Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: https://www.tandfonline.com/loi/uaoh20

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**To cite this article:** Ronald J. Kovein & Paul A. Hentz (1992) Real-Time Personal Monitoring in the Workplace Using Radio Telemetry, Applied Occupational and Environmental Hygiene, 7:3, 168-173, DOI: 10.1080/1047322X.1992.10389174

**To link to this article:** https://doi.org/10.1080/1047322X.1992.10389174

Published online: 24 Feb 2011.

# Real-Time Personal Monitoring in the Workplace Using Radio Telemetry

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A system used to transmit data by radio from remote locations within a workplace to a personal computer for immediate interpretation has been developed. The system consists of several radio transmitters and a base receiver that is capable of multichannel reception. Exposure data obtained from any direct-reading instrument with an analog 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 displayed on a video monitor for immediate assessment while being stored for later analysis. If there is more than one worker under study at a time, multiple exposure records 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. In terms of portability and convenience, the radio transmitter is similar to a wireless telephone. 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.

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 an air quality analyzer. Relative methylene chloride exposures were remotely observed 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. **Kovein, R.J.; Hentz, P.A.: Real-Time Personal Monitoring in the Workplace Using Radio Telemetry. Appl. Occup. Environ. Hyg. 7(3):168–173; 1992.**

## Introduction

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.[1] 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. The PIMEX method has made integral use of radio transmissions (illegal in the United States because of their frequency band) to route measurements to the mixer. These transmissions have allowed video mixing on site so that superimposed videotapes could be available for the company debriefing.

In recent years, researchers at the National Institute for Occupational Safety and Health (NIOSH) have used microcomputers, data loggers or coaxial cables, and videotaping techniques during hazard control studies to help acquire real-time exposure data.[2–4] The data source was a portable direct-reading instrument that measured 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.[5] 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 data logger for a real-time record of exposure levels, or it can be converted into an audio signal and transmitted over a radio channel to a distant receiver for immediate processing by a microcomputer.

## System Description

The radio telemetry system, discussed herein, was developed to improve this real-time exposure monitoring by allowing 1) the remote acquisition and analysis of exposure data from nonstationary sources and 2) immediate access to exposure information that is not possible with data loggers. The radio telemetry system overcomes the

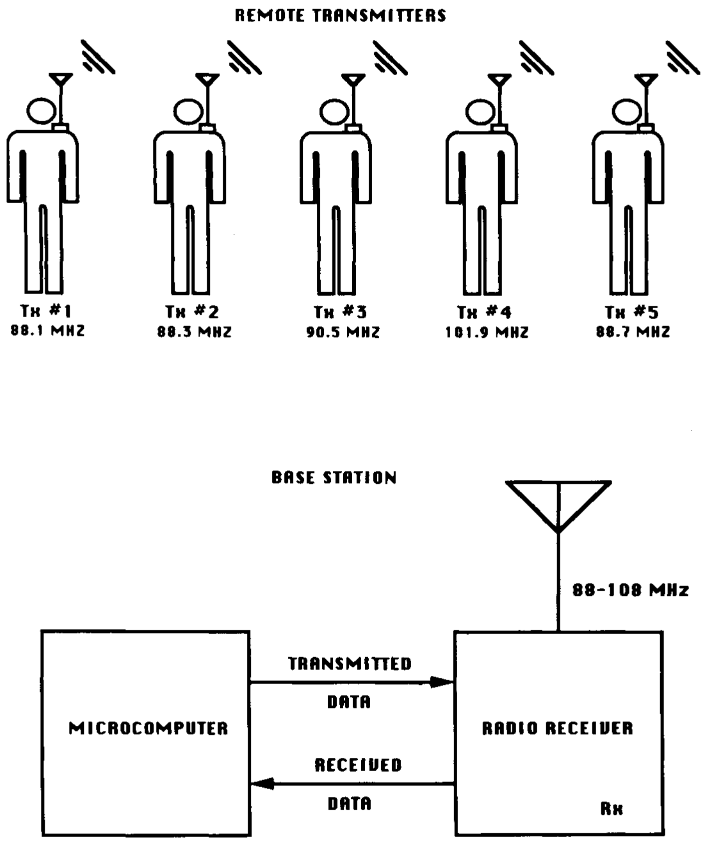


**FIGURE 1.** Radio telemetry block diagram.

distinct disadvantage of delay by continuously supplying data to a personal computer during a monitoring session.[A] 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). The 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, the scanner loads the data into 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 can be quickly discovered and corrected.

Figure 1 shows the microcomputer and base receiver sharing two-way communications through an RS-232C interface. When the computer is directed to listen to a particular carrier frequency (88–108 MHz), the computer sends a tuning instruction to the receiver. Once the receiver has tuned to the specified frequency (channel), the computer will process digitized exposure measurements from the remote transmitter that is operating on the same channel until redirected. 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 incoming data 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.

The base receiver was a modified Regency Z60 Programmable Scanner. Normal keyboard programming was replaced with an RS-232 interface connection to an IBM® AT™ or compatible computer. Programs in BASIC were written during system development to evaluate performance; C-language programs were used in the field for data collection. The receiver costs under $200, excluding modification expenses.

The input section of a remote transmitter consisted of an 8-bit, successive approximation, analog-to-digital (A/D) converter. The A/D converter operated continuously in a free-running mode. Although a fixed-frequency transmitter would have been less expensive, a frequency synthesizer was chosen for the transmitters to provide programmability. A transmitter can be programmed to an FM frequency (88.1–107.9 MHz) by the actuation of two DIP (dual in-line package) switches inside the transmitter case.[6] Selection of the carrier frequency is important, since reception can vary from one broadcast region to the next. The hardware costs of a frequency-synthesized transmitter were approximately $500, but the final per-unit costs can

[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.

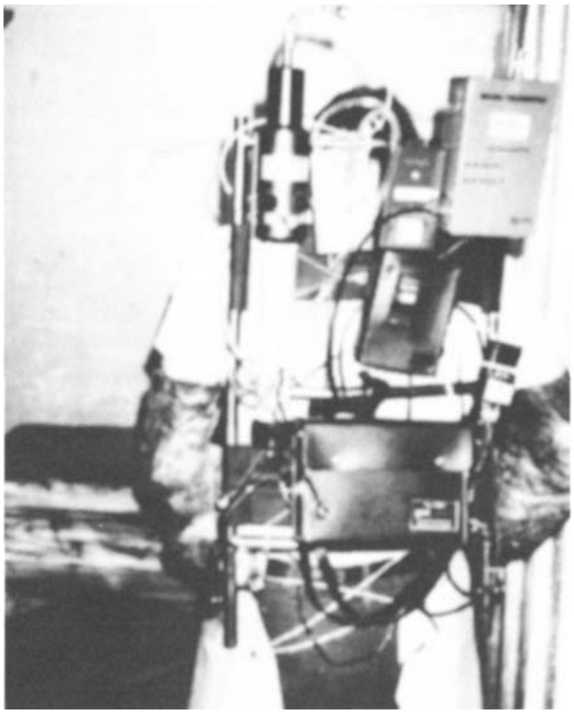

FIGURE 2. Equipment backpack.

include fees associated with the design and testing of a Part 15 (CFR 47) device. Engineering firms that specialize in radio-frequency (RF) design can build a transmitter to specifications. Independent RF testing laboratories can provide the certification required by the Federal Communications Commission (FCC). Once certified, the system can be legally operated anywhere in the United States without a license.

## Field Demonstration

The radio telemetry system's first field use was in a furniture refinishing facility where the substance under study was methylene chloride.[7] A 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 a chart recorder, the analog signal was split between a data logger (Rustrak® Ranger) and a radio transmitter. Two air sampling pumps were also 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 relative approach. Instead of parts per million (ppm), direct current (DC) voltage (the analog output of the direct-reading instrument) was used to identify and minimize peak exposures to methylene chloride. For example, 0.5 volt DC (VDC) may represent a concentration of 50 ppm, but it is approximately one-half the exposure represented by 1.0 VDC. The worker's relative exposure levels (0–5 VDC) to the methylene chloride vapors were displayed on a video monitor as they occurred. The TIP II was "zeroed" on indoor air away from any chemical source. With a mid-range span (sensitivity) setting, a 5-volt measurement on the monitor indicated that the instrument was operating in a saturated condition in response to the detection of an off-scale concentration.

During the field demonstration, the subject worker and equipment backpack provided relative exposure data from three separate work areas within the facility. Figure 3 shows the work area of prime interest. Furniture finishes were removed (stripped) at this station. A 100-inch by 50-inch recovery basin collected methylene chloride through a drain. A metal grate, upon which furniture was placed for stripping, was supported by the outside walls of the basin. A plenum, with a 6-foot by 4-foot vertical face, exhausted contaminants through four adjustable slots.

The second work area of interest was the rinse room that was adjacent to the furniture-stripping station. The rinse room (Figure 4) contained a walk-in shower stall. Stripped furniture was taken into the stall to receive a pressurized water spray. The worker would occasionally interrupt a chemical strip/water rinse cycle to enter into a third work area. This was done as necessary to check on a circulation pump that forced stripping solution to the furniture-stripping station through a supply hose. In the absence of chemical leaks or spills, the worker was not subjected to a vapor buildup in this third work area.

A cart was located just beyond the double-door entry of the furniture-stripping work area. The cart provided mobility for the computer, video monitor, and base receiver. A discone antenna (an omni-directional design) was mounted on a tripod base near the cart. Although the antenna received signals during test runs from transmitters over 100 feet away, the maximum range required to cover the furniture stripper's movements was about 30 feet (from the base station to the remotest region of the rinse room).

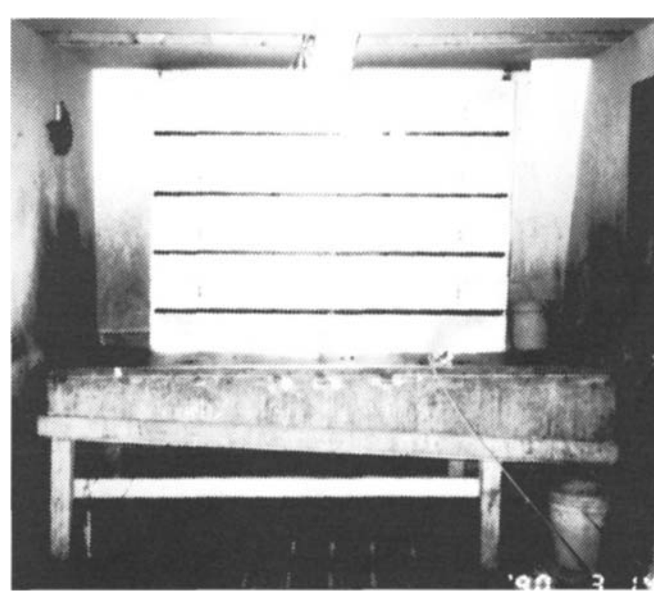

FIGURE 3. Workstation.

FIGURE 4. Rinse room.

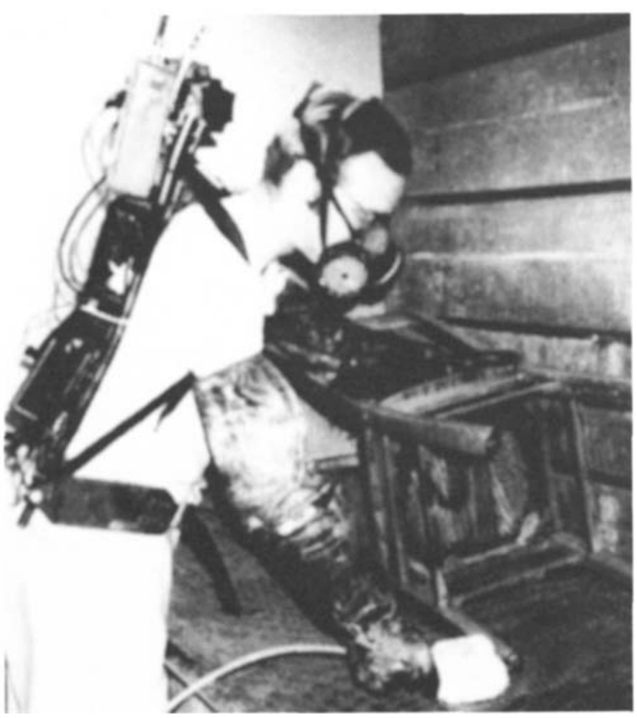

FIGURE 5. Stripping furniture.

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.[8] Each time the worker completed a piece of furniture, a table or chair, he 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 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. System (computer) time was noted on a simple work sheet with every change of location. The work sheet was invaluable when reviewing the data that had been saved on disk. The ideal alternative would have been to follow the worker's movements on a video recorder. This would have required the internal clocks of the computer and the video recorder to be synchronized.[3]

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. 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.[9] 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. Of the two types of furniture that were stripped, tables usually provided greater peak exposures than chairs (the top of the table has more surface area to load with solvent than the seat of a chair). 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.

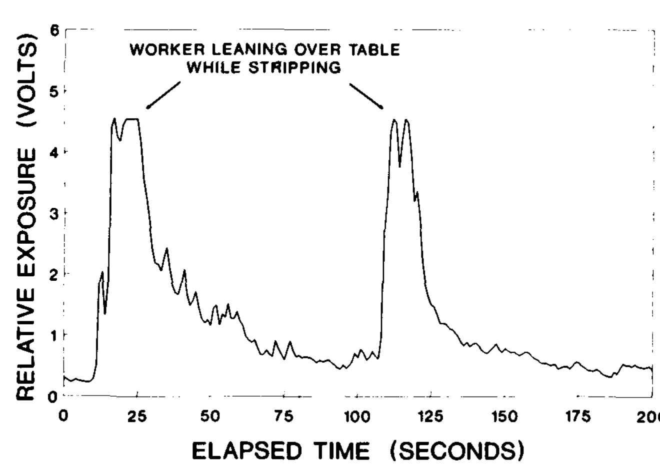


FIGURE 6. Personal exposure as a result of poor work practices.

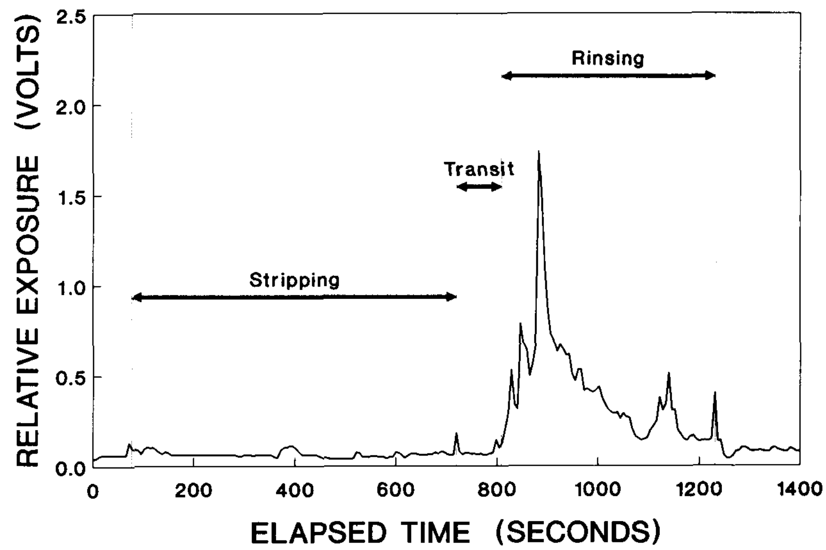


**FIGURE 7.** Chemical stripping/water rinsing.

While the local exhaust appeared to be effective at the furniture-stripping station, another potential area of concern was discovered. Figure 7 depicts a personal exposure during a chemical strip/water rinse cycle. A piece of furniture underwent 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 both after 800 seconds. Note the worker's relative 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 to dissipate in terms of breath cycles. 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 evaporation and product loss.[B] Through the use of radio telemetry, immediate action was taken to correct the problem.

## Conclusion and Recommendations

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 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

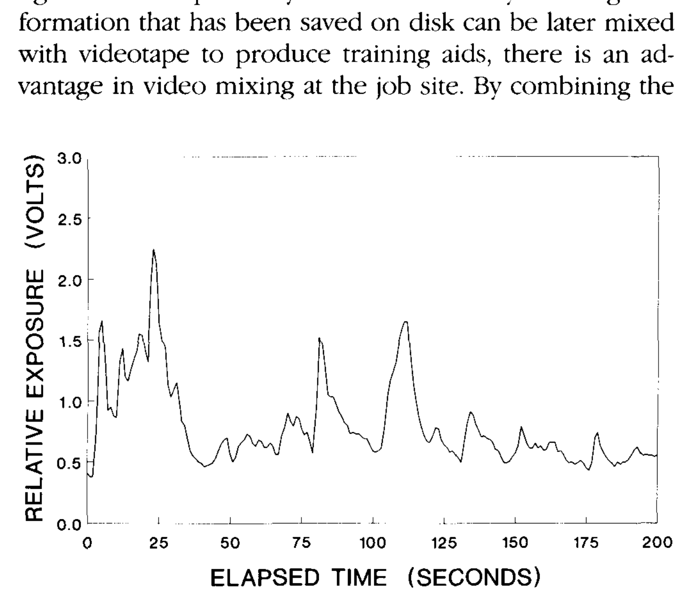


**FIGURE 8.** Peak exposures in the rinse room.

[B]Temperature Range: 60°–85°F per product label instructions for paint remover #2105 manufactured by Kwick Kleen Industrial Solvents, Inc., Vincennes, Indiana.

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 can be more productive, as 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 benefits of radio telemetry. 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.


## Acknowledgments

The authors wish to thank Martin Abell of NIOSH and William Metzger, a NIOSH summer employee, for their assistance in the development of the radio telemetry system software. Mention of a company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.


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Received 12/26/90; review decision 2/11/91; revision 7/22/91; accepted 8/16/91