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OPPDRAGSRAPPORT NR. 1/82  
REFERENCE: 23881  
DATE: JANUAR 1982

ON THE SUITABILITY OF "BADGE" AIR  
SAMPLERS FOR HUMAN EXPOSURE ASSESSMENT

A BRIEF LITERATURE SURVEY

BY

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ISBN 82-7247-288-0

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ON THE SUITABILITY OF "BADGE" AIR  
SAMPLERS FOR HUMAN EXPOSURE ASSESSMENT  
A brief literature survey

1 INTRODUCTION

Present ambient air quality standards and guidelines (e.g. (1)) have been set largely on the assumption that fixed monitoring station measurements of air pollutant concentrations are representative of the exposures\* people receive. It has been common in health effects studies (e.g. (2)) to treat human subjects as homogeneous receptors of air pollutants. Instead of measuring the true exposure of individual subjects (or population groups), ambient concentrations at fixed air monitoring stations (sometimes interpolated spatially) are used to estimate the unmeasured concentrations at receptor locations. It is clear, however, that human subjects do not behave like fixed receptors: they carry on a variety of activities and spend a major part of time in non-outdoor environments (e.g., dwellings, the workplace, at recreation, in transit), they smoke or are with smokers. An increasing number of studies now suggests that there can be substantial variations between fixed station measurements and individual exposure measurements (e.g. (4)).

There are two possible methods (4) for determining the (total) exposure of a person (or a population) to air pollution:

(a) modelling, which must take into consideration both the activities of persons, as a function of time, and the concentrations to which they are exposed during each of the activities; and (b) field studies, utilizing personal air pollution samplers, to measure an individual's exposure (or the exposures of a sufficiently large population sample), during the exposure period.

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\*The terms "exposure" and "dose" (and the corresponding "exposure meter" and "dosimeter") are often used interchangeably. Properly, "exposure" is defined as an event in which a pollutant comes into contact with the "physical boundary" of a person. Only when the pollutant crosses this boundary (i.e., is absorbed by the human protoplasm), a "dose" is said to occur (3)(4). Depending on the physical activity of a subject, the difference between exposure and dose can be significant.

Although individual, or personal sampling has had a long history in the occupational hygiene field, it was not until the mid-1970s, when the need for and the state-of-art of personal exposure meters or monitors (PEM) for ambient air applications were first stressed and examined (5). A 1975 U.S. workshop surveyed candidate techniques and concluded (6) that "the importance of population exposure estimates in air pollution epidemiology makes it imperative that future epidemiological studies include exposure estimates more representative of what people actually breathe" and that "the use of individual air pollution monitors is a necessary factor in the design or performance of definitive studies of the health effects of air pollution." Since then, the necessity of PEMs for individual or population exposure assessment has been further reenforced (7). In the years 1976-77 alone, six major U.S. studies of research needs recommended national research and development programs on ambient level personal monitors. Major advances in PEM development, however, have been stimulated largely by monitoring regulations for the workplace environment (8-10). Lack of clear commitment and the continuing uncertainty about the market potential of personal samplers have delayed a similar full scale development and implementation of the devices for community air pollution applications (11).

## 2 OBJECTIVE OF STUDY

The stated objective of SFT\* for this preliminary study (for-prosjekt) was to assess, by means of a literature search, the suitability of currently available personal passive samplers of the "badge"-type for measuring exposures of individuals and populations to certain gaseous air pollutants.

The common community air pollutants carbon monoxide (CO), sulphur dioxide (SO<sub>2</sub>) and nitrogen dioxide (NO<sub>2</sub>), as well as any other substances potentially harmful to human health (e.g., benzene), were to be considered. Depending on the findings, field testing of candidate devices may be indicated.

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\* "Prosjektskisse :Litteraturgjennomgang angående personbåret prøvetaking/måleutstyr for omgivelsesluft." H Hæ, SFT, 06.03.1981.

Because of the limited scope of this preliminary study, only a cursory literature scan was conducted. Manufacturers' information on commercially available PEMs was also solicited. In what follows, relevant air sampling techniques and devices are examined, their commercial availability noted, and their suitability for the task briefly discussed.

### 3 PERSONAL EXPOSURE SAMPLERS

Personal samplers are worn (usually near the breathing zone) by the individual to determine his/her exposure to the air pollutant(s) of interest, in the same way as the familiar film badge (i.e., radiation "dosimeter") is employed in assessing ionizing radiation exposure. In addition to measuring directly the exposure of the wearer, personal sampling also serves to validate and calibrate exposure models for deducing individual exposures (and/or doses) from fixed station monitoring.

There are basically two types of personal sample acquisition methods: active sampling and passive sampling (11). Active sampling involves the continual supply, at a constant rate, of sample air to the collecting medium of the sampler. Miniaturized, but otherwise conventional sampling components are used, i.e., a pump and sample volume or flowrate meter. A passive sampler, on the other hand, relies on the transport of the pollutant through ambient air to the collection site by natural convection and diffusional or permeation transfer, at a rate proportional to the pollutant concentration. A passive sampler obviates the need for the relatively cumbersome and often troublesome pumps, flow regulators or meters, mechanical and electrical connections, or batteries.

For either type, the desirable physical characteristics of PEMs include (11):

small size	safe
light weight	reliable
easily worn	accurate
quiet	inexpensive
rugged	easily maintained and calibrated

### 3.1 Active sampling/devices

The initial approach to personal monitoring in the occupational health field was based on the use of active sampling devices, which provided most of the data in the early pioneering studies on exposure hazards. The disadvantages of active PEMS include relatively high cost, bulk, weight, noise, and the general inconvenience and even resentment on the part of the wearer.

The subject of this report is passive sampling and devices; consequently, active sampling, other than for comparison purposes, will not be further discussed.

### 3.2 Passive sampling/devices

The literature scan indicates that recent development activity of passive PEMS has largely centred in the U.S., with only a few efforts evident elsewhere (e.g. (12)). Correspondingly, by far the greatest number of literature accounts on passive devices has appeared in American publications, particularly the American Industrial Hygiene Association Journal.

The current generation of passive PEMS are integrating devices, which permit measurement of the total exposure to (e.g., ppm x hrs) and time-weighted average concentration (e.g.,  $\mu\text{g m}^{-3}$ ) of a pollutant for the period of exposure (13). With few exceptions (e.g., those employing colour or stain development) passive samplers are only sampling devices and not complete analytical systems. Most require subsequent sample treatment and/or recovery followed by appropriate analytical "finish".



Although sufficiently short response time is essential for integrating peak concentrations to obtain true time-weighted averages, current passive devices are not designed to measure transient peak values themselves. Thus, they generally provide only "historical" information and not real-time indication of concentrations for initiating immediate corrective or protective action, if necessary.

Almost all the passive PEMs described in the literature depend on transfer of the pollutant substance of interest to a suitable collection matrix by diffusion through an air column or by permeation through a membrane. Although both gases/vapours and particles diffuse, the diffusion rates for particles are several orders of magnitude lower than for gaseous materials. Thus, collection of any significant quantity of even the smallest particles is theoretically impossible, and the samples obtained with these type of passive samplers contain substances in the gaseous form only. The collection medium is a sorbent, appropriate for capturing the transferred substance. Liquid absorbents, solid adsorbent substrates, as well as various chemisorbents have been used for this purpose. Organic vapours are well suited for adsorption onto solid phases, such as activated carbon, followed by desorption and analysis. Inorganic gases, because of their higher reactivity, are more suited to absorption, followed by reaction in the collection phase and subsequent measurement of the product.

The principle on which diffusion and permeation samplers operate is that of concentration difference acting as the driving force, and the diffusion or permeation barrier acting as a resistance, controlling the flux of the pollutant through the barrier. Thus, the methods sample at a rate proportional to the pollutant concentration, instead of the constant rate maintained by active samplers. Although there are similarities between the diffusion and permeation processes, there are subtle, but at times important, differences which influence the selection and the design of the samplers.

### 3.2.1 Diffusion\_sampling/devices

The most widely applied approach for passive monitoring has been based on the well-known phenomenon of diffusion. Diffusion samplers

depend on the transfer of a quantity of gas/vapour by molecular diffusion through a tube, holes, orifices, porous membrane, or other cavities of fixed dimensions to the collection matrix. Under steady state condition, the quantity of gas/vapour transferred,  $M$  ( $\mu\text{g}$ ), during an exposure time,  $t$  (s), can be calculated (11) from the integrated form of Fick's First Law of Diffusion:

$$M = JAt = DA \frac{C_o t}{L} \quad [1]$$

where:  $J$  = flux of mass,  $\mu\text{g cm}^{-2}\text{s}^{-1}$   
 $A$  = cross-sectional area of cavity,  $\text{cm}^2$   
 $D$  = diffusion coefficient of substance,  $\text{cm}^2\text{s}^{-1}$   
 $C_o$  = ambient concentration of substance,  $\mu\text{g cm}^{-3}$   
 $L$  = length of cavity, cm

The boundary conditions are:

- (a) the concentration of the gas/vapour at the surface of the collecting medium is zero (i.e., a complete sink with 100% collection efficiency);
- (b) the concentration of the gas/vapour at the face of the diffusion barrier is the ambient concentration  $C_o$  (i.e., all mass transfer resistance is internal).

As can be seen from Eqn. [1], diffusion sampling depends on three constants:  $D$ ,  $A$  and  $L$ , and on two variables:  $C_o$  and  $t$ . For a particular sampler,  $A$  and  $L$  are known, and  $D$  can be estimated from literature values (e.g. (14) (15)).  $DA/L$  has the units of  $\text{cm}^3\text{s}^{-1}$ , and can be regarded as the sampling rate of the diffusion sampler. Thus, the sampling rate can be varied (within limits) by adjusting  $A$  and  $L$  in the design of the sampler.

Since the time of exposure,  $t$ , is known, the time-weighted average concentration,  $\bar{C}_o$  ( $\mu\text{g m}^{-3}$ ), can be calculated from a measurement of the amount collected,  $M$ , which is obtained by the analytical finish after the sampling exposure. This usually means conventional chemical analysis methods, but some commercial badge samplers utilize on-site sample treatment (16) (17) and colourimetric evaluation (17). In practice, empirically determined calibration

factors may be applied in the calculations to account for the influence of parameters, such as, geometrical factors of the diffuser, and the collection and desorption efficiencies of the collection matrix and sample recovery procedures. Temperature, pressure, windage and interferences can also affect the sampled concentration of the diffusing substance (11) (13).

Kinetic theory of gases predicts that the diffusion coefficient,  $D$ , is a function of both absolute temperature,  $T$ , and pressure,  $P$ . The net effect of  $T$  and  $P$  is, however, offset to some degree by the corresponding changes in concentration with  $T$  and  $P$ , so that the diffused mass,  $M$ , is a function of  $(T)^{\frac{1}{2}}$  only (18).

Diffusion-controlled samplers require a slight air movement across, or impinging upon, the face of the device. The samplers can be expected to sample accurately as long as essentially all resistance to the gas/vapour transfer is contained within the stagnant air layer inside the diffusion cavity (boundary condition (b) above). However, as the velocity of air across the face of the device decreases, the external resistance to mass transfer, associated with convection increases until the mass collected becomes less than predicted by Eqn. [1]. The most common way of reducing such a windage effect is to provide a resistive layer to buffer mass transfer effects due to wind velocity. For this, draft shields and attenuating sheets or membranes on the face of badge-type PEMs have been used, to keep convective airflow from becoming the rate determining step of mass transport (18). Higher cavity length to diameter ratios ( $\geq 3$ ) can also minimize windage effects (19).

An important function of any sampling device is the ability to integrate adequately high peak concentrations, which is directly related to the response time of the sampler. A measure of response time is the average residence time of the gas/vapour within the diffusion zone. If the sorbent collection efficiency is 100% (boundary condition (a) above), the residence time,  $t_r$ , can be estimated (18) from:

$$t_r = \frac{L^2}{2D} \quad [2]$$

Thus, increasing the diffusion cavity length to minimize windage is likely to result in decreased response time. Response times of diffusion-type PEMs are normally of the order of seconds, and thus are considered sufficient for sampling time-weighted average concentrations in most occupational situations.

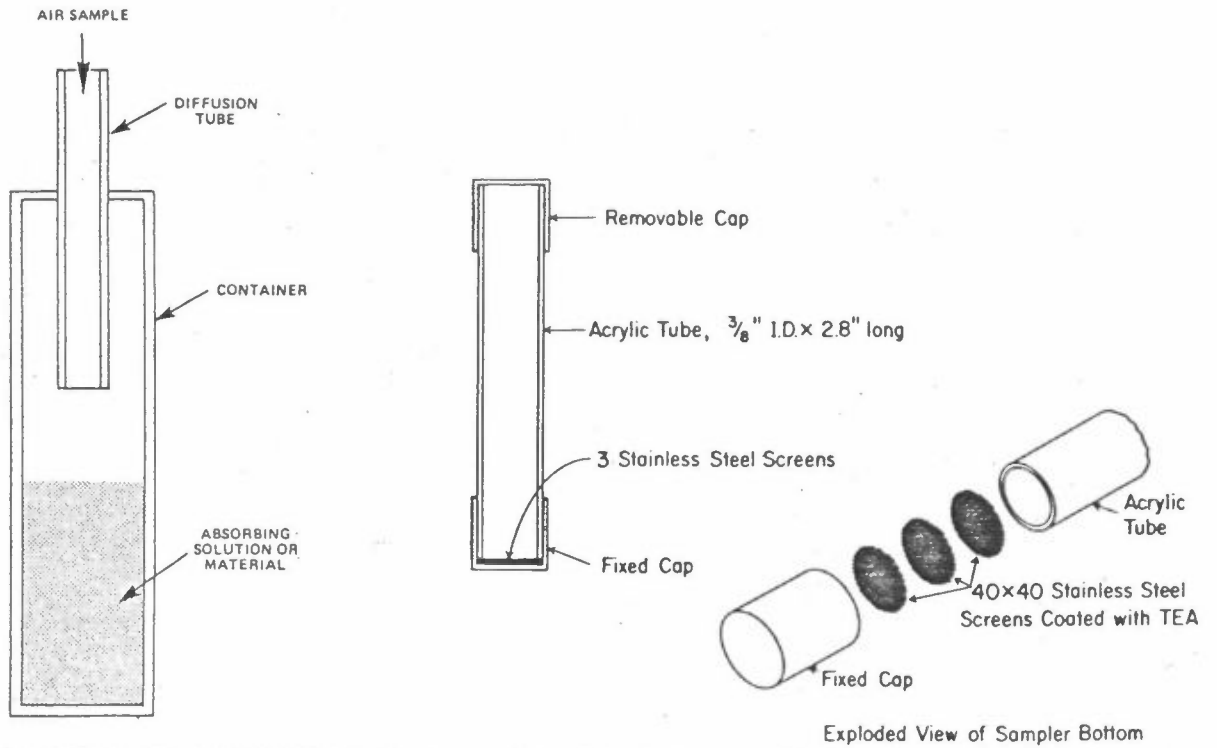
Interferences from other co-present gases or vapours for diffusion samplers relate to the analytical finish of the samplers. Any interferences inherent in sample recovery, treatment, and particularly the quantitative analysis method used will obviously affect the accuracy of the measurement.

There are several other potential influences, which could affect the performance of passive sampling systems, but which cannot be predicted from theory. These include the effect of changing humidity, sorbent stability and shelflife, out-gasing (or back-diffusion), detection and saturation limits, linearity of response, and the presence of complex mixtures of gases or vapours. These must be assessed empirically for each type of PEM.

The transient response of diffusion samplers to cyclic concentration excursions has been theoretically analyzed (20) through the application of Fick's Second Law of Diffusion. A method for correcting field measurements for the sampler's transient behaviour has been suggested. The method applies to any device which operates on the principle of one-dimensional diffusion, and therefore should be appropriate also for permeation-type sampling (cf. Section 3.2.2).

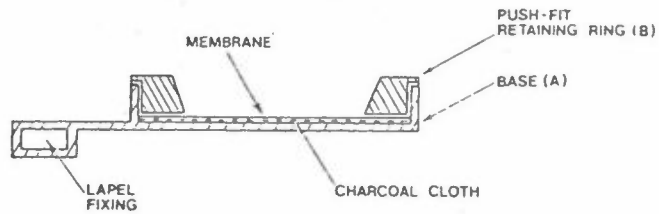
Successful PEMs, based on diffusion sampling, have been recently developed for a variety of gases and vapours (12) (13) (21-27). Diffusion-type PEMs are now commercially available (8) (10) (28-37) and are marketed by several firms.

The construction features of some prototype diffusion samplers and commercial diffusion sampling badges are shown in Figures 1 and 2.



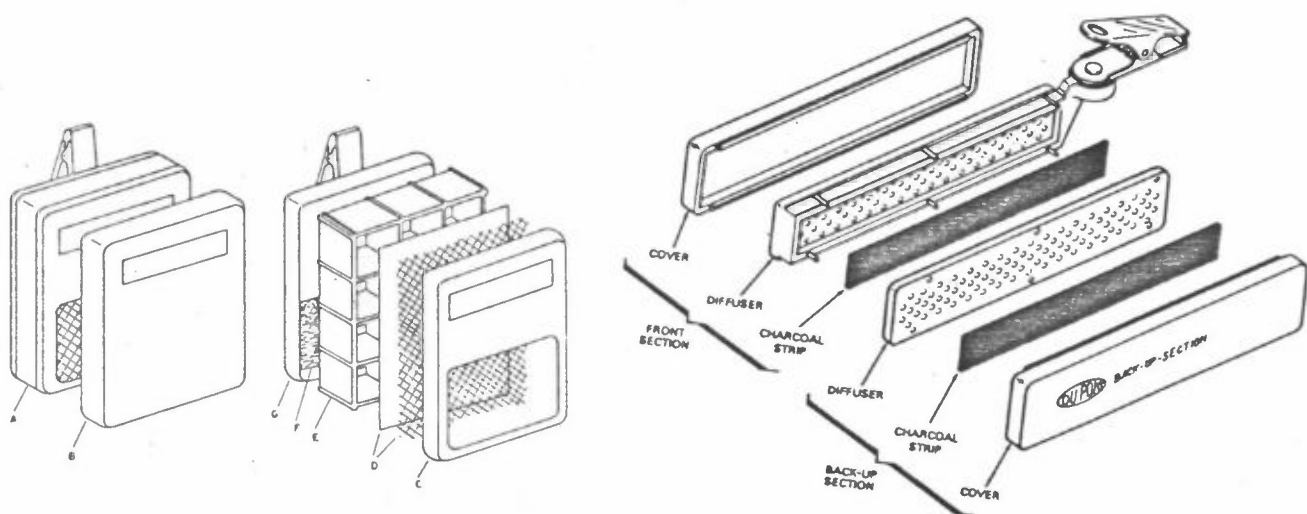
(a) Prototype diffusion tube sampler for sulphur dioxide (21).

(b) Prototype diffusion tube sampler for nitrogen dioxide (23).



(c) Porton diffusion badge sampler (12).

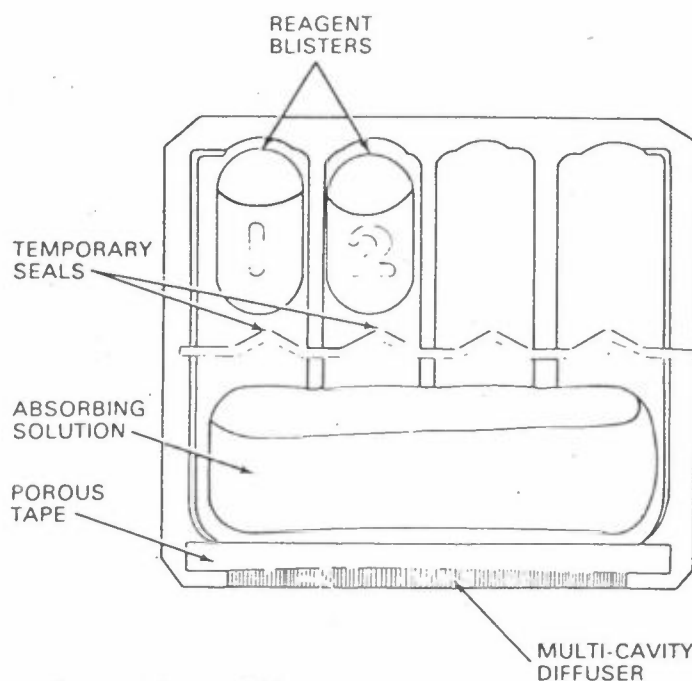
Figure 1: Construction features of some prototype diffusion-type personal samplers.



(a) Exploded view of Abcor GASBADGE<sup>TM</sup> ammonia dosimeter (31).

(b) Exploded view of Dupont PRO-TEK<sup>TM</sup> badge for organic vapours (19).

- |                  |                    |
|------------------|--------------------|
| A - body         | E - grid           |
| B - cover        | F - adsorption pad |
| C - front piece  | G - back piece     |
| D - draft shield |                    |



(c) PRO-TEK<sup>TM</sup> colourimetric badge for  $\text{NH}_3$ ,  $\text{SO}_2$  and  $\text{NO}_2$  (17).

Figure 2: Construction features of some commercial diffusion badge samplers.

### 3.2.2 Permeation sampling/devices

Permeation is a well-known means of preparing standard gas mixtures for calibration purposes, but its application for passive sampling devices was first introduced by Reiszner and West (38).

Permeation is essentially a dissolution process. Gas or vapour molecules, upon coming in contact with a solid barrier of appropriate composition (such as a polymeric membrane), dissolve and pass into the barrier under a concentration gradient until saturation is achieved (38)(39). If an effective collecting matrix is introduced on the other side of the barrier, equilibrium is disturbed and the permeating molecules are removed, providing a means for quantitative mass transfer. The total mass permeated is (as in the case of diffusion) a function of the species and the time of exposure. The amount of the gas/vapour species,  $M$  ( $\mu\text{g}$ ), captured by the collection medium is obtained through conventional chemical analysis of the collected sample. Since the exposure time,  $t$ , is known, the time-weighted average concentration,  $\bar{C}_o$  ( $\mu\text{g m}^{-3}$ ), can be calculated from:

$$\bar{C}_o = \frac{Mk}{t} \quad [3]$$

where:  $k$  = the permeation constant.

Permeation through a polymeric membrane is described mathematically much the same way as dissolution and diffusion in liquids (12). The permeation constant,  $k$ , is a function of the permeability, cross-sectional area and thickness of the membrane. The permeability is characteristic of each membrane material and the permeating species. The constant  $k$  is usually determined empirically by exposing a given permeation sampler to a standard atmosphere, having a concentration,  $C$  ( $\mu\text{g m}^{-3}$ ), of the gas/vapour of interest, for an appropriate time period. From the amount of the species,  $M'$ , collected during the exposure, the constant is calculated from:

$$k = \frac{Ct}{M'} \quad [4]$$

and is then properly called the "calibration constant".

The permeation sampling rate can be varied by choosing appropriate cross-sectional area and thickness of the membrane, but added flexibility is added by the possible choice of different membrane materials with different permeation rates.

Permeation and diffusion samplers are thus similar in several respects, although they differ in the mode of sampling action. Compared with direct diffusion, permeation through membranes has the advantage of permitting selective passage of different gaseous species. Although all gases permeate membranes, polar gases, such as  $\text{NO}_2$ ,  $\text{SO}_2$ ,  $\text{H}_2\text{S}$ , and  $\text{CO}_2$ , do so far more rapidly than  $\text{NO}$ ,  $\text{CO}$ ,  $\text{N}_2$  and  $\text{O}_2$  (40). For example, the permeation rate of  $\text{NO}_2$  is ca 12 times the rate of  $\text{NO}$ , and this difference permits selective permeation for  $\text{NO}_2$ .

Amass (41) has listed the desirable characteristics a successful permeation membrane should have. These include mechanical strength, uniformity of thickness and permeability, lack of reaction with collection matrix, low permeability for water, rapid time response for integrating peak values, and low sensitivity to temperature or flow pattern changes.

Studies of the permeation phenomenon have disclosed a variety of temperature effects for different compounds (e.g., negative effect for  $\text{SO}_2$  (38) and positive for  $\text{CO}$  (42)). Temperature effects, however, can be minimized or even eliminated by use of membranes made of silicone polymers (38)(40). The permeation membrane also provides the resistive layer necessary to buffer mass transfer effects due to wind velocity. Permeation sampling is essentially free from other ambient influences, with neither windage nor humidity changes having an effect (9)(41)(43).

Permeation of gaseous species through polymeric membranes is not an instantaneous process, since it depends on three independent processes: dissolution of the gas/vapour by the membrane, diffusion through the membrane, and evaporation from the membrane. Response time of permeation devices depends on the rate at which the system attains an equilibrium state between these three processes. Response time estimates of from 30 s to 10 min have been reported



(38) (40) (45). Thus, permeation type PEMS are considerably slower responding than diffusion samplers.

There have been no interferences with the sampling process itself due to co-pollutants reported (9). As in the case with diffusion samplers, the measurement will include any interferences inherent in the particular analytical procedure used, whether it be gas chromatography, spectroscopy, ion electrodes, or any other applicable technique. The same applies to sample and collection media stability.

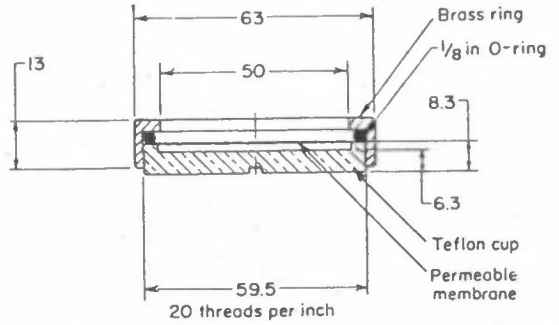
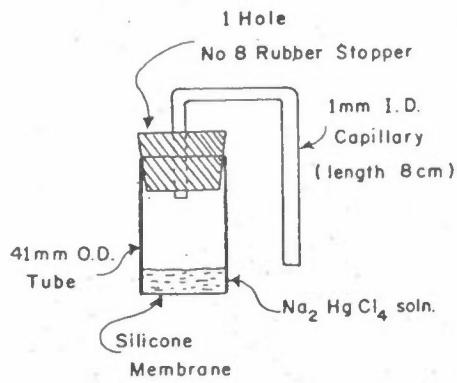
Both solid and liquid sorbing systems can be used in permeation-type badge samplers, because the close containment provided by the membrane prevents sloshing or spilling of the liquids. Full contact of the liquid sorbent with the membrane, however, is not necessary for accurate concentration integration (41).

In parallel with the development of diffusion PEMS, a number of permeation devices for various gases and vapours have been described in the literature, principally by West and his associates at Louisiana State University (9) (38) (39) (42-48). At this time, there appears to be only one commercial outlet for badge-type permeation PEMS (9) (39) (44). Figure 3 shows typical features of permeation PEMS.

Several authors (49) (50) have pointed out the analogy between permeation and diffusion sampling and electrical metering. For example, the application of Ohm's Law can aid in the analysis of the design of passive sampling devices, particularly where the use of permeation or diffusion elements in series is considered.

#### 4 BADGE SAMPLERS FOR SPECIFIC AIR POLLUTANTS

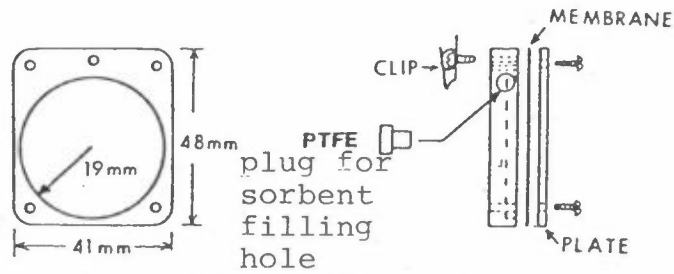
Successful PEMS have been developed mostly for monitoring occupational exposures to a variety of gases and vapours, and prototype and commercially produced devices are described in the literature for the common air pollutants of interest in this study (i.e., CO, SO<sub>2</sub>, NO<sub>2</sub> and benzene). Not all of these are of the badge-type,



Note: All dimensions are in millimeters unless noted otherwise.

(a) Prototype permeation sampler for sulphur dioxide (38). (Capillary tube eliminates possible pressure gradients).

(b) Prototype permeation badge for nitrogen dioxide (40).



(c) Prototype permeation badge for vinyl chloride (43).

Figure 3: Construction features of some prototype permeation samplers and badges.

but all are small and light enough to be easily attached (e.g., clipped to the lapel) to the garment of the exposed individual. Most of these PEMs have undergone laboratory testing and some field testing and/or comparisons (37)(51-59).

Diffusion-type PEMs for various gases/vapours are manufactured by:

Abcor Development Corporation\*: GASBADGE<sup>TM</sup>  
(850 Main St. Wilmington, MA 01887, USA)

3M Company\*\*: Series 3000 Monitors  
(St. Paul, MN, USA)

DuPont de Nemours & Company\*\*\*: PRO-TEK<sup>TM</sup> (2 types)  
(Wilmington, DE, USA)

MDA Scientific, Inc.\*\*\*\*: Model 530  
(Glenview, IL, USA).

The only commercial outlet for permeation-type badges is:

Reiszner Environmental and Analytical Labs, Inc. (REAL)\*:  
MiniMonitor and BioBadge  
(P.O. Box 3341, Baton Rouge, LA 70821, USA).

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\* Address of local distributor (if any) unknown.

\*\* Local distributor: 3M Verneprodukter  
3M Norge A/S  
Hvamveien 6, P.b. 100  
N-2013 Skjetten

\*\*\* European marketing: DuPont (U.K.) Ltd.  
Wedgewood Way  
Stevenage, Herts, SG1 4QN  
England

Local distributor: Oleico AB  
Sandhamnsgatan 25  
S-115 28 Stockholm  
Sverige

\*\*\*\* European distributor: MDA (U.K.) Ltd.  
Unit 6, No. 1 Haviland Road  
Ferndown Industrial Estate  
Wimborne, Dorset BH21 7PQ  
England

The Abcor GASBADGE<sup>TM</sup> (cf. Figure 2(a)) is 8 cm long, 5.7 cm wide and 2 cm thick. The sampling opening is 4.4 cm by 3 cm. The badge weighs ca. 40 g. It is reusable by replacing the collection element.

The various 3M Co. monitors (not shown) are circular badges. Including the clip, they are ca. 10 cm long, 4.4 cm at the widest point, and 1.2 cm thick. The sampling opening has a 3 cm diameter. The badges weigh ca. 14 g, and are not reusable.

The two types of DuPont PRO-TEK<sup>TM</sup> badges are the organic vapour badge (cf. Figure 2(b)) and the colourimetric badges (cf. Figure 2(c)). The solid sorbent, dual sampling rate organic vapours badges measure 7.7 cm long by 1.4 cm wide by 0.8 cm thick, and 7.7 cm long by 1.6 cm wide by 0.9 cm thick (without covers), depending on whether they contain single or double adsorption elements. Dual sampling rates are achieved by simply removing one or both covers of the badge during sampling. The respective weights are 8 and 11 g. The colourimetric badges measure ca. 7 cm by 6.5 cm by 1 cm thick, and weigh ca. 16 g. The badges contain liquid sorbents and reagent "blisters" for after-sampling colour development. The PRO-TEK<sup>TM</sup> badges are not reusable.

The MDA Scientific, Inc. PEM for NO<sub>2</sub>/NO<sub>x</sub> is a commercial version of the Palmes-type (23-25) diffusion samplers, which have a cylindrical shape, ca. 1.3 cm dia. by 8 cm long (cf. Figure 1(b)).

The REAL, Inc. MiniMonitor and BioBadge (not shown) are circular badges 5 cm in diameter, and 0.6 cm and 1.7 cm thick, respectively. The sampling openings are formed by 16 circular perforations (each ca. 0.5 cm dia.) in the cover of the badges. The MiniMonitor weighs 35 g (with activated C adsorbent) and the BioBadge ca. 28 g (empty). These permeation-type badges are intended for reuse.

Product literature for all the commercial badges is readily available, and includes detailed operating and calculation procedures.

The unit cost of commercial badges differ substantially for diffusion and permeation units, with the disposable diffusion

badges being approximately ten times cheaper (ca. USD 10 vs. USD 100). This cost differential, however, may be quickly offset, because the permeation units can be repeatedly reused, and once calibrated can be used for months or even years without re-calibration (9).

#### 4.1 PEMs for carbon monoxide

Carbon monoxide is about the only common air pollutant for which there are no successful passive monitors, although some active devices might be suitable (4)(11)(59). A proposed colourimetric permeation device (42) exhibited significant temperature dependence and suffered from interferences of several possible co-pollutant gases (e.g.,  $\text{SO}_2$ ,  $\text{NH}_3$ ,  $\text{H}_2\text{S}$ ). 3M's badge for CO (Monitor No. 3400) provides only the roughest of indication (colour change) of work-place CO concentration excesses, and is likely to be unsuitable for ambient measurements.

At the present time, carboxyhemoglobin determination in blood samples (inconvenient as they are), or even in exhaled air, may provide the best means for assessing personal exposure to carbon monoxide.

#### 4.2 PEMs for sulphur dioxide

Both diffusion (8)(17)(18)(21) and permeation PEMs (38)(39)(41)(45) have been developed, and some are commercially available.

The GASBADGE<sup>TM</sup> (Abcor)\* collects  $\text{SO}_2$  by diffusion on impregnated solid substrate (18). The PRO-TEK<sup>TM</sup> (DuPont) colourimetric badge absorbs diffused  $\text{SO}_2$  in a liquid solution. After sampling, the absorbing solution is mixed with an appropriate reagent (included in the badge) and the intensity of the developed colour can either be evaluated on-site with a simple readout instrument, or by laboratory spectrophotometry (17). The latter procedure increases the sensitivity of detection of the method and expands its useful range (1-200 ppm x hrs). The diffusion badges have response times of a few seconds.

\*No trade literature with details on the GASBADGE<sup>TM</sup> was received in time for this writing.

MDA Scientific trade literature states that a Palmes-type SO<sub>2</sub> PEM (21) is currently being developed.

The SO<sub>2</sub> BioBadge (REAL) permeates SO<sub>2</sub> through a silicone polymer membrane and absorbs it in liquid reagent (38). The useful range of the badge is 0.1 - 10 ppm x hrs, but the response time is about 10 minutes.

#### 4.3 PEMs for nitrogen dioxide

Judging from this literature scan, the largest number of publications on passive devices pertain to NO<sub>2</sub> measurements. Although most of these devices are for diffusional (8) (17) (18) (23) (24) or permeation (40) sampling of NO<sub>2</sub>, modifications to measure only NO (48) (61) (62) or NO<sub>x</sub> (25) (40) have also been proposed. The latter method utilizes a prototype NO<sub>2</sub> monitor (23), but first converts (by oxidation with chromic acid) NO to NO<sub>2</sub>, and then collects NO as NO<sub>2</sub>. By exposing simultaneously an NO<sub>x</sub> and NO<sub>2</sub> monitor, NO can also be measured by this method.

Passive PEMs for NO<sub>2</sub> have also been the ones most extensively used for personal exposure monitoring in dwellings (25) (54) (55), and even for area monitoring (56). The devices in these studies, however, were the prototypes (cf. Figure 1(b)), developed by Palmes and associates at New York University (23), and not commercial NO<sub>2</sub> badge monitors.

Except for the analytical procedure for the GASBADGE<sup>TM</sup>, and the absorbent/reagent system for the colourimetric PRO-TEK<sup>TM</sup>, the badges for NO<sub>2</sub> detection are the same as for SO<sub>2</sub> (Section 4.2). The useful range of these commercial badges is from 1-200 ppm x hrs.

At the present time, no permeation badges for NO<sub>2</sub> are marketed, but are expected to appear on the market sometime in 1982 (63).

#### 4.4 PEMs for benzene

All organic vapour PEMs utilizing adsorption onto solid phases are suitable for benzene measurement. Both diffusional (10) (16)

(18)(30)(33) and permeation sampling (19)(39) has been proposed, but at this time no commercial permeation badges for benzene are marketed. A novel benzene PEM is under development in which a gum rubber disk serves both as a limiting resistance to mass transfer and as the collection element (64).

GASBADGE<sup>TM</sup>, 3M's Monitor No. 3500, and PRO-TEK<sup>TM</sup> G-AA or G-BB organic vapour badges have been used to measure benzene exposures in occupational environments. The GASBADGE<sup>TM</sup> claims a useful range of 0.2-160 ppm/8 hrs (33).

#### 4.5 Miscellaneous passive PEMs

Pollutant gases/vapours of some public health significance, for which passive PEMs have been described in the literature, include formaldehyde (48)(58), chlorine (46), ammonia (31)(41), and mercury (28)(57). There is also a whole host of monitors suitable for other toxic, mainly organic substances used in industry and commerce (8)(9)(10)(12)(19)(26)(27)(29)(32)(34-37)(43)(47)(53). For many of these, commercial badges for monitoring exposure levels in occupational situations are marketed.

## 5 DISCUSSION

Increasing evidence suggests that people receive air pollution exposures that are not well represented by data from fixed station monitors. Any true assessment of the impact of air pollution on public health must take into account all the combined events making up an individual's exposure. Personal exposure monitors have been shown capable of determining actual exposures to air pollutants, and thus useful to both the epidemiologist for developing dose-response relationships, and the environmental manager for determining more directly the effect of pollution abatement and control strategies. Until recently, however, there was very little interest in personal sampling for non-occupational use. Consequently, the techniques and devices proposed for sampling the personal environment of individuals during their daily activities have largely depended on spin-offs from research and

development, which were primarily motivated by the need to measure exposures in the workplace.

Measurement of the high pollutant concentrations in the workplace is a relatively simple task compared to the measurement of low ambient levels, generally one or two orders of magnitude lower. As a result, few commercial PEMS, passive or active, exist for measuring reliably typical community air pollution levels. Most commercial monitoring badges are designed for optimum operation at concentrations near (below and above) occupational TLVs, and thus have low sensitivity and require long collection time to accumulate a detectable sample from the ambient air (11) (59). Furthermore, additional uncertainties in the functioning of the devices are likely, because of the much wider fluctuations in ambient air temperature, humidity and wind conditions than those encountered in industrial environments and manufacturers' test.

Although several impartial and rigorous evaluations of PEMS used in industry have been carried out in the past (51) (59), they are largely lacking for passive air quality monitors. In the absence of such information, only indirect evidence can be sought concerning the feasibility of using existing PEMS for monitoring non-occupational environments. Thus, the claimed detection limits of commercial badge samplers can be compared, for example, with the proposed Norwegian air quality guidelines (1) for comparable averaging periods. On this basis, only the REAL, Inc. BioBadge may be adequate for ambient  $\text{SO}_2$ , while the other commercial makes are at best only marginally suitable for  $\text{SO}_2$  and  $\text{NO}_2$  monitoring. On the other hand, some of the prototype devices for  $\text{SO}_2$  (e.g. (45)) and  $\text{NO}_2$  (e.g. (23)) appear feasible candidates. Fortunately, the latter are fairly simple to construct and relatively inexpensive to fabricate. Commercial organic vapour badges could be satisfactory for urban benzene exposure measurements, provided the collected sample stability and out-gasing characteristics are satisfactory over sampling periods longer than 8 hours, which are likely to be necessary to acquire minimum loadings for accurate quantification.



As appropriate PEMS for non-occupational exposure assessment become available, rigorous testing by independent organizations, to determine the accuracy, precision, sensitivity, ruggedness, and other performance characteristics, under diverse and exacting environmental conditions, will be necessary.

## 6 CONCLUSIONS

This brief literature scan suggests that:

- (a) Given the enormous costs of air pollution control and regulation, and the considerable uncertainties in our present understanding of the health impact of air pollution, development and use of PEMS are imperative;
- (b) passive PEMS offer a simple, inexpensive and convenient tool for individual exposure and time-weighted average concentration measurements;
- (c) passive PEMS are only sampling devices and not complete analytical systems; thus, for most substances they require sophisticated and often expensive analytical finish;
- (d) sufficient progress in PEM development has been made to warrant evaluation of the suitability of existing devices for environmental studies;
- (e) commercially available badge monitors are almost exclusively intended for occupational applications, and may be inadequate, or only marginally capable of measuring ambient levels of SO<sub>2</sub> and NO<sub>2</sub>;
- (f) some prototype passive PEMS for SO<sub>2</sub> and NO<sub>2</sub> appear to be suitable candidates for non-occupational exposure monitoring;
- (g) there are no passive PEMS currently available for reliable measurement of ambient CO;

- (h) commercial organic vapour badges appear suitable for long-period (e.g., 24 hrs or more) ambient benzene assessment, provided their sample retention characteristics during extended sampling are adequate.

## 7 RECOMMENDATIONS

The early optimism about quick development and commercialization of passive PEMs for ambient sampling applications (11)(59) has apparently not yet been fulfilled. The lack of sufficient number of commercial candidate devices suggests that a detailed evaluation program in Norway may be premature, and should await further developments.

As a first step, however, limited, stationary field comparisons can be recommended. These can consist of side-by-side measurements of 24-hr ambient SO<sub>2</sub> and NO<sub>2</sub> average concentrations with passive PEMs and continuously-recording monitors at selected, fixed sites. In addition to average concentrations, these results could also provide indication on how well the PEMs used integrate any short period concentration fluctuations in the time-weighted averages.

For SO<sub>2</sub>, the REAL SO<sub>2</sub> BioBadge, the PRO-TEK<sup>TM</sup> colourimetric badge and perhaps the prototype long-term SO<sub>2</sub> monitor (45) could be tried. Since the analytical finish for the first two is essentially the West-Gaeke reference method, parallel and concurrent 24-hr integrated West-Gaeke absorption sampling could also be conducted.

For NO<sub>2</sub>, the MDA Scientific NO<sub>2</sub>/NO<sub>2</sub> PEM or the Palmes prototype (23), the REAL NO<sub>2</sub> badge (if available) and the PRO-TEK<sup>TM</sup> colourimetric badge would be compared with the 24-hr average concentration derived from a continuous NO<sub>2</sub> monitor record.

For the SO<sub>2</sub> and NO<sub>2</sub> comparison tests, it would be preferable to select a location where the ambient concentrations of these gases are known to reach, or even exceed, the Norwegian guideline (1) values for 24-hr averaging periods. The placement of the PEMs

should be such as to satisfy the minimum air movement requirements for the samplers.

For benzene, 24-hr or longer side-by-side comparison sampling would be conducted, using the various commercial organic vapour badges (e.g., GASBADGE<sup>TM</sup>, 3M Monitor No. 3500, PRO-TEK<sup>TM</sup> G-AA or G-BB) and an appropriate standard or reference method (charcoal tube sampler).

A heavily-trafficked street or a busy car parking garage could be chosen for the fixed sampling site for benzene.

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POSTBOKS 130, 2001 LILLESTRØM  
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TLF. (02) 71 41 70

RAPPORTTYPE OPPDRAGSRAPPORT	RAPPORTNR. OR 1/82	ISBN--82-7247- 288-0
DATO JANUAR 1982	ANSV.SIGN. B. Ottar	ANT.SIDER 32
TITTEL On the suitability of "badge" air samplers for human exposure assessment. A brief literature survey.		PROSJEKTLEDER V. Vitols
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TITLE On the suitability of "badge" air samplers for human exposure assessment. A brief literature survey.		
ABSTRACT (max. 300 characters, 5-10 lines)		
A brief literature scan suggests that personal monitoring of human exposures to air pollutants is essential in health impact assessment. Passive personal exposure monitoring devices (PEMs) are simple, inexpensive, rugged, and convenient to use, but at present are available mainly for occupational monitoring. Only a few prototype and commercial badge-type PEMs may be suitable for ambient SO <sub>2</sub> , NO <sub>2</sub> and benzene measurements. A limited, fixed-location evaluation study is recommended for candidate devices.		

\*\*Kategorier: Åpen - kan bestilles fra NILU           A  
                  Må bestilles gjennom oppdragsgiver B  
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