and treats the worker as a person and not merely as a productive unit, can do much to bring contentment and at the same time increase production.

The worker, also, has his responsibilities. Where means of protection against personal injury are provided he should use them. Where certain acts are prohibited in the interests of safety he has a strong moral, as well as a legal, duty to refrain from them. Otherwise he may endanger the lives of others as well as himself.

Without the full cooperation of the worker full success is unlikely, but the major responsibility rests with the employer. In that connexion I quote two axioms laid down many years ago by Sir Thomas Legge:

(1) "Unless and until the employer has done everything—and everything means a good deal—the workman can do next to nothing to protect himself, although he is naturally willing enough to do his share.

(2) All workmen should be told something of the danger of the material with which they come into contact and not be left to find it out for themselves—sometimes at the cost of their lives."

The scientist should not offer industry new processes or materials, nor should industry accept them, without first ensuring that they are unlikely to cause injury to health.

The full cooperation of the trade unions is necessary. They should seek for good conditions of work rather than for "danger money" to compensate for bad.

The full achievement of the aims of occupational hygiene calls for the devoted work of scientists, cooperating with each other and with industry, in seeking for a fuller understanding of the relation between man and his environment, and in endeavouring to remove any hazard to health with all speed, once it has been recognized, even though the perfect method of assessing the hazard may not yet have been found. Such research is likely to be arduous and often prolonged, and it may not bring resounding fame to the researcher but he will be making his contribution towards the welfare of mankind.

Finally, a yet stronger sense of mutual obligation is needed, so that employers will seek to provide healthful conditions as a moral duty, while employees will readily use the means of protection provided, as a duty to themselves and to their fellows.

So, health and happiness may be promoted, and, I believe, material prosperity increased.

DR. HENRY F. SMYTH, President of the American Industrial Hygiene Association, conveyed formal congratulations and best wishes and presented the Society with a gavel on behalf of his Association.

Measuring the Workers’ Environment

S. A. ROACH

From the Pneumoconiosis Research Unit of the Medical Research Council, Llandough Hospital, Nr. Cardiff

Although harmful materials may enter the body by ingestion with food or by absorption through the skin, in many industries their most important mode of entry is by inhalation. The material may, like poisonous gas, be immediately dangerous, or its effects may be the result of the accumulated exposure of a life time. The problems arising in determining the risk to health by means of measurements of the environmental conditions may appear at first sight to be very different, but I hope to show in this paper that they are actually very similar, if not identical.

The Period of Accumulation

A substance may enter the respiratory tract in the form of solid particles or liquid droplets or as a gas. Solid particles and liquid droplets are deposited on the upper respiratory tract, the coarser particles being deposited first and the finer particles sedimenting out in the deeper parts of the tract. If they are not immediately dissolved the coarser particles are removed by ciliary action and may subsequently be swallowed. The finer particles which have been deposited in the alveoli may remain in the lungs indefinitely if they are insoluble, so that the amount of dust in a man’s lungs is roughly proportional to the product of his age and the average concentration of dust to which he has been exposed since birth.

On the other hand a relatively soluble dust such as lead is absorbed in the lungs so that it fairly rapidly accumulates in the blood, tissues, and skeleton, and is eventually excreted. The rate of solution increases with the amount of material deposited in the lungs and the rate of excretion of the material increases with the amount in the body, so that under exposure to a constant concentration a level of equilibrium will eventually be reached when the amount in the body is such that the rate of excretion just equals the rate of deposition in the lung.

In contrast to coal and silica, the lead in the body is slowly excreted when exposure ceases and the lead content usually reaches normal values within about 18 months (Kehoe, Thamm, and Cholak, 1933). Thus the amount of lead in the body is determined by the level of exposure over the previous 18 months and, to a great extent, by that within the previous few weeks.

The period of accumulation is even shorter in the case of harmful gases. Both absorption and elimination take place in the lungs, and, once the blood becomes saturated, accumulation in the rest of the body (when it takes place to any significant extent) is dependent on the concentration in the blood. For example, with a vapour such as benzene, saturation of the blood is reached within a few minutes; and saturation of the tissues is reached in two or three days (Schrenk, Yant, Pearce, Patty, and Sayers, 1941).
These points are illustrated in Fig. 1. The top half of the diagram indicates the situation in which a man is exposed to a constant atmospheric concentration of the material for a given length of time. The bottom half of the diagram illustrates how, as a result of this exposure, the material accumulates in the body to an extent dependent upon the solubility of the material deposited in the lungs. With materials which are for all practical purposes insoluble, the amount accumulated in the body increases steadily at a constant rate proportional to the atmospheric concentration. The material remains in the lungs more or less permanently, even after exposure ceases. With materials which are removed from the lungs by solution and are eventually excreted, or removed and eventually eliminated in some other way, the amount accumulated in the lungs, tissues, and skeleton rises to a maximum level depending upon the atmospheric concentration and the properties of the material. It should be pointed out here that once this state of equilibrium is attained the amount accumulated in the body is independent of the duration of exposure and if the effects on the men are non-progressive the risk to health is a function of the atmospheric concentration alone and the duration of exposure may safely be ignored.

There is, then, a continuous spectrum of different kinds of risk from inhalation, varying from those in which the amount of the material in the body is the result of the accumulated exposure of a life time to those in which it is the result of exposure for a few minutes only.

Variable Concentrations

When the atmospheric concentration of the material is constant or very nearly constant the evaluation of the risk is fairly straightforward. There can, however, be few industries in which this situation holds. The importance of a given atmospheric concentration of harmful material depends on its magnitude and its duration. Some knowledge of the variability of concentration with time is thus essential for a proper appraisal of the risk to health. Further, from the frequency and magnitude of the variations it is possible to estimate the risk of a dangerous situation arising in the future.

The ventilation of factories and workshops may depend very much on weather conditions. Even in places such as coal mines, where the ventilation current is rigidly controlled, the operations which give rise to air pollution are so numerous and variable that large fluctuations in concentration occur. The importance of these fluctuations of concentration depends upon the position of the harmful material on the scale of accumulation-time. If the amount of material in the body depends upon a lifetime of exposure short-term fluctuations of concentrations are of no importance except in so far as they render the average level of concentration difficult to determine. This will be the case with the pneumoconioses, in which the rate of accumulation is proportional to the average concentration. A progressive accumulation of the material occurs under exposure to even the lowest concentrations. On the other hand, in the case of the toxic gases or any material which is excreted, exhaled, or removed in some other way, the body can tolerate indefinitely atmospheric concentrations materially higher than those found in clean air. When equilibrium is reached the material is being eliminated from the body as fast as it is being deposited in the lung. However, short-period, high concentrations may lead to a temporary accumulation in the body sufficiently great to be harmful. For example, it is generally accepted that an average concentration of carbon monoxide of 100 parts per million for a 40-hour week is quite safe, although were the same dose inhaled in one hour, that is with a concentration of 4,000 parts per million, then almost certainly the exposure would be fatal (Henderson, Haggard, Teague, Prince, and Wunderlich, 1921). Thus in this case the fluctuations of concentration from hour to hour are of primary importance.

These considerations have an important bearing on the sampling period of instruments used to measure concentration. In the case of coalworkers' pneumoconiosis an instrument which sampled for as long as a week would be adequate to detect a potentially dangerous environment. On the other hand, in the case of the toxic gases an instrument which integrates the exposure over a week will fail to detect fluctuations in concentration which nevertheless are of sufficient duration to give rise to serious effects on the workers. An instrument which samples for an hour or even less might then be required to detect these small-period fluctuations. In other words, the period covered by each sample should be determined from a knowledge of the period of accumulation required to produce a harmful effect on man, as well as from a knowledge of the magnitude of the fluctuations in concentration.
The Habits of the Workers

To assess the risk to health from studies of the workers' environment it is necessary to measure the period of exposure to the air contaminant. For those materials which accumulate slowly the amount accumulated by the body will be roughly proportional to the time spent at work each day, while for the toxic gases the number of occasions for which the worker is exposed to concentrations above a specific level will again be roughly proportional to the time spent at work. The risk to health in both cases is higher for those workers who work the longest hours.

It might be thought that the period of exposure would vary very little from one group of workers to another in the same industry or from one worker to another, and could thus be assumed constant. We have investigated this assumption in coal-mines. Surveys were made of a particularly important and well defined occupation, that of the coal-getters at a number of collieries. The principal results at four collieries are illustrated in Fig. 2. The coal-getters are men who work at the coal-face digging the coal and shovelling it on to a conveyor. Usually it is found that more than 80% of their dust exposure occurs when they are actively engaged in getting the coal or fixing temporary roof supports. Detailed time studies were made at these four collieries to determine the average duration of this period of activity. The four columns in the figure are divided into three parts. The top portion of each column represents the average time spent walking while getting to the coal-face from the pit-bottom at the beginning of the shift and walking back at the end of the shift. The shaded portion is the average time spent actually working at the face, either getting the coal, fixing roof supports or otherwise actively engaged in useful work. The remainder, the dotted portions in the diagram, is the average time spent resting. The mid-shift break for food, lasting from 20 to 100 minutes, is included in this period. It will be seen that the average period of activity varied from five and three-quarters hours at Colliery A to a little under two hours at Colliery D. If the dust concentrations were the same in these collieries these hitherto unsuspected large differences in the duration of the period of activity would indicate that there are large differences in the dose of dust inhaled per day and consequently in the risk of developing pneumoconiosis. Similarly, the total time of exposure to concentrations above a specific level varies in a similar way. This might be of greater importance in other industries.

Individual workers also vary amongst themselves in the time they spend at work each day. Some habitually work overtime while others get through their work as fast as possible. They also vary in the number of days they work each year. It is well known that some workers attend much more often than others. In following the attendance of the coal-getters at one colliery it was found that the number of shifts worked during a year varied from 150 shifts to 300 shifts.

One might argue that these large differences in duration of exposure would not be found in industries other than coal-mining, but in our limited experience of other industries exactly similar conclusions were reached.

![Fig. 2](http://oem.bmj.com/)

Sampling Procedures

It will be clear from the earlier remarks that a really satisfactory sampling procedure must take account of the airborne concentration of the material being investigated, the fluctuations in concentration about the average and the period of time the men are exposed, the relative importance of these factors depending upon the manner in which the material accumulates in the body.

The concentration of air contaminants in a mine or factory varies from place to place according to where the material is produced and dispersed into the atmosphere, and according to the amount and direction of the ventilation. It follows that where air samples are taken at fixed sampling sites, such as the middle of a workshop, subsidiary information is also required to relate these measurements to the exposure of the men not actually working around the sampling instrument. This involves a complicated programme of time studies and surveys to determine the way in which the concentration varies from one position to another.

A sampling procedure which we have found to be much simpler in coal mines and, we believe, would be found equally useful in all other environmental surveys concerned with measuring the risk to health due to airborne contaminants, is that in which the sampling technician directs his attention to an individual worker throughout a working day (Oldham and Roach, 1952). The technician meets the worker when he arrives and samples alongside him until the worker leaves to go home. Samples are taken as far as possible within the workers'
breathing zone. On different days other workers are
chosen for study. The particular workers studied are
chosen at random from the whole population under
investigation. The random sample gives a fair cross-
section of the workers and the mean of the sample is
an unbiased estimate of the mean for the whole popu-
lation. The results provide unbiased estimates of the
mean concentration, the mean duration of exposure,
the variations in exposure from worker to worker and
to day to day, the magnitude of the fluctuations in
exposure over a period of time, and the variability from
day to day and worker to worker.

The results tell not only the risk to workers but also
the working places where the greatest exposure arises
and thus pinpoint the most important operations where
preventive measures would be most effective in reducing
the risk.

Interpretation of the Results

Having measured the exposure of the workers, the
next problem is to reduce the results to a single figure
which relates closely to the resultant risk to health.

There are, however, very few workers who stay in
one mine or factory doing the same job in the same
place throughout their working lives, and in order, for
instance, to make a fair appraisal of the risk of pneumo-
coniosis, the result of the accumulated experience of a
life time, the pattern of behaviour of the workers must
be taken into account. The length of time a man stays
in the industry and the frequency with which he changes
his job both affect his chances of developing pneumo-
coniosis.

The situation becomes somewhat simpler with materials
which are eliminated from the body at such a speed that
the amount in the body and resultant risk to health are
determined by the exposure over a period short in
comparison with the period that a man stays in a parti-
cular job.

With exposure to lead, for example, we could
reasonably expect a man entering the industry to stay in
the same job for at least a year or two, the period of
accumulation for lead. Also in estimating the risk to
health due to a toxic gas, in which equilibrium between
the body and the environment is attained extremely
quickly, the duration of employment and the changes of
job are of quite minor importance.

It is sometimes assumed that all men react equally to
the same exposure so that there is a fixed level of exposure,
measured in units appropriate to the properties of the
material, above which all men exhibit a given response
and below which none do. However, people do differ
from one another in their rate of working and con-
sequently in the rate at which they inhale the contaminant.
In addition they differ in their ability to tolerate foreign
materials. The magnitude of the exposure which causes a
specific response, whether it be a slight dizziness or a
serious illness resulting in death, will thus vary from man
to man according to their variation in individual
susceptibility. In addition, both the measurement of
exposure and the detection of the response are subject
to error, and will have an apparently similar effect since
those whose exposure is underestimated will appear
to be unduly susceptible while those whose exposure is
overestimated will appear to be unusually resistant.
The effect of all these variations is to produce a
continuous gradation of increasing risk with increasing
exposure (Roach, 1953).

We can conclude from this that although preventive
measures such as improved ventilation or dust suppression
will reduce the risk to health, they are, in practice,
unlikely to prevent the occurrence of symptoms of
excessive exposure altogether. For a complete safe-
guard periodic medical examinations are needed also
to detect the men who show the effects of excessive
exposure either because they are unduly susceptible or
have chanced to be exposed to harmful conditions.

Summary

In estimating the risk to health due to atmospheric
contaminants by measuring the atmospheric concentra-
tion the essential difference between different materials
is in the duration of the period of accumulation. Some
materials accumulate in the body until their rate of
removal equals their rate of deposition in the lungs,
when an equilibrium level is reached. Others are not
removed at all, so that accumulation continues steady-
ly throughout exposure. The period of accumulation
may therefore be one of only a few minutes, or it may be
the whole working life. The period of accumulation
determines the time scale of those fluctuations in
exposure which need be taken into account.

Examples are given to show that in measuring the
exposure of workers it is not safe to assume that their
duration of exposure is constant and it is recommended
that a sampling procedure based upon the exposure of
individual workers be used. In gauging the risk to
health the likely duration of employment and the
changes of job within an industry must be considered,
since both affect the risk when the period of accumulation
is of many years' duration. Owing to variations in
individual susceptibility and errors of measurement
there is a continuous gradation of increasing risk with
increasing degree of exposure. Consequently, preventive
measures may not eliminate the risks altogether, and
periodic medical examinations are needed as well to
protect the occasional case of excessive exposure.

REFERENCES
Henderson, Y., Haggard, H. W., Teague, M. C., Prince, A. L., and
Medicine, 9, 112.
Schrenk, H. H., Yant, W. P., Pearce, S. J., Patty, F. A., and Sayers,