

**REAL-TIME PERSONAL MONITORING IN THE WORKPLACE
USING RADIO TELEMETRY**

Ronald J. Kovein

National Institute for Occupational
Safety and Health

Paul A. Hentz

National Institute for Occupational
Safety and Health

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Abstract

A system used to radio transmit data from remote locations within a workplace to a personal computer for immediate interpretation has been developed by NIOSH researchers. The system consists of several radio transmitters and a base receiver that is capable of multi-channel reception. Exposure data obtained from any direct-reading instrument with a recorder output signal can be displayed and stored at the computer. The worker being monitored carries the instrument in a backpack, along with a radio transmitter. Using telemetry, the concentration of the airborne contaminant under study can then be plotted on a video monitor for immediate assessment. If there is more than one worker under study at a time, multiple exposure curves can be displayed on the screen.

The base receiver is a commercial (frequency) scanner that has been modified to accept RS-232 serial communication. The manual keypad has been removed so that channel selection is accomplished through system software. The radio transmitter is similar to a wireless telephone; there are no wires to entangle. The radio telemetry system

allows a worker unrestricted movement within its effective range. It also can be used to monitor up to five individual workers per program execution.

A case study involving a furniture refinisher's exposure to methylene chloride is described here to demonstrate the utility of radio telemetry. The worker carried a radio transmitter that was attached to a photoionization air analyzer. Qualitative methylene chloride exposures were remotely monitored on a video monitor throughout the day. Increases in exposure levels, due to job tasks, work practices, and emission sources were immediately identified so that corrective action could be taken at that time.

It is important for researchers who are developing real-time monitoring techniques to consider the procedures discussed in this report. Also, researchers conducting field studies should be cognizant of the variety of real-time monitoring techniques and use them to their advantage in evaluating worker exposure.

Introduction

In recent years, researchers at the National Institute for Occupational Safety and Health (NIOSH) have used microcomputers, data loggers or coaxial cables, and video-taping techniques during hazard control studies to help acquire real-time exposure data.^(1,2,3) The data source was a portable direct-reading instrument that measures a worker's exposure to a hazardous vapor, gas or dust. Such instruments measure the concentration of airborne pollutants through detection by flame ionization, photoionization, electrochemical reactions, infrared and ultraviolet radiation, and chemiluminescence.⁽⁴⁾ Most of these devices provide a continuous analog signal through an output connector that is proportional to the concentration detected. The signal can be routed to a strip chart recorder for a continuous record of exposure levels, or it can be routed to an electro-mechanical device (e.g., a solenoid valve) for process control. Or, the analog signal can be converted into an audio signal and transmitted over a radio channel to a distant receiver for immediate processing by a microcomputer.

The radio telemetry system, discussed herein, was developed to improve this real-time exposure monitoring by allowing: (1) the acquisition and analysis of exposure data at locations remote from non-stationary sources and (2) immediate access to exposure information that is not possible with data loggers. The radio telemetry system overcomes the distinct disadvantage of delay by continuously supplying data to a personal computer throughout a monitoring session.^(A) An interface modification of a commercial (frequency) scanner allows the computer to selectively tune up to five separate frequencies through its RS-232 serial port (i.e. the system would permit monitoring of five individual workers per program execution). The

(A) Recent changes in the Code of Federal Regulations, Part 15 have had an impact on the Federal Communications Commission's type approval of telemetering devices. As a result, the telemetry system, discussed herein, is currently under review by the authors for compliance.

operator specifies, in system software, a carrier frequency that a remote transmitter will be utilizing in operation. Each transmitter can then be connected to the output signal of any direct-reading instrument involved with the analysis of a vapor, gas, or dust concentration. Data are continuously transmitted to the scanner. Upon reception, data enters the computer. While data are being stored to disk, the information is simultaneously displayed on a video monitor in either a text or graphic format. Should a breakdown in the equipment occur (i.e., battery failure), it could be quickly discovered and corrected.

This radio telemetry system has been deployed on several field studies with encouraging results. One such study involved the generation of methylene chloride vapor during the removal (stripping) of old furniture finishes. NIOSH engineers performed an evaluation of a newly-installed ventilation system at the refinishing facility.⁽⁵⁾ Using the radio telemetry system and a photoionization air analyzer, a worker's qualitative exposure levels were remotely monitored as they occurred. A work practice or emission source that caused an increased exposure was immediately identified so that proper corrective action could be taken at that time.

System Description

Referring to Figure 1, the microcomputer and base receiver share two-way communications through an RS-232C interface. When the computer is directed to listen to a particular carrier frequency (88-108 MHz) in accordance with system software, the computer sends a tuning instruction to the receiver. Once the receiver has tuned to the specified frequency (channel), the receiver will continuously send digitized exposure measurements from the remote transmitter that is operating on the same channel. Each transmitter is programmed to a unique carrier frequency before it is placed in operation. Every direct-reading instrument is assigned a particular channel so that its exposure measurements can be positively identified upon reception at the computer. The transmitters digitize, then modulate, the analog signals (exposure measurements)

for transmission over the radio channel. Using frequency-shift keying (FSK) modulation, the advantages include an error rate that is essentially independent of signal amplitude, equal per-digit error probabilities for a mark and space, and simple noncoherent detection without need to process the carrier.

The base receiver, a modified Regency Z60 Programmable Scanner, contains the FSK demodulator needed to reconvert a transmitter's audio-frequency signals (FSK tones) back to binary signals. The Z60's normal keyboard programming has been replaced with an RS-232 interface connection to the IBM AT[®] or compatible computer. Programs in BASIC were written during system development to evaluate performance; C-language programs are used in the field for data collection.

The input section of the remote transmitter consists of an 8-bit successive approximation analog-to-digital (A/D) converter. The A/D converter operates continuously in a free-running mode. Each frequency-synthesized transmitter can be programmed to operate on any frequency in the FM broadcast band.⁽⁶⁾ Selection of the carrier frequency is important since reception can vary from one broadcast region to the next. Engineering firms that specialize in radio frequency (RF) design can build a transmitter to Part 15 (CFR 47) specifications. Independent RF testing laboratories can provide the certification required by the Federal Communications Commission (FCC).

Field Demonstration

The radio telemetry system's first field use was in a furniture refinishing facility where the substance under study was methylene chloride (NIOSH recommends that worker exposure to methylene chloride be controlled to the lowest feasible limit).⁽⁷⁾ A photoionization air analyzer (Photovac TIP II[™]) was strapped to a rack which, in turn, was attached to a tubular-framed backpack (Figure 2). The TIP II[™] comes with a receptacle that allows an electrical connection to a portable chart recorder.

Instead of the chart recorder, the analog signal was split between a data logger (Rustrak[®] Ranger) and a radio transmitter. Two air sampling pumps also were attached to the backpack. (The data logger and pumps shown in Figure 2 were unrelated to the demonstration of the telemetry system, and will not be further discussed.) Although data collected through radio telemetry could be used to determine if exposure limits were exceeded, the data presented here are the result of a qualitative approach. Instead of parts per million (ppm), DC voltage (an analog output of the direct-reading instrument) was used to identify and minimize peak exposures to methylene chloride. For example, 0.5 VDC may represent a concentration of 50 ppm, but it is approximately one-half the exposure represented by 1.0 VDC.

During the field demonstration, the subject worker and equipment backpack provided qualitative exposure data from three separate work areas within the facility.⁽⁸⁾ Figures 3 and 4 show where furniture finishes were removed (stripped) and rinsed off, respectively. In the absence of chemical leaks or spills, the worker was not subjected to a vapor buildup in the third work area.

A cart provided mobility for the computer, video monitor, and base receiver. The system demonstrated during test runs that data transmissions could be accurately received over 100-ft. distances within the facility.

Figure 5 shows the worker stripping the finish from a wooden chair, while wearing an air-purifying respirator. (It should be noted that NIOSH recommends the use of either a supplied-air respirator, or a self-contained breathing apparatus with a full facepiece and operated in a pressure-demand mode for any detectable concentration of methylene chloride.)⁽⁹⁾ Each time that he completed a piece of furniture, a table or chair, the worker had to carry it into the rinse room to spray off the chemical residue. After the rinse, the furniture was usually placed outside the double doors (in the area of the cart) to air dry. The worker also sometimes left the stripping room to replenish his supply of solution before

starting another piece. Regardless of the worker's activity or location, it was important to maintain accurate records during monitoring.⁽⁸⁾

While the video monitor displayed the worker's exposure to methylene chloride vapors, the computer simultaneously stored the data to disk. Figures 6 through 8 are reproductions from selected data that were stored on the disk. The reproductions are similar to the original graphs that were temporarily viewed at the work site as the exposures occurred. With few exceptions, the emission sources and work practices which led to increased exposure were easily identified.

It should be noted that researchers should consider instrument response time when viewing work processes. To pinpoint the sources and practices that contribute most to the overall level of exposure, the researcher should avoid choosing instruments with a response time of more than 10 seconds (5 seconds in some applications). A delayed response may create difficulties in interpreting the relationship between instantaneous exposure levels and the work process itself.⁽¹⁰⁾ If the duration of a delayed response is known, data that have been saved on disk can be offset to reflect the true time for each exposure level.

Figure 6 illustrates the worker's relative exposure to methylene chloride during the removal of a table's finish. When the worker was observed leaning directly over the table, the particular exposure level that was seen provided evidence that worker participation in the elimination, or reduction, of personal exposure is as important as engineering controls. The relationship between the exposure of a worker to solvents and the work method used is often a comparison of actions and consequences.

Dramatic improvements can be obtained in the job environment by relatively simple changes in work practices. A method called Picture Mix EXposure (PIMEX) was developed at the National Institute of Occupational Health in Solna, Sweden that specifically addresses the problem of employee awareness.⁽¹¹⁾ The method assumes that exposure depends to some extent on the way the individual employee works at his/her workplace. Good examples of this are a spray painter's exposure to solvents, a welder's exposure to welding fumes, and many other cases in which an employee handles the source of the contaminant. Swedish field studies employing video techniques make it possible to identify problems on videotape. Through the use of a video mixer, measurements obtained by direct-reading instruments are superimposed at the edge of a monitor screen in a form similar to a bar chart. The height of the bar is proportional at all times with the level of the signal. Since the PIMEX method uses radio transmitters to route the measurements to the mixer, video mixing is performed on site so that superimposed videotapes can be available for the company debriefing. While NIOSH researchers use a videotaping system, present video techniques exclude video mixing on location.^(1,2) Superimposed videotapes are not available until the exposure measurements (data) have been averaged, formatted and synchronized to the appropriate videotape.

While the local exhaust ventilation system appeared to be effective at the furniture-stripping station, another potential area of concern was discovered. Referring to Figure 7, a piece of furniture is undergoing a chemical strip approximately 80 seconds after the start of the file. The piece, dripping with solvent, was removed by the worker, and entered the water rinse booth after 800 seconds. Note the worker's qualitative exposure during the next 450 seconds.

Besides registering a sizeable peak in exposure as a result of the initial water rinse, the contamination is slow, in terms of breath cycles, to dissipate. The initial peak, followed by a gradual reduction in the relative vapor concentration, was characteristic for both types of furniture. Figure 8 shows the water rinse of another piece of furniture. The series of smaller peaks following the initial one is a response to the jet of water striking fresh solvent on unrinsed areas of the furniture.

There appeared to be a potential ventilation problem in the rinse booth that required further investigation. NIOSH researchers were alerted by the exposure levels that were being displayed on the video monitor (Figure 8). Once alerted, a smoke tube was discharged in the booth and its trail was followed. It was found that the temperature of the chemical solution was outside the chemical manufacturer's recommended range, resulting in a breakdown in a paraffin-based vapor barrier which created unnecessary fuming and product loss.^(B) Through the use of radio telemetry, immediate action was taken to correct the problem.

Conclusion

The usefulness of radio telemetry, a system that instantly transmits exposure data from direct-reading instruments to a microcomputer, has been demonstrated on a field survey at a furniture-stripping operation. The system offers advantages over other methods of data collection. Using telemetry, workers under study can enjoy more natural movement than they can by being tied with coaxial cables. Unlike data loggers, radio signals produce instantaneous results. The researcher can view exposure information received from several workers and/or processes on a moment-by-moment basis, thus preserving the primary advantage (instant feedback) of direct-reading instrumentation. Immediate exposure

(B) Temperature Range: 60° to 85°F per product label instructions for paint remover #2105 manufactured by Kwick Kleen Industrial Solvents, Inc., Vincennes, IN.

determinations are needed in the workplace to prevent employee injury and to advise management. Such determinations allow the swift elimination of emission sources and the timely development of exposure scenarios, proper work procedures and training aids.

Video techniques used by Swedish researchers have recognized the expediency of radio telemetry. Although information that has been saved on disk can be later mixed with videotape to produce training aids, there is an advantage in video mixing at the job site. By combining the results as they occur, the need to mix hours of data files and videotape at another time and place is eliminated.

Finally, the application of radio telemetry provides more flexibility and personal involvement while monitoring in the workplace. Personnel involved in a field study are generally more productive. There is more interaction, observation, and discussion. The focal point of this activity centers around the video monitor. As exposure information is updated on the screen, comments can be made and notes taken. Researchers have the opportunity to take additional measures in response to higher-than-expected exposure readings. Follow-up investigations could become unnecessary when corrective actions are proven effective before leaving the work site.

It is important for researchers who are developing real-time monitoring techniques to consider the procedures discussed in this report. Also, researchers conducting field studies should be cognizant of the variety of real-time monitoring techniques and use them to their advantage in evaluating worker exposure.

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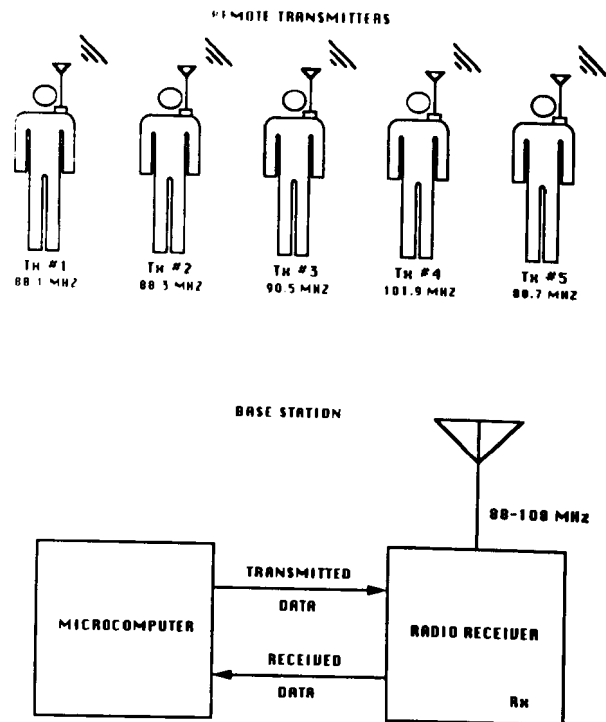


Figure 1. Radio Telemetry Block Diagram



Figure 2. Equipment Backpack



Figure 4. Rinse Room



Figure 3. Workstation



Figure 5. Stripping Furniture

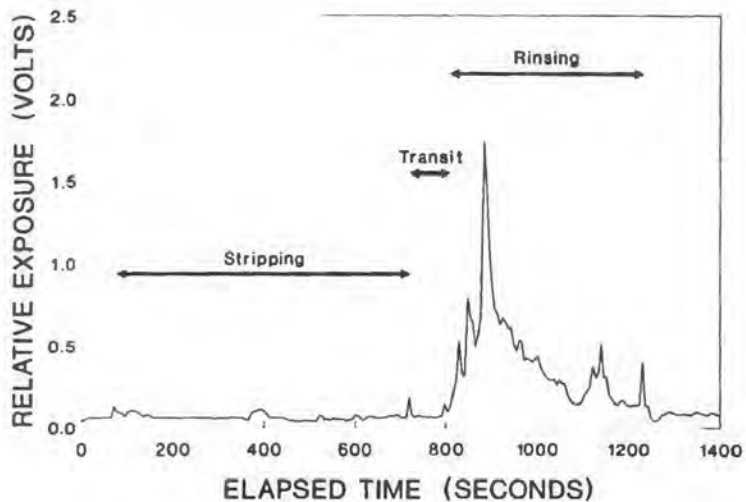


Figure 7. Chemical Stripping/Water Rinsing

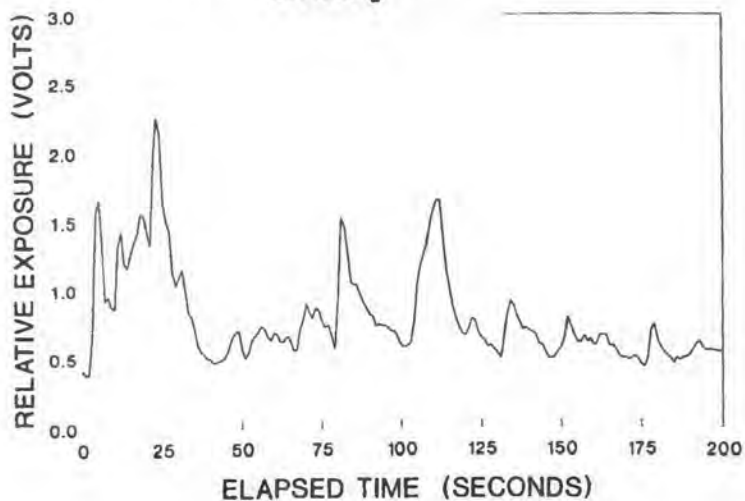


Figure 8. Peak Exposures in the Rinse Room



Figure 6. Personal Exposure as a Result of Poor Work Practices

DISCUSSION

MATT STINCHFIELD: Did you attempt to calibrate your relative reading to actual air concentrations, and if so, how did you do it?

RONALD KOVEIN: That's something we took for granted. We were not out to determine the exact concentration in that room. This is like a background sniff to identify the sources, practices, so on. In other words, along the y axis there may or may not be 50 ppm. But in a relative fashion we know the air quality of that room, that rinse booth, was far less superior than, say, close proximity to the ventilation system.

MATT STINCHFIELD: Yes, the work procedure and the corresponding spike that we saw was apparent. Have you considered how you might go about calibrating your field instrument?

RONALD KOVEIN: Yes, it is highly doable at this stage. In my mind it is even secondary to others because it is so doable. We've tested the hardware. For instance, the A to D in the front end of that transmitter is highly linear. We can improve system software. It's still growing. All these things can help make the system more user friendly and to allow for actual concentration readings. It is highly doable.

MATT STINCHFIELD: One final part to that. The software you were using for receiving the information through your RS-232- is that a commercially available type of data acquisition software, or was that something custom?

RONALD KOVEIN: Yes, it is. But once it's on the floppy disk it's part of the data storage and you can use just about anything you want, similar to a data logger. It is custom in that everything was built from scratch. We're not aware of anything out there commercially that does quite what we do. And in fact, we think it is quite unique, though it may be considered very basic. You'll notice it is simple. It is asynchronous, one-way communications. We have nothing sophisticated or as expensive as cyclic redundancy checking, for instance. I don't feel we need it. We have improvements down the way, and it is going to get better in range. There is so much left to do. The commercial scanner by the way, is rough. It did a great job for what we wanted it to do, but we can optimize it. We can give it better filtration making it much more sensitive and selective. And at the same time we have improvements to do on the prototype transmitters. We can increase field intensity for instance. Now with the revision of CFR 47 for a Part 15 device, it can go from about 50 microvolts per meter up to 250. So as I say, things are starting for our system in both performance and quality.

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