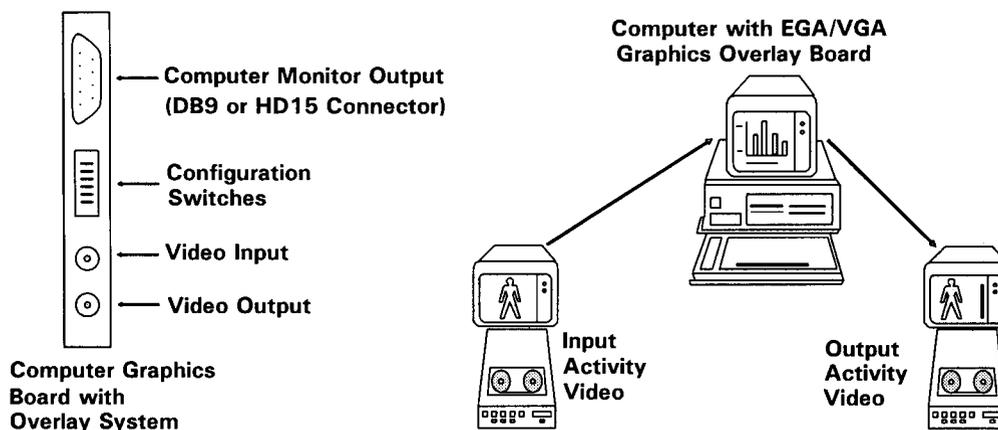

FIGURE 2. Diagram of the system's equipment and connections.

intervals and should be able to transfer the data to a spreadsheet program.

Currently, NIOSH researchers are investigating the possibility of expanding the use of the Video Exposure Monitoring technique to other types of exposures. Previous studies have concentrated primarily on exposures to aerosols and vapors. This new work will explore the potential of monitoring for exposures such as noise and vibration.

Finally, future work should be considered for evaluating the utility of the video recording for training purposes. These recordings appear to have high potential as a training tool. However, up to now, this potential has never been fully evaluated.

The Video Exposure Monitoring technique has been shown to be a valuable tool for determining sources of worker exposure to air contaminants. Determining these exposure sources can be critical to developing effective engineering controls for reducing occupational exposures. By improving components and expanding the types of exposures monitored, industrial hygienists can use this technique to more fully characterize workplace exposures, a necessary step in ensuring a safer work environment.

The bar generating program can be obtained by contacting the authors.

Disclaimer

Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

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