Applied Occupational and Environmental Hygiene

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

A Prototype Active End-of-Service-Life Indicator for Respirator Cartridges

G. J. Maclay , C. Yue , M. W. Findlay & Joseph R. Stetter

To cite this article: G. J. Maclay , C. Yue , M. W. Findlay & Joseph R. Stetter (1991) A Prototype Active End-of-Service-Life Indicator for Respirator Cartridges, Applied Occupational and Environmental Hygiene, 6:8, 677-682, DOI: 10.1080/1047322X.1991.10387960

To link to this article: https://doi.org/10.1080/1047322X.1991.10387960

Published online: 24 Feb 2011.

A Prototype Active End-of-Service-Life Indicator for Respirator Cartridges

G.J. Maclay, C. Yue, M.W. Findlay, and Joseph R. Stetter
Transducer Research, Inc., 1228 Olympus Drive, Naperville, Illinois 60540

Respirator cartridges are used to allow workers to remain in an environment that contains gases which would be harmful to breathe. One of the problems users face is determining when the cartridge service life has ended. Air-purifying respirators for use with vapors are certified by the National Institute for Occupational Safety and Health (NIOSH). When the cartridge is no longer reducing the toxic gas concentration below the minimum permissible level, a "warning" may take the form of an odor; an irritation to the eyes, nose, or throat; or perhaps dizziness.

From the viewpoint of a user, the most desirable cartridge should have an indicator that actively and unambiguously notifies the operator when the cartridge's useful service life is almost ended. In 1984, NIOSH published standards for certification of Active-End-of-Service-Life-Indicators (AESLI) to encourage the development of AESLI systems. AESLI should provide advance warning to the user that the cartridge is 90 percent expended. To this date, development efforts have not been extensive, and no AESLI has been certified in an air-purifying respirator.

This article presents a prototype AESLI designed to be used with organic vapors. The prototype device consists of a sensor that is to be located within the bed of the cartridge and is electrically connected to a signal-processing module located on the face mask. The small, low-power module causes a LED alarm to flash when the gas concentration reaches a preset threshold value. The LED is mounted on the mask, directly in front of the user, and is clearly visible when flashing; however, it does not obstruct vision. Locating the sensor within the filter protects the sensor from species in the ambient air that do not pass directly through the cartridge bed during use, thus reducing the demand for sensor selectivity and protecting the sensor from exposure to the breath of the user.

The active element is a chemiresistor, a device whose resistance changes with the concentration of the toxic species. Important features of the sensor are 1) a generic response to many of the contaminants that the cartridge is designed to remove and 2) room-temperature operation which results in very low power consumption and safe operation even in a flammable or explosive atmosphere. The sensors were tested for response to cyclohexane in air mixtures (100–4000 ppm). Further, initial tests of the sensors in a compensating bridge circuit suggest that the effects of changing relative humidity and temperature may be minimized.
Maclay, G.J.; Yue, C.; Findlay, M.W.; Stetter, J.R.: A Prototype Active End-of-Service-Life Indicator for Respirator Cartridges. Appl. Occup. Environ. Hyg. 6:677–682; 1991.

Introduction

Air-purifying respirator cartridges are used to allow workers to remain in an ambient atmosphere that contains toxic gases which would be harmful to breathe. Depending on the concentration of the toxic gas and other factors, respirator cartridges may last from minutes to days before they are expended. One of the major problems users face is determining when the cartridge service life has ended. At present, there are basically two methods: sensory indicators and passive indicators. The National Institute for Occupational Safety and Health (NIOSH) certifies air-purifying respirators for use with vapors. When the cartridge is no longer reducing the concentration of the toxic vapor to below the minimum permissible level, a sensory "warning" may take the form of an odor; an irritation of the eyes, nose, or throat; dizziness; etc. For carbon monoxide, mercury vapor, chlorine gas, and several other compounds, cartridges are available that contain a passive indicator whose color changes when the cartridge service life has expired. In order for this colorimetric indicator to be effective during use, the operator must periodically check for the color change. If the operator forgets to inspect the indicator or if it is not easy to see due to the nature of the job or fogging in the face mask, a warning will not be noticed and overexposure can occur.

From the viewpoint of both safety and economy to the user, the most desirable cartridge would have an indicator that actively and unambiguously notifies the operator when the cartridge has expended 90 percent (or less) of its useful life. This is the requirement set in 1984 when NIOSH published standards for the certification of Active-End-of-Service-Life-Indicators (AESLI)[1] and invited manufacturers to develop AESLI. To date, development efforts have not been extensive and no AESLI has yet been certified in an air-purifying respirator. If AESLI were available, it might be possible to employ negative-pressure, air-purifying respirators instead of self-contained breathing apparatus (SCBA) for certain substances.

The purpose of this article is to present the initial research and development of a prototype AESLI designed to be used with organic vapors. The prototype device consists

1047-322X/91/0608-677$2.00/6 © 1991 AIH

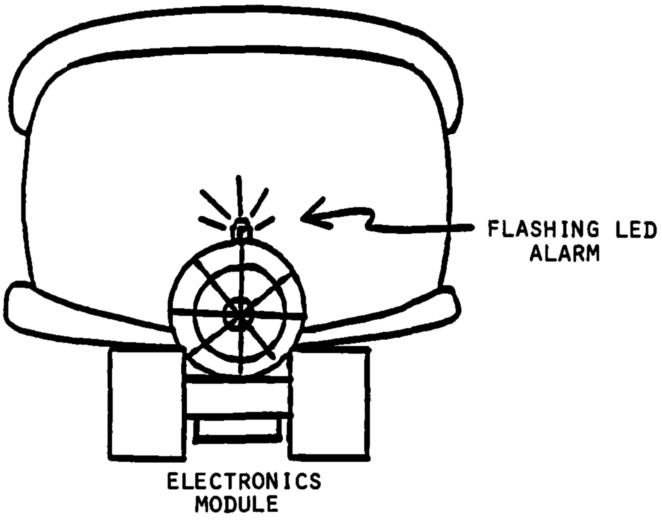

FIGURE 1. Schematic of a prototype AESLI with an electronics module mounted on a full-face mask. A flashing LED was mounted on a negative-pressure respirator and connected to the sensor. A circuit was constructed that uses microwatts of power. The sensor, when subject to hydrocarbon vapor, will trigger the flashing LED alarm.

of a sensor that is to be located within the bed of the cartridge and connected electrically to a signal-processing module located on the face mask. The small, low-power module causes a LED alarm to flash when the gas concentration reaches a preset threshold value. For a standardized testing protocol at a fixed concentration, this threshold level equals the level at which 90 percent of the useful life is expended. The design goal for the final product is such that the sensor, together with the electronics and alarm, will add less than 10 percent to the size, weight, and cost of the existing equipment. The AESLI can in no way hinder the normal use of the respirator. The LED is mounted on the mask, directly in front of the user (Figure 1), and is clearly visible when flashing, but it does not obstruct vision (Figure 2). Locating the sensor within the filter bed reduces exposure to species in the ambient atmosphere that are not drawn directly through the cartridge bed when the mask is being used. Thus, placing the sensor within the bed reduces the demand for sensor selectivity and prevents the user's breath from affecting the sensor or triggering the alarm. The prototype device was built on a full-face respirator, although in principle, it could be put in a half-face respirator.

When a respirator bed is exposed to a challenge vapor, a concentration gradient is established inside the bed.[2] As the time of exposure increases, the filter medium near the beginning of the bed becomes saturated, and the concentration of the challenge species in this region of the bed will approach the challenge concentration. With continued exposure, the concentration gradient and the saturation zone will move uniformly toward the end of the bed, approaching the AESLI sensor. By conducting experiments in which a constant challenge to the bed is maintained until breakthrough is obtained, one can determine the sensor output at which the alarm should be triggered to indicate 90 percent of the bed life is expended. Note that one does not need linearity of sensor response or even to know the precise concentration at which the sensor triggers. All that is required is that one can accurately calibrate the threshold response.

The requirements for an AESLI differ from those of chemical sensors used in other applications, e.g., pollution monitoring or process monitoring. Normally, a chemical sensor is required to show a reversible, selective response with linearity as a desirable feature. On the other hand, the ideal AESLI must indicate a concentration at which the cartridge life is 90 percent expended, an event that occurs only once in the life of the cartridge. Hence, the sensor does not have to exhibit a reversible response. In addition, the AESLI need not be linear since it must only indicate one concentration, namely the concentration indicating the service life is ending; however, the AESLI does need a stable base line and stable sensitivity for long periods of time. The electronics are calibrated to trigger the alarm at the proper concentration. Further, the AESLI need not be selective; in fact, a broad response may be advantageous, provided the sensitivity does not vary excessively for different compounds.

The sensor employed in this research is a chemiresistor, a device whose resistance is a function of the concentration of the toxic species. Important features of the sensor are 1) a generic response to many of the contaminants that the filter is designed to remove and 2) room-temperature operation, which results in very low power consumption and safe operation even in a flammable or explosive atmosphere. The initial sensors were tested for response to hydrocarbons using cyclohexane in air mixtures. Further, initial results suggest that the effects of changing temperature and relative humidity may be minimized.

FIGURE 2. A mask with the AESLI in use. The LED location is indicated by the arrow.

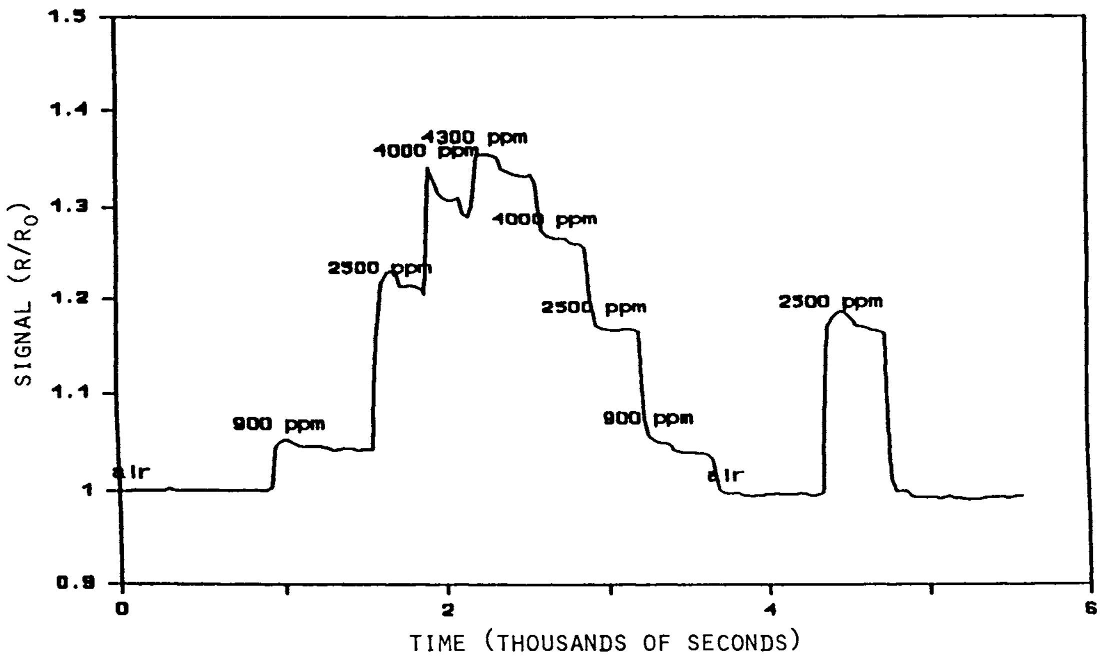

FIGURE 3. The response of the sensor to cyclohexane concentrations from 900 ppm to 4300 ppm.

Experimental

The sensors were tested in small, sealed chambers through which the test gas flowed. Sensor response was determined at temperature from 0° to 25°C to varying concentrations of cyclohexane in air (100–9000 parts per million by volume, ppmv). Some additional experiments were conducted to screen response to other compounds. The response is given as R/R_0, where R_0 is the resistance of the sensor before exposure and R is the resistance after exposure. The resistance was determined using a Wheatstone bridge circuit with a supply voltage of 6 volts. The output voltage of the bridge circuit was used to drive the LED alarm using a simple op-amp circuit powered by a 9-volt, direct-current battery.

The cyclohexane mixtures were prepared by volumetric dilution of a vapor of known concentration of cyclohexane. The concentration of the vapor, which was in approximate equilibrium with liquid cyclohexane at 0°C, was determined gravimetrically by measuring the adsorption at a set flow rate for a known time on a preweighed charcoal tube. The accuracy of the determination is about ±7 percent.

Temperature compensation of the sensors was obtained by using two sensors in a bridge circuit, with only one of them actually being exposed to the gas. The effect of relative humidity on sensor response was also investigated using wet and dry cyclohexane vapors.

Results

Sensor Response

The response of the silicon-carbon chemiresistor sensor to a challenge of cyclohexane vapor in air from 900 to 4300 ppm is shown in Figure 3. The time-weighted average (TWA) for cyclohexane is 300 ppm. For concentrations of cyclohexane below 500 ppm, the response of the sensor to cyclohexane vapor in air is shown in Figure 4. The initial response is very rapid, and the response time (to 90% of the final signal) is approximately 30–45 seconds. Screening measurements were done on several other compounds with the following results given in terms of the response to cyclohexane: methylene dichloride and benzene, 100 percent; hexane, 85 percent; carbon tetrachloride, 50 percent; acetone, 5 percent; and ethanol and methanol, 3 percent.

The temperature dependence of the sensor base line was investigated as the temperature was changed from 26° to 0°C and back. Figure 5a shows the shift in the uncompensated bridge output voltage as the temperature was changed. In this experiment, three of the four bridge resistors were standard carbon resistors with a temperature coefficient of about 0.05 percent/C°; the fourth was the chemiresistor. The sensor is sensitive to temperature, with a temperature coefficient of about 0.7 percent/C°. This high temperature sensitivity could make field use difficult without proper compensation. Figure 5b shows the change in the bridge output when one leg of the bridge was temperature-compensated by placing two sensors in it, only one being exposed to the cyclohexane. Use of the temperature compensation reduces the change in the base line bridge output from 15 percent to less than 1 percent, more than an order of magnitude less drift.

Figure 6 shows the sensor response in a temperature-compensated bridge circuit to gradually increasing concentrations of cyclohexane in a simulation of breakthrough. Note the stability of the base line. This test is crucial to establishing the viability of this sensor. A graph of the sensor response versus concentration for this break-

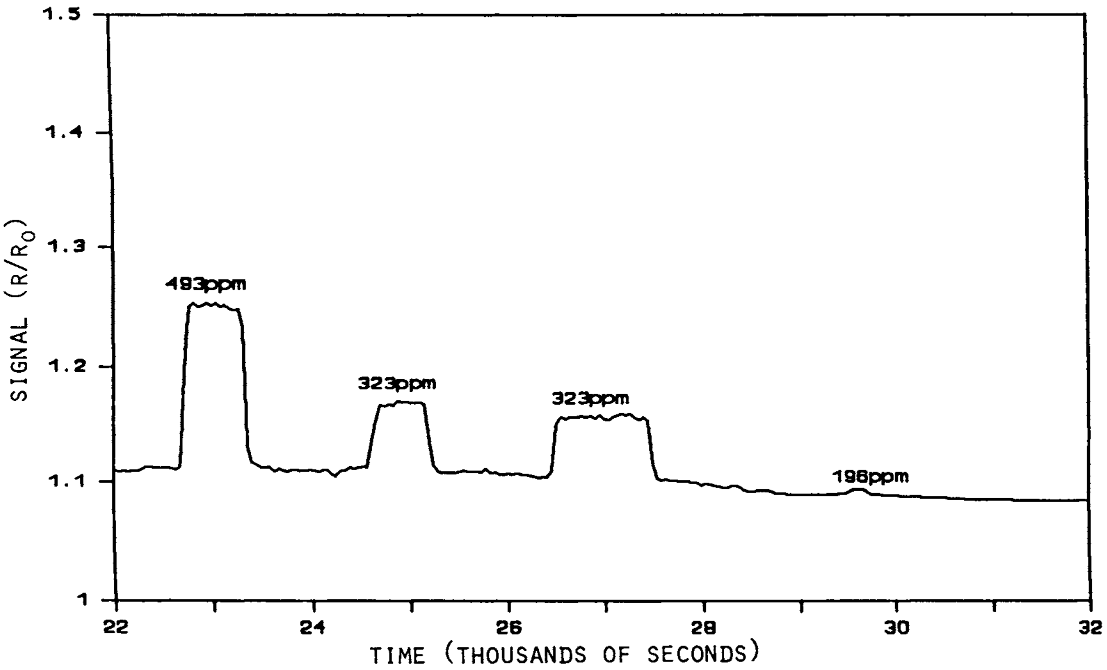

FIGURE 4. The response of the sensor to cyclohexane for concentrations below 500 ppm.

through test is shown in Figure 7 and illustrates an approximately linear response with a minimum detection limit of several hundred ppm.

Preliminary experiments were conducted to determine the effect of relative humidity (RH) on the sensor and to determine if it is possible to compensate for the RH effects. In these experiments, a stream of either dry air or air saturated with water vapor was passed over the reference sensor, then mixed with cyclohexane and passed over the measuring sensor. This configuration is designed to compensate for RH and temperature effects. Figure 8 shows the normalized sensor resistance as the sample stream was switched from "wet" (70% RH) to "dry" conditions (0.5% RH). The signal for 400 ppm of cyclohexane showed a small sensitivity to moisture that would be equivalent to less than 100 ppm of cyclohexane, which is greatly reduced from the humidity dependence seen without any compensation. Although more development is required to fully compensate for RH dependence, the preliminary results suggest that it may be possible to compensate for RH and temperature effects by using a reference sensor in a bridge circuit.

Discussion

The chemiresistor microsensor may be able to meet many of the requirements for an AESLI sensor. It has low power consumption; it is intrinsically safe; it gives a stable, temperature-compensated base line; it shows an unambiguous signal on first exposure to the test gas; and it requires only simple, compact, low-power signal processing to provide an alarm. The placement of the sensor in

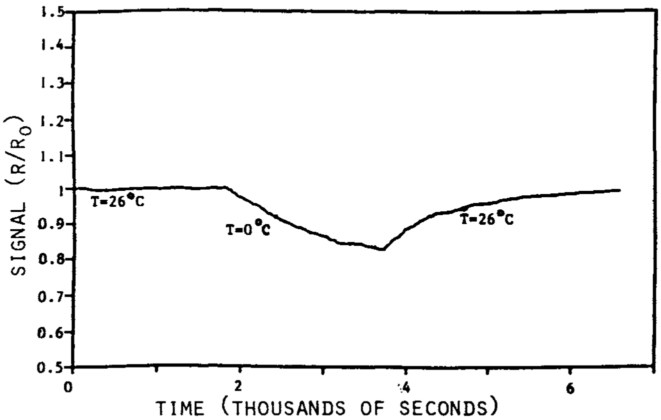

FIGURE 5a. The base line from the uncompensated Wheatstone bridge circuit when the ambient temperature is changed from 26° to 0°C.

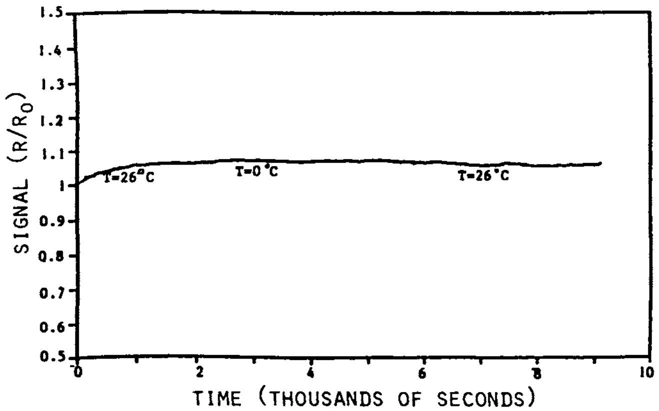

FIGURE 5b. The base line from the compensated bridge circuit showing the effect of ambient temperature.

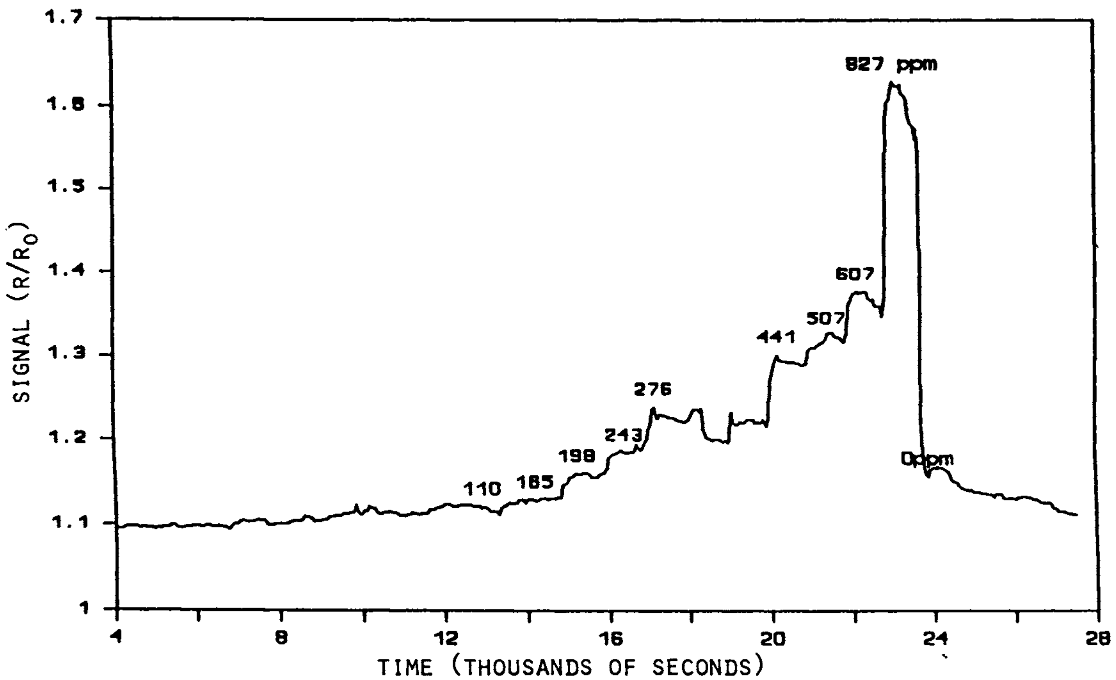

FIGURE 6. A simulation of breakthrough, showing the sensor base line and the response to the increasing concentration of cyclohexane.

the absorbent bed will determine the concentration at the sensor at breakthrough and, therefore, will dictate the sensitivity requirements. Since the sensor is set to alarm at a certain concentration within the absorbent bed, irrespective of the challenge concentration, exactly 90 percent of the cartridge life will be expended only for the proscribed test protocol and challenge concentration. In principle, however, the sensor placement can account for variations in challenge concentration, although the alarm may occur at less than 90 percent of the actual life.

The power consumption of the bridge circuit is only microwatts. The largest power drain is the flashing LED; however, by control of the duty cycle, the LED power consumption can be minimized. The alarm will only be on at the end of the cartridge service life. An alarm test button may be required on any active alarm device. Passive indicators can have no provision for an end-of-service-life alarm test.

Use of the compensated bridge design will tend to minimize the effect of changes in the ambient conditions, such as temperature and RH. The compensated AESLI may be able to account for the RH dependence of the adsorption capacity of carbon beds for different compounds, such as trichloroethylene;[3] this may prove to be an important advantage in situations where there are significant RH changes. The sensor is compact and can go inside the cartridge bed where it will be protected from ambient species that do not pass directly through the cartridge. Thus, the sensor can provide a true indication of the readiness of the bed to remove the contaminant.

The sensor needs additional study to increase its potential viability and utility and to increase the sensitivity at the 100 ppmv level and below. The screening data for selected hydrocarbons and alcohols suggest that the sensors tested appear to respond more strongly to compounds that were nonpolar (e.g., cyclohexane, benzene) than to polar compounds (e.g., methanol). Other sensor materials must be tested for both sensing and passivating properties. A simple, but rugged, technique must be developed for the electrical connections from the electronics module to the sensor. The electronics package needs to be integrated into a mask in a manner that allows the mask to be cleaned, maintained, and used in the normal way. The package, which contains a battery usable for approximately several hundred hours, must also provide a stable environment for the electronics with adequate immunity to electromagnetic noise, shock, and vibration. A second LED is

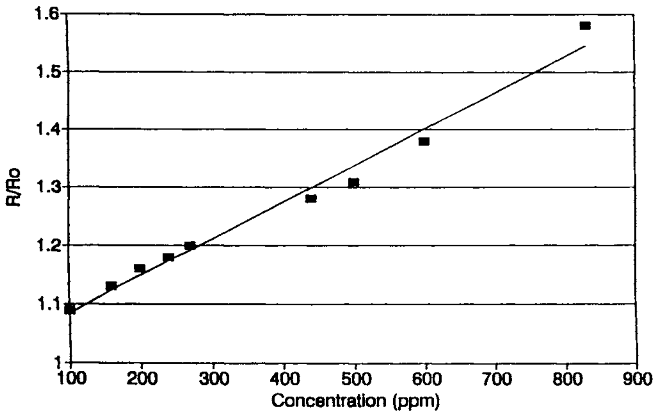

FIGURE 7. The response of the sensor versus the concentration. The data is taken from Figures 5a and b.

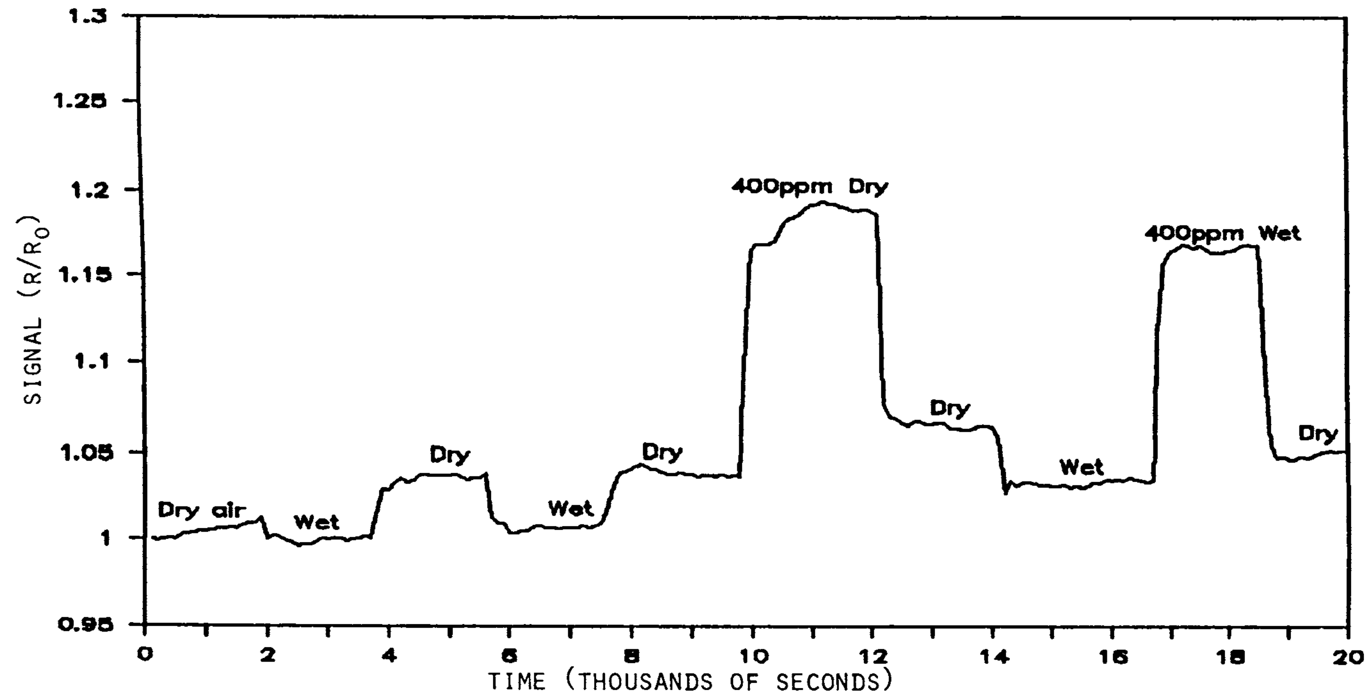

FIGURE 8. TRI ARD sensor humidity test results (cyclohexane vapor with dry air and wet air). The effect of relative humidity (RH) on the normalized sensor signal, given as R/R_0. The sensor was in a bridge circuit in which the reference sensor was exposed to RH but not to the cyclohexane. The response to 400 ppm cyclohexane does not change within experimental error as the RH is varied from less than 1% to about 70% RH.

suggested to indicate that the AESLI is in use and functioning properly.

Conclusion

A viable, prototype AESLI has been described. It employs a chemiresistor sensor placed in the cartridge bed, which is coupled to a small, low-power circuit that triggers a flashing LED alarm visible to the user. The alarm gives the user a positive indication before the service life of the cartridge is expended.

An AESLI is an attractive and safer alternative to the commonly used sensory warning that indicates cartridge service life has almost been expended. It is also more economical than simply replacing cartridges periodically. In addition, if regulations permit, a suitable AESLI may allow the use of negative-air-purifying respirators with certain gases and vapors that do not provide adequate sensory warning to the user. Consequently, in these cases, self-contained breathing apparatus would not be required, resulting in a substantial monetary savings and in increased user comfort.

Acknowledgments

This effort was supported by NIOSH Contract # 2 R44 OHO2312-02.

References

1. Fed. Reg. 49(140):29270–29272 (July 19, 1984).
2. Ackley, M.: Residence Time Model for Respiratory Sorbent Beds. Am. Ind. Hyg. Assoc. J. 46(11):679–689 (1985).
3. Okazaski, T.T.: Prediction of Binary Adsorption Equilibrium of Solvent and Water Vapor on Activated Carbon. Chem. Eng. Jpn. 11(3):209 (1978).

Received 1/22/90; review decision 2/26/90; revision 10/25/90; accepted 11/30/90