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Instruments for use in Occupational Hygiene

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Dr. C. G. Warner, the retiring President of the Society, occupied the chair for the first day of a Conference held by the British Occupational Hygiene Society at Canterbury Hall, University of London, on April 16th and 17th, 1957. On the second day the new President, Dr. P. Pringle, Chief Medical Officer of the Central Electricity Authority, took over. The eight authors who presented papers were entertained by the Society at a dinner on the evening of the 16th, and the Annual General Meeting was held immediately before the Conference continued on the 17th.

The subject of the Conference embraced the nature and use of instruments for guarding the health of industrial workers in the performance of their various occupations, which nowadays so often expose them to potential danger if the materials they handle and their environment are not carefully controlled. Instruments specially adapted for preventing accidents and illness due to dust, poisonous gases and vapours, radiation, explosions and mechanical failure were enumerated.

Throughout the Conference a broad view was taken, both by the authors and by those who entered into discussion with them; general surveys of the techniques available, together with operational principles and their reaction upon design, featured more strongly than technical details, though the latter were by no means lacking. A striking characteristic was the enormous range of complexity featured in the instruments mentioned. Although electronic devices containing hundreds of valves and performing subtle and ingenious feats were required at one end of the scale, there was still an insistent need for the simplest possible hand pump sampler, which remained a subject for investigation and improvement. When faced with certain intractable problems even the most elaborate assembly of the physicists failed to give an interpretable answer and recourse was had to direct observation of effects upon the human subject. Clinical assessment of the state of health of a human being, based on meter readings derived from his environment, was possibly only in the most elementary circumstances.

SAMPLING PROGRAMMES AND SAMPLING INSTRUMENTS

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Introduction

THE title of this talk makes a clear distinction between two aspects of sampling which are not always dissociated. Most books on industrial poisons have a chapter on sampling, which consists, perhaps naturally, almost entirely of descriptions of sampling instruments. It is generally stated that great care is needed to collect a sample that accurately represents the quantity of air from which it is taken, since otherwise the careful work of the analyst may be wasted. Occasionally, some mention is made of the principles which must lie behind the design of a successful sampling instrument. However, recognition that the sampling problem does not end there is generally confined to one or two sentences such as "Since no atmosphere is likely to be uniform it is desirable to make tests at various points," or, "Most of the methods are snap tests and they will not record fluctuations in concentration, nor the mean concentration over a period of time; it may be necessary therefore to perform a series of tests at the same site." No one, not even the statistician, can complain at such sentiments, which are unexceptionable, but the reader might well complain that they give no help in answering questions such as "Where do I site my instrument?", "Do I need to sample at more than one place?", "How many samples do I need?", "How do I interpret the results?". The detailed answers to these questions depend on the local characteristics of the problem concerned, but there are general principles which can and should be understood by all. The present paper will endeavour to make some of these principles clear.

Although it is intended to lay down general principles, attention will be restricted to problems of sampling air for the presence of noxious substances which would in certain circumstances be harmful to the worker. It will be assumed that it is not intended to carry out continuous sampling, day in day out, since in these circumstances there is no need for a sampling programme at all. Within these limits, and they are not as restrictive as they may seem, I shall try to be as general as possible. When it comes to examples, however, these will be taken unashamedly from the field of sampling of airborne dust underground. This is partly because it is easier to illustrate from one's own experience, but also because so little has been published in other fields.

Factors Determining a Sampling Programme

The details of an experimental sampling programme are ultimately determined by three factors. First the environmental conditions with their changes in space and time; secondly, the information required from the sampling programme; and thirdly, the types of sampling instrument available. Of these factors, the first is one over which the experimenter has no apparent

control—he has to work in such conditions as are presented to him. The second factor is also largely beyond his control. It may be that the information which was at first asked for gives rise to such an unwieldy sampling programme that the original demands may be modified, but we must consider this as a fundamental condition which it is up to our ingenuity to overcome. These two factors are therefore in quite a different category to the third factor, which is the choice of sampling instrument. In fact, it is more strictly correct to say that we have four variables, two of which—the environmental conditions and the information required—being independent and the other two—the sampling instrument and the sampling programme—dependent. Either of the two dependent variables could then be described as being defined by the two independent variables and the other dependent variable. Thus in mathematical parlance we may write :

$$P=f(E,\ R;\ I)$$
$$\text{or} \qquad I=g(E,\ R;\ P)$$

where E, R, P and I stand for the environment, the required information, the sampling programme and the instrument respectively.

The fact that we have dared to write the relationship in such a simple form by no means pre-supposes that the relationship itself is simple, or indeed that it is one which can be expressed mathematically. The particular problem which is most commonly encountered is in fact to determine the sampling programme given the other factors. Since this is the aspect which is best known, we will therefore devote the most of our attention to it. In the final section of the paper we can see if some of the principles we have established for this better known problem may be transposed to the more difficult problem of specifying a sample instrument. It will not be possible to discuss this at any length, however, and the most useful section of the paper may well be written in the course of the subsequent discussion.

To begin with we will therefore consider in some detail the way in which the environmental conditions and the information required affect the type of sampling scheme which may be proposed.

Variations in Environmental Conditions

It is not possible to discover the patterns of environmental conditions without first carrying out a sampling programme. It is also not possible to design an efficient sampling procedure unless something is known of the environmental pattern. This paradox is no more than a re-statement of the obvious fact that it is foolish to embark on a large-scale experimental programme until some preliminary pilot work has been carried out ; in this connection a sampling programme is not to be treated more lightly than a research programme. The purpose of this section is therefore to examine the way in which environmental conditions can vary from place to place and from time to time, and thus to illustrate the information that such a pilot survey may be expected to investigate.

Most working tasks fall into a repeated pattern—based on the shift or a cycle of operations. It is convenient to consider the possible variations in conditions in two parts, those occurring in the course of a shift, and those changing from shift to shift. For convenience the shift has been chosen to represent the natural unit of change, but a cycle of operations or some other term could be substituted without affecting the principles.

The pattern of conditions that may occur during a shift may best be illustrated from an actual example. Table 1 presents the results of a survey to show the dust concentration at different places on a coal face while a cutter is in operation at different times during the shift.

Table 1

Mean Concentration (particles/c.c) at different Places on the Coal Face

Sample Number	Position				
	Time	A	B	C	Mean
1	9.00	1114	888	938	975
2	9.30	1058	1065	1071	1066
3	10.00	1216	—	746	931
4	10.30	1042	974	892	968
5	10.50	859	638	702	728
6	11.10	859	589	371	573
7	12.00	928	688	575	716
Mean	—	1011	806	724	833

Position A In return airway, 10 yards from end of face
Position B At end of face, downwind from cutter
Position C 15-20 yards downwind from cutter

Two main features are immediately apparent.

(i) At postition A the mean concentration is generally higher than at the other two sampling points.

(ii) The concentrations are generally lower in the last three samples than in the first four samples.

However, the concentration at each point does not exactly follow the pattern dictated by these position and time effects ; thus at 9.30 a.m. the concentration at A is apparently lower than at B and C. There are two possible reasons for this. The effect may be entirely fortuitous, due to sampling error, unsteadiness of air-flow or other unpredictable reasons. On the other hand it is possible that there was some feature of the operation that would cause low results at A at that time, this may be described in statistical jargon as a position—time interaction.

This example is no way exceptional, the variations within a shift must generally be described in terms of these four factors ; a position effect, a time effect, a position—time interaction and an overall random fluctuation. In a given problem any of the first three may be absent but all must be examined before a programme can be safely prescribed.

The above example is interesting not only because it illustrates the probable types of variation, but also their magnitude. Thus, the mean concentration at Sample 6 differs from that at Sample 2 by a factor of nearly two to one. The variation at position C, near to the machine, is even greater. It is clear therefore that a single sample, wherever it is taken, gives very little useful information as to working conditions. At

the very least, an average figure for the shift is required. Before we can say whether even a shift's average is of any value, it is necessary to repeat the experiment on a number of different days. It should then be possible to measure how the various effects alter from day to day, i.e., whether the pattern for different positions and different times is consistent or not. The experiment described above was repeated on seven different shifts and the results are summarised in the following Table, which shows the mean concentration at each sampling position on each day.

Table 2

Summary of Dust Concentrations on Several Days

Day	A	B	C	Mean
17.8.53	1011	806	724	833
20.8.53	740	520	843	682
21.8.53	679	664	635	655
15.3.54	607	615	511	572
16.3.54	760	836	791	791
17.3.54	883	730	807	798
19.3.54	637	530	597	553
Mean	740	665	697	689

Sample No.	Mean Concentration
1	773
2	738
3	782
4	724
5	624
6	643
7	574
Mean	689

It will be seen that the first day's sampling was not typical in that the mean concentration at position *A* was very much higher on that day than on other days. Indeed, on certain occasions, position *A* shows the lowest concentration. There are a number of possible factors to examine in a mass of data of this kind, and these can only be satisfactorily sorted by use of the statistical technique known as analysis of variance. No attempt will be made to present this analysis in detail, but a summary of the conclusions may be of value.

The greatest source of variation, after the overall short term fluctuations was the change in mean concentration from day to day. The tendency for the concentration to drop in the latter half of the shift persisted from day to day, but the magnitude of the drop varies from day to day. Although one position or another may appear to give high results on a particular day, there is no consistent tendency of this kind. The above analysis does, therefore, draw attention to the fact that although patterns of variation may exist on a particular day and may, indeed, persist from day to day, they are generally outweighed by changes in conditions occurring from day to day. As a consequence, there seems to be little point in taking anything less than a shift average as the basic unit for a sampling procedure.. Furthermore, the variations occuring between shifts are large enough for it to be unlikely that a single shift's sampling will provide a sufficient picture of conditions.

The Purpose for which the Sampling is Required

The Need to Define the Information Required

When a new field of investigation is being opened, so that perhaps only one type of sampling instrument is available, and little is known of the appropriate sampling techniques, it is often necessary to state requirements in the broadest terms. In fact, instead of designing a sampling scheme to provide the information required, it is often a matter of carrying out the only sampling programme possible and seeing what information comes out. On the other hand, as soon as there is some knowledge of the environment and a choice of sampling procedures and instruments, it is generally necessary to concentrate attention on certain items out of all that could be studied. To take a simple example, until recently the only instrument for obtaining a reliable measure of the dust concentration at a working place underground was a conventional type of thermal precipitator which took samples over a period of about twenty or thirty minutes. If sampling was carried out for longer than this the dust deposit became too dense for reading, whereas if sampling was done for a shorter period the trace was too thin to provide an accurate measure of dust concentrations. As a consequence information was automatically available as to the variation in dust conditions from one half-hour period to another, whatever further information was obtained as to the average conditions during a shift or in the variations from shift to shift. At the present time several modifications of the standard instrument are available which provide a single sample representing average conditions over a shift. Such instruments considerably reduce the labour both of sampling and evaluation and are therefore much more efficient instruments provided that detailed information is not required as to what happens during the shift. This very simple example is illustrative both of instrument design and of the design of sampling programmes. A gain in efficiency, whether it results in a reduction in labour or an increase in the precision of certain information, is usually only obtained at the expense of a less precise knowledge of certain other factors.

Perhaps the most fundamental decision that has to be taken before designing a sampling programme is to decide whether the sampling is to be carried out for the purpose of measurement or control. At first sight the distinction may seem to be an unreal one, since up to twenty years ago all sampling programmes were primarily designed for the purposes of measurement and yet were used for control as well. However, some of the most exciting work in the field of practical statistics in the last twenty years has been aimed at the problem of what sampling procedures should be used if we only require to know whether conditions differ from a specified standard. It can easily be seen that in some circumstances a sampling programme of this sort will result in very much less work than a programme which sets out to measure the average value of some parameter to a given precision irrespective of whether it is close to the standard or not. Thus, if the conditions at a working place are so dusty that you cannot see your neighbour, very little sampling is required to discover that conditions are far worse than any reasonable standard would allow, whereas a great deal of sampling might be necessary to establish the average dust concentration with any accuracy. In such a situation a method of control sampling, which is only concerned in detecting whether conditions are

different from the standard, will obviously result in less work than a sampling programme designed to measure the mean concentration.

Measurement Sampling

The main reason for measurement sampling is to find out sufficient about the conditions in which men work, and their reaction to them, to be able to say that so much exposure in an environment of a given composition is likely (at some probability level) to cause the disease. It will be observed that it has been necessary to phrase this in terms of probabilities, since absolute certainty either as to the environment or a man's reaction to it can never be obtained. An essential feature of sampling for measurement is that it is necessary to measure the environment in which the man actually works and to relate this, together with other relevant factors, to his medical history. With certain industrial diseases, a closer correlation with a man's condition might be obtained if his actual consumption (whether of dust, gas, etc.) could be measured. This total consumption will be both a function of the type of work and of the individual concerned; Dr. Lawther will no doubt have more to say of the variation between individuals and their use as measuring instruments in the next paper. For the present we shall be concerned only with the environment, and the need to obtain an unbiased estimate of the amount of toxic material present with as great precision as possible.

Control Sampling

With control sampling, the picture may be different. This type of sampling is carried out primarily to see that conditions in which the men work are " safe," although it may also be desirable to provide secondary information as to what particular operations need further study if conditions are unsatisfactory. It will generally be advisable to concentrate on the primary purpose, since rather than provide at all working places a lot of information which will only occasionally be required, it will generally be found more efficient to use the primary sampling scheme as a sieve and to devise a subsidiary sampling programme to examine those places where further preventative measures may be required. The major feature which distinguishes control sampling from research sampling is that it is no longer necessary directly to sample each worker's environment. For example, in industrial quality control a machine may be set up to produce articles to a certain specification; experiments are carried out to determine which is the best setting of the machine to provide articles to meet the standard, and how far the setting may alter before unsatisfactory articles are produced. The control may then be carried out by testing the articles to see whether the setting has altered, and the tests may never be carried out directly against the standard itself. In effect, a secondary standard has been established. This same principle may be applied in environmental control sampling. As an example consider the problem of ensuring that conditions are safe at the coal face. Here, work is being carried out at all positions along the face, each operation producing additional dust. The air moves from one end of the face to the other with some leakage, and conditions at the end of the face are generally at least as dusty as they are at any point of the face, and are usually more dusty. It is, therefore, satisfactory to exercise control on dust conditions on the face by measuring at the return end of the face. Indeed, such a system is more satisfactory than sampling at any place on the coalface, for in this way it is possible to exercise control over the whole face, whereas otherwise control can only efficiently be exercised for a single worker at a time. It is apparent therefore that if sampling is to be carried out for control purposes, both the sampling position as well as the sampling procedure may be different from that used in measurement work.

It is, of course, not sufficient just to decide that the problem under consideration calls for control sampling, since " control " implies the existence of specified standard conditions defining a border between safe and unsafe conditions. It is of the utmost importance that this borderline should be stated in unambiguous terms and in a manner which is capable of being incorporated into a rational sampling procedure. It might be thought that the borderline should be stated simply in terms of a given concentration but such a figure in itself is meaningless. Would it refer to the concentration returned by a spot sample or one lasting five, ten or twenty minutes, or to the average of a number of samples? Would it refer to an average figure which should not be exceeded or a limiting level which should never be exceeded? If the standards are to be meaningful, and a positive contribution to the health of the worker, it is essential that standards should be thought out with such questions in mind. The following are some of the points that need to be borne in mind when preparing standards for a sampling programme:

(i) Care must be taken that the standards are couched in terms appropriate to the problem under consideration. It is not possible to assume that sampling procedures and sampling standards appropriate to one problem in the field of industrial hygiene are necessarily appropriate in another. e.g., Problems such as the detection of accumulations of explosive gas, or the detection and prevention of fires, call for entirely different procedures from those which apply in the prevention of, say, lead poisoning or silicosis, since the immediate danger associated with the former leads to standards which are quite inappropriate to the latter.

(ii) Confusion often arises because a clear distinction is not made between control sampling of the worker's environment and sampling to ensure that the preventive measures associated with a particular machine are in operation. For example, if we wish to ensure that the preventive measures associated with a particular machine are effective, it is necessary only to sample when the machine is in operation. If, on the other hand, we are sampling to measure the total dosage received by a workman, it is satisfactory to sample continuously throughout his possible time of exposure. In the former case, continuous sampling is not possible unless it is geared so as to stop and start with the machine. It is not possible satisfactorily to sample for both at once.

(iii) Standards are often expressed in terms of maximum permissible conditions. This, however, is quite unsatisfactory for any type of intermittent sampling procedure. In such a case it is never possible to provide absolute certainty that a limiting value will not be exceeded and it is only possible to couch our beliefs in terms of probabilities. Moreover, the probability of exceeding a given limit is not only a function of the average conditions but of the variability of the conditions. This means that the so called maximum permissible concentration is not simply related to the dangerous dosage as measured by the mean. It would appear, therefore that any rational secondary standards must be based upon mean concentration and not on maximum concentrations; it is possible that in this they might differ from the corresponding primary standard.

Finally, when discussing the purpose for which the sampling is required it may be salutary to draw attention to what no sampling procedure can do. First, no sampling procedure can, or should, directly affect the conditions it is measuring. It is sometimes implied that if conditions at a working place are unsatisfactory, sampling should be increased in frequency until conditions improve, whereas there is more justification for not taking more samples until practical steps have been taken to remedy the situation. Secondly, it must be realised that unless sampling is continuous, there can be no absolute assurance that conditions are always satisfactory; there can only be a strong probability, couched if required in numerical terms.

Sampling Programmes

Types of Error

The need for a sampling programme arises from the fact that it is not generally possible to keep and maintain an accurate record of all conditions in which the men may be working at all times. It is therefore necessary to make a selection, or sample, of all the possible positions and times, and to use the information so obtained as a measure of the conditions as a whole. The whole value of such a procedure depends on it being sufficiently reliable and before discussing the design of suitable sampling programmes it is desirable to consider the ways in which the results may be misleading. Briefly, the errors of sampling may be divided into two classes. The first of these are known as random errors, that is errors leading to results sometimes being higher than and sometimes lower than the true figure. Random errors can never be entirely eliminated from a sampling process; they are present to a lesser extent when sampling chemicals in a laboratory and to a much greater extent when sampling in environmental conditions, but they are always present. These random errors may usually be measured and, if necessary, their magnitude can be reduced by increasing the number of samples taken. The second class of error is known as systematic error, or bias, and such errors are particularly dangerous since they are difficult both to detect and eliminate. Bias is difficult to eliminate since it will be common to all samples taken according to the same programme so that the error cannot be reduced by increasing the number of samples. In fact, it can only be eliminated by changing the programme. Bias is difficult to detect since it can only be revealed by checking either against the true figure, which is seldom available, or against an unbiased sampling method. It is important therefore to know the principles on which an unbiased sampling programme must be built.

Programmes for Measurement

For simplicity, let us consider the sampling programme necessary to measure the average hazard of a group of workers. We shall assume that an individual sample consists of an estimate of a particular worker's environment for one shift. So far as possible we wish for a complete or systematic coverage of all items—i.e., every worker and every day of the week. For example if there are only five workers, and if we can sample during a working week, then we can sample each worker once, and sample one worker on each day, but we cannot sample each worker on each day. It is therefore necessary to choose the particular day on which a particular worker is to be sampled, in such a way that the final answer will not be biased. This is done "at random"—i.e. by allotting each worker a number and then taking them in the order indicated by a table of random numbers, say 1 5 2 4 3. If the experiments were repeated a different random order might be chosen say, 3 1 2 4 5. By this means we ensure that there is no tendency to sample a particular worker on a particular day. If the experiments were carried on for five weeks, it would be possible to obtain a more systematic arrangement, so that each worker was sampled once on each day of the week. Thus the sampling pattern might be

1 2 3 4 5	or	3 5 2 1 4
2 3 4 5 1		5 2 4 3 1
3 4 5 1 2		1 3 5 4 2
4 5 1 2 3		2 4 1 5 3
5 1 2 3 4		4 1 3 2 5

The latter, randomised, pattern is to be preferred. Generally speaking, therefore, an unbiased sampling scheme will cover as many factors at it can in a systematic fashion, and will then randomise everything else to avoid bias. If in our example we had had more than five workers to consider we should have either had to split them into five groups. selecting a man randomly from each group on the appropriate day or a man would have to be chosen randomly on each day.

A further difficulty arises when samples cannot be taken continuously, and certain times of sampling have to be chosen. A natural procedure would be to sample systematically at regular intervals of time. Such a procedure may however lead to error if there is any periodic pattern of dustiness. To take an obvious example, if a sample were always taken on the hour and meal breaks always occurred near the half-hour a sample would never be taken during the breaks when no work was being carried out. Some modification of the procedure is therefore necessary. One alternative is to take samples at random during the shift. This could therefore be done in the following manner.

(i) Allot a number to every $\frac{1}{4}$ hr. in the shift.
(Thus 8.00=1, 8.15=2 . . . 4.45=36, 5.00=37).

(ii) If, say, nine samples are to be taken, choose nine numbers from a Table of random numbers (say, 23, 6, 18, 2, 35, 5, 28, 14, 30).

(iii) Rearrange the random numbers in ascending order (2, 5, 6, 14, 18, 23, 28, 30, 35).

(iv) Substitute the corresponding times for the random numbers. (8.15, 9.00, 9.15, 11.15, 12.15, 1.30, 2.45, 3.15, 4.30).

These are the random times at which samples should be taken. An alternative procedure is to choose a sampling time at random within each hour, e.g., 8.45, 9.00, 10.25, 11.50, 12.50, 1.10, 2.20, 3.35, 4.05.

The steps in the procedure for measurement sampling should by now be clear.

(i) Enumerate the factors which may affect the answer, e.g., worker, place of work, day of week.

(ii) So far as possible cover these systematically and completely.

(iii) Where this is not possible, randomise.

A sampling procedure designed on these lines, and known as the " Random Collier " method has recently been proposed by Oldham and Roach[1]. Its first application was, as the name implies, for assessing the amount of dust in a coal miner's environment, but its possible application is quite general. It will usually be desirable to sample different occupations separately (e.g., as in the Pneumoconiosis Field Research of the N.C.B.). The results will then yield an unbiased mean exposure for each occupational group with a knowledge of the variability of results and an estimate of the accuracy of the final mean.

The previous examples have been discussed in terms of measurement of the environment of individual men. To complete our study of measurement sampling programmes, we should consider an alternative approach in which sampling is carried out at fixed positions in the working space rather than in the vicinity of individual men. Such a method is obviously convenient and would enable us to establish the general pattern of dustiness in the room. Unfortunately, such information cannot be used to estimate the hazard to which the men are exposed unless the pattern of their movements is also known, since they may spend a disproportionate amount of time in certain parts of the room. If this were possible, then a very complete picture of the hazard for all men in the working room could be established. The labour required in obtaining such information is considerable however, and this will often force one back to the " Random Collier " approach.

Control Sampling Programmes

Sampling for control purposes calls for a different approach. The procedure is, generally, not to attempt to obtain an average figure for conditions as a whole but to set up subsidiary standards relating conditions at one or more positions to conditions in the room as a whole. This means that the complication that was introduced into measurement sampling by randomisation may be avoided. Indeed, rather than try to eliminate bias, we may deliberately encourage biased sampling—provided of course that we can relate the results obtained to actual conditions. Thus, if there is forced ventilation in a room it may be possible to carry out effective control by examining the air exhausted from the room. The mean concentration might well be below that at certain points in the room, but the two are likely to be related, so that an increase in concentration at one place will be reflected by an increase in the concentration in the exhausted air. Alternatively, sampling might be carried out at a point where the concentration of noxious material was greater than at any place where work was done. In either case, sampling might be effective for control purposes, even though it were biased.

The ultimate purpose of a control sampling programme is to decide whether conditions are " safe " or not. To do this satisfactorily, three main requirements are necessary. The procedure should, of course, be consistent, i.e., if the sampling is repeated the same decision should be obtained. Secondly, it must lead to a definite decision; it is not satisfactory, at the end of a sampling programme, to say that insufficient information has been obtained. Finally, the programme should be as short and economical as possible. The first two factors inevitably conflict with the third, since if it is insisted that an answer should be given when insufficient work has been carried out, there is inevitably a chance of obtaining a different answer if the sampling is repeated. In particular, it is not possible to carry out effective control sampling using spot samples. Thus, in industrial quality control the mean of a number of samples is usually taken, whereas for sampling on the coal face, a shift average is the very smallest unit that is worth considering. Even then a decision cannot usually be reached on the basis of a single shift's sample. The number of samples required for a decision will depend to a large extent on the sort of divergence from standard conditions that is considered to be allowable. Thus, if it is essential that a deviation of 20 per cent from standard conditions should be detected, it will be necessary to take sufficient samples such that the standard deviation of the mean is of the order of 10 per cent.

The obvious method of interpreting the results of routine sampling is to take the average of a prescribed number of samples and then to see if this is greater or less than the standard figure. Such a procedure has certain disadvantages. If the number of samples prescribed is such that the results are consistent unless the average conditions are very near the standard (absolute consistency is unobtainable in this fallen world), then far too many samples will be taken in cases where conditions are very bad or very good. A more satisfactory plan is to use one of the many sequential procedures which have been devised by statisticians in the last fifteen years. The purpose of these schemes is to enable the experimenter to continue sampling only until he has enough information for a decision. After each sample he reassesses the position, and stops as soon as he has an answer. It may be of interest to describe a procedure of the type which we have recently been trying out within the National

Coal Board as a means of detecting whether conditions are " approved " or not. " Approved conditions " are defined by agreement as being " not exceeding 850 particles/c.c. over periods of maximum dustiness." As 100 per cent certainty cannot be obtained, this has been interpreted as ensuring that the shift average figure (over periods of activity) should not exceed the limit on more than one shift in ten. Using information already available as to shift-to-shift variability the procedure was deduced as follows.

A face may be " approved " if a single shift's sample is less than 450 particles/c.c. or if two successive samples between 450 and 700 particles/c.c.

A face is " not approved " if a single shift's sample exceeds 850 particles/c.c. or if two successive shifts' samples give values between 700 and 850 particles/c.c.

The theoretical justification for these procedures is given in Ref. 2. On the average it is possible to make a decision after about two visits to each face ; only rarely are more than three visits necessary. Such a scheme may not be applicable in detail in many cases, but there are similar schemes which could be applied with advantage in many instances.

It should, perhaps, be pointed out that such a scheme, though an improvement on most previous methods of control sampling, is not yet the ideal. Ideally, a method of statistical control is most efficient when it is set up to detect changes from an equilibrium value. In practice, this would mean that preliminary sampling would be carried out when preventative measures were applied and fully in operation ; this would establish a norm. Further sampling would then be designed to show when conditions had deteriorated from the norm, so that remedial action could be taken ; this might be long before the " standard " was exceeded. Such a system is obviously preferable to testing directly against the standard, where the warning can only be given when conditions have already deteriorated beyond desirable limits. Here, as elsewhere, the gain in efficiency is not obtained free of charge. The setting up of norms on individual machines, or occupational groups, may be a task which is economically impossible. We can only state the principle, and decide each case on its merits.

The Choice of Sampling Instruments

What has been said in previous sections of the paper may appear to have little bearing on the design or choice of sampling instruments, and this may be partly true. Certainly the principles which have been stated are true whatever sampling instruments may be used. Nevertheless, these principles have set out certain conditions that the sampling instrument must satisfy. Thus, both for control and measurement sampling, it is desirable to use a shift average as the basic figure so that the sampling instrument should preferably provide an integrated figure for the whole shift. Whether this integrated figure can be obtained from sampling continuously throughout the shift or not depends on the purpose of the sampling. If this is done to control or measure the worker's total dosage throughout the shift sampling should be continuous. If, on the other hand, sampling is carried out to ensure that preventative measures are in operation on a particular machine or group of machines, the sampling must in some way be geared to the machines.

Another feature of some importance is the robustness and portability of the instrument. For measurement sampling, which involves following the workman throughout the day, portability is vital. Robustness may be important, but the instrument is likely to be in the hands of a trained operator. For control sampling, however, the instrument will usually be located in one place so that portability is not so important. On the other hand, it may be desirable to have it operated by unskilled personnel so that robustness will be essential. Moreover, it will be left unattended for periods of a shift or so, so that it must be reliable and safe from damage by inquisitive fingers. Such factors may be of the utmost importance. Most instruments tried out underground fail from the point of view of robustness and construction rather than principle.

Finally, no paper connected with modern development of science and technology is complete without some discussion of automation. This is particularly true in the field of instrumentation, which has made automation possible. Is there any hope of automation in environmental sampling? So far as measurement sampling is concerned there does not appear to be much hope unless we develop more satisfactory sampling instruments to be attached to a man, so that his environment is automatically measured wherever he is working. In the field of radiation and X-ray, this is available in the crudest form by the use of films carried in workers pockets, but such methods have not been much developed in other fields. For control sampling the prospects appear to be brighter, particularly if the standards are couched in the right terms. An instrument which records average figures for a shift or more, and which is operated by the turn of a key is already far on the road to automation. How far it is desirable to have a complete continuous control is, of course, a matter for debate. For fire prevention, continuous detectors are essential but whether it would ever be necessary or economical to instal completely automatic control for the purposes of industrial hygiene is a matter for local circumstances to decide.

Acknowledgments

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DISCUSSION

Points emerging from the discussion of Mr. Tomlinson's paper centred around his concept of control sampling. Continuous sampling was stated to be necessary to estimate a man's full exposure and would include the effects of peak concentration automatically, thus eliminating the chance of missing those transient conditions if spot sampling was employed. It was felt, however, that peak concentrations should be controlled as well as the average values, at least for some substances. There was often a lack of correlation between the actual exposure of an operative and the amount of dust in the general atmosphere.

SOME INSTRUMENTS AND INSTRUMENT TECHNIQUES IN USE AT THE SAFETY IN MINES RESEARCH ESTABLISHMENT

By C. A. A.Wass (Deputy Director) and S.M.R.E. Staff

Synopsis

STUDIES of the ways in which the safety and health of mine workers can be maintained and improved lead to the need for a wide variety of measurements and observations including :

Observation and recording of phenomena associated with the development of explosions in gases and dust clouds using high-speed cameras and devices for measuring blast (wind) speed, explosion pressures, etc. ; examination of the air in mine roadways to determine the proportions of inflammable gases, especially methane ; estimation of the concentration of respirable dust in the mine air and study of the dispersion of dust from its source ; determination of the proportions of quartz and other minerals in samples of dust from mines and from human and animal lungs; observation of the smaller dust particles by means of electron microscopes ; high-speed photography of the growth or decay of flame kernels initiated by small electric sparks ; non-destructive testing and metallurgical examination of cage suspension chains and other mine gear.

Introduction

The Safety in Mines Research Establishment of the Ministry of Power is engaged in applied and fundamental research with the object of promoting the health and safety of workers in all the mines and quarries of Great Britain. The work covers a wide range of scientific and technical topics ; some of the instruments and instrument techniques in use are described in this paper, together with brief references to the background of mining problems.

Explosions

In most years the number of accidents in Great Britain due to explosions is relatively small, but there have been in the past ten years two major explosions which between them killed 187 persons. Furthermore, although the more numerous small explosions and ignitions cause comparatively few casualties, each one is a potential disaster. The main work of the Buxton laboratories of S.M.R.E. is concerned with the study of explosions caused by gas or dust and instruments have been devised to examine the conditions of pressure, fuel movement and concentration immediately before and during explosions (Fig. 1).

Blastmeters

Continued propagation of a dust explosion depends on the ability of the blast ahead of the flame to raise dust from the floor and disperse it as a cloud of the required density. Two types of blastmeter have been devised to measure the magnitude and record the variations in the blast ahead of explosions of varying strength.

In one type of blastmeter, called the " reed anemometer," a reed in the form of a thin steel blade, is clamped at one end and positioned to present one face of the blade to the wind. Deformation is measured by electrical strain gauges on the faces of the reed. Wind speeds of the order of several hundreds of feet per second have been recorded during a fully-developed coal-dust explosion.

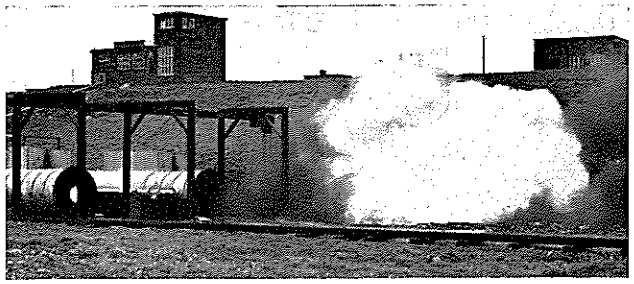


Fig. 1.—Explosion of coal dust in Buxton gallery.

Another blastmeter records the phase difference between signals from two receivers equi-distant from a sound transmitter in the same horizontal plane but on the opposite side of the gallery[5]. With still air in the gallery the received signals are in phase : a phase difference indicates air movement and the magnitude depends on the air speed. One advantage of this method is that there are no obstructions in the gallery.

Flame Triggers

An established explosion can be quenched if a suitable agent such as water or stone dust is uniformly dispersed in sufficient quantity ahead of the flame. There is thus a need for an explosion detector which will automatically disperse a quenching agent. The device must be fool proof and simple and must not deteriorate if left standing for long periods ; it must not provide any additional hazard from use, misuse, or accident, and it must operate within a few milliseconds of receiving an impulse.

For various reasons, methods operated by light, by infra-red radiation ahead of the flame, or by atmospheric pressure changes were all considered unsuitable, and it was decided to use the heat in the explosion flame. A device using a thermistor has been developed, but the standing life is limited by battery drain. A simpler device uses a spring-loaded switch which is permanently held open, against the spring, by means of nylon threads 0.005 in. diameter. The threads are protected from accidental mechanical damage but are exposed to an approaching explosion flame. Within 15-20 milliseconds of arrival of flame the thread softens sufficiently to allow the switch to close and the resultant electrical signal can then operate barriers at suitable points.

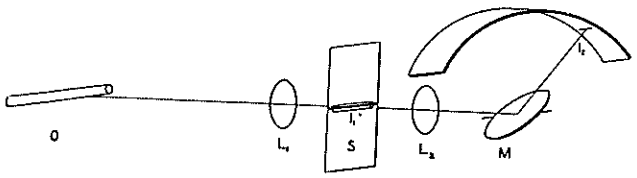


Fig. 2.—Rotating mirror camera for Schielren photography.

Cameras

Various forms of Schlieren camera have been used[1, 2] for photographing shock waves. The optical system of a rotating mirror camera for schlieren photography of shock waves from explosives, designed in 1940 but based on an earlier design[3] is shown in Fig. 2. Light from the object O is focussed by lens L_1 on a narrow horizontal slit S which thus restricts the field of view to a narrow band. After passing through the slit the light goes through a second lens L_2 to a rotating mirror M which is at the centre of a cylindrical film carrier. An image of the slit is formed on the film and thus, as the mirror rotates, a time-distance graph of the movement of the object is produced on the film.

For Schlieren photography a continuous background light is used and it is therefore necessary to restrict the passage of this light to one revolution of the mirror and to synchronise the event with this revolution. A slotted rotating disk, geared to the mirror, allows the light to pass for one revolution in each 16 revolutions of the mirror. A contact on the disk shaft triggers a circuit which operates a slow magnetic shutter and also arranges for the explosive to be detonated the next time light is reflected onto an adjustable photocell from a small mirror fixed to the disk shaft. This arrangement ensures the correct placing of the record on the film and prevents fogging.

The writing speed of this camera is nearly 400m/sec., which is adequate for waves having speeds up to 10,000m/sec.

A Courtney-Pratt camera has been used to record and study short duration self-luminous phenomena such as sparks or rapidly moving particles[4].

Pressure Gauges

The statutory testing of "flameproof" electrical equipment for use in atmospheres containing inflammable gases requires that gas/air mixtures should be exploded within the casing; the pressure developed by the explosion must be measured. For most purposes, a diaphragm gauge incorporating an optical lever for magnification of the deflection has proved adequate[6]. In certain circumstances, however, even very stiff diaphragms are distorted or vibrate violently and then a piezo-electric gauge is used[7]. A time-constant of about 30 seconds is required which is obtained by means of an impedance converter having an input impedance of 1,000 megohms.

Methane Estimation

Almost all major explosions begin with an ignition of a methane-air mixture, which in turn ignites coal dust, so that frequent and regular testing for methane is essential in most mines. The methane-air mixture is explosive if the methane content is between about 5 per cent and 15 per cent, and under the Mines and Quarries Act (1954) work is not allowed to proceed if the concentration of firedamp in the general body of the air at the working place exceeds 2 per cent by volume (2.5 per cent in certain prescribed circumstances); electrical power must be cut off is that concentration exceeds 1.25 per cent. Other actions are required at 0.8 per cent and 0.6 per cent.

The greater part of the "searching and testing" for gas is carried out today either by taking samples which are analysed later in the laboratory, or by estimating the height of the "flame cap" in a flame safety lamp. Laboratory analysis is inconvenient and slow, while the flame lamp relies very much on the skill, eyesight, and judgment of the user. Furthermore, the flame lamp cannot detect methane concentrations less than about 1 per cent. Portable methanometers of several other types have accordingly been developed.

Methanometers

The choice of operating principle lies roughly between the combustion of methane and the measurement of one of its physical properties. The instruments at present approved for use in British mines make use of combustion methods, which have the advantage of being specific to the hazard: the physical methods have, however, received greater attention in recent years.

The oldest approved methanometer is the McLuckie Type M (Fig. 3)[8]. Methane is burned on a platinum filament in a closed chamber and when the water produced by the reaction has condensed the change of pressure in the chamber is measured. High accuracy

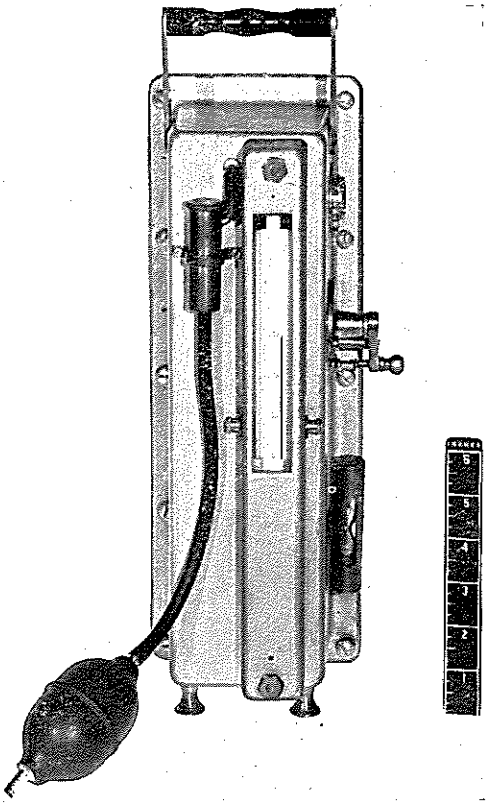


Fig. 3.—McLuchie methanometer.

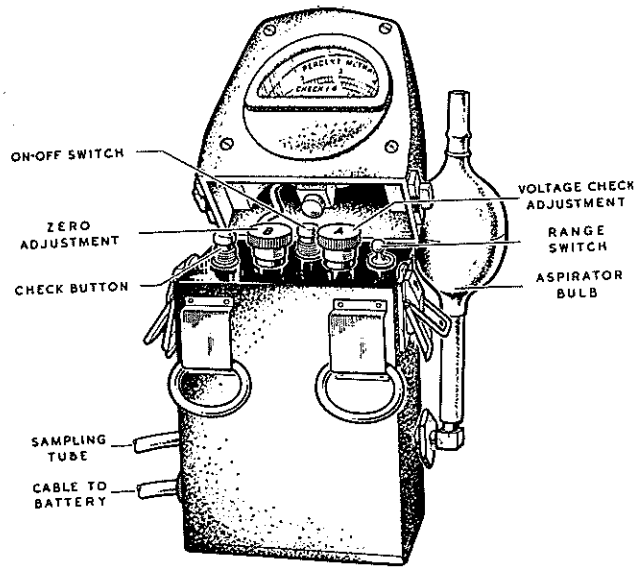


Fig. 4.—M.S.A. W-8 methanometer.

and sensitivity can be achieved provided the initial water vapour content of the sample is controlled. The instrument is slow in operation (7 minutes for one determination), heavy and bulky.

In the Ringrose Pocket methanometer[9], the gas to be tested is allowed to diffuse through the porous walls of a small cylindrical chamber for about a minute. When the palladium filament is switched on the methane is burned and there is a transient reduction of pressure within the chamber which is measured by a liquid gauge. The pressure changes are small, 3 cm. water corresponding to 2 per cent methane, and the scale of the gauge is rather cramped. Response is not entirely independent of the humidity of the atmosphere, but in normal underground conditions errors from this are small. A single determination takes about $1\frac{1}{4}$ minutes.

A disadvantage of both the McLuckie and the Ringrose methanometers is the use of a liquid-filled gauge which requires them to be carried upright.

Combustion Instruments

If a combustion filament is used as one arm of a bridge circuit the change in its resistance due to the combustion on its surface and consequent change of temperature can be conveniently measured by the out-of-balance current, which is roughly proportional to the methane concentration, up to about 2 per cent. This is the most popular of the various principles which have been suggested for portable methanometers, but successful application of this principle depends on the development of a stable, long-life filament. Simple instruments with one filament and three fixed bridge arms have given place to more precise models in which the sample is brought into contact with two matched filaments in adjacent arms of the bridge. One filament promotes combustion and the other one is rendered inactive and helps to compensate for changes in barometric pressure, temperature and humidity.

The Mine Safety Appliance Company's Type W-8 methanometer (Fig. 4) is of this type[10]. The combustion and compensating filaments are mounted in separate compartments of a metal block, and the air is passed through the instrument by a small pump. Only a small and controlled percentage of the sampled air reaches the filaments, by diffusion and convection through holes in specially shaped metal sheaths. This flow system allows some degree of continuous estimation, which is an advantage when making gas surveys. Adjustments are provided for balancing the bridge with both compartments filled with pure air before proceeding underground, and for setting the voltage applied to the bridge to a standard value before each test. Power is supplied from a battery which also supplies the miner's lamp. The meter has two scales, calibrated from 0 to 2 per cent and from 2 to 5 per cent methane, and estimations to within less than ± 0.05 per cent methane of the true value are possible on the more sensitive range : the error is greater towards the upper part of the higher range. Expert maintenance is required to ensure such performance which, with the cost of the equipment, tends to restrict its use to survey work by specialists and ventilation officers, rather than by deputies and shotfirers for routine duties.

The Verneuil 54 methanometer[11], developed by the Centre d'Etudes et Recherches des Charbonnages de France, is a more compact, single range (0-3 per cent) methanometer somewhat simpler than the M.S.A. instrument. Both filaments are mounted in a chamber which is first filled with the air to be tested by means of a small pump built into the instrument; after adjustment of the input voltage the bridge is switched to the battery. Only a single determination is obtained from the transient out-of-balance current with this system. Large-scale tests with this instrument are in progress in France, but experience in this country is limited to laboratory tests which have shown that it is sufficiently accurate for a general purpose instrument.

The National Coal Board have developed a combustion instrument in the form of a flame lamp with thermocouples which operate an electrical recorder.

Interferometer Instruments

In Japan and in Germany interference methanometers have been made (Fig. 5) [12]and several thousand are in use in Japanese mines. They are basically miniature interferometers of the Jamin type in which a beam of collimated light is split into two beams, each of which passes several times through a cell. One of the cells contains the gas sample and the other contains pure air. The two beams emerging from the cells are combined and a telescope is used to view the displacement of the interference fringe over a graduated scale. The displacement of the fringe pattern corresponds to the difference in the refractive indices of the air containing methane and of pure air, provided the oxygen/nitrogen ratio of the mine air remains normal. An oxygen deficiency of the mine air of 2 per cent corresponds to a reading of $+0.27$ per cent methane. Barometric pressure and temperature also affect the readings, but corrections can easily be applied. Where corrections for pressure have been made, the majority of readings taken underground should lie within $\pm\frac{1}{4}$ per cent. methane of the true value in the range 0-3 per cent.

In both instruments carbon dioxide and water vapour

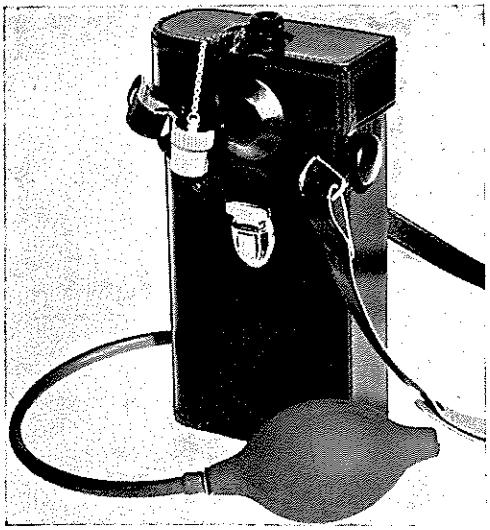


Fig. 5.—Zeiss interference methanometer.

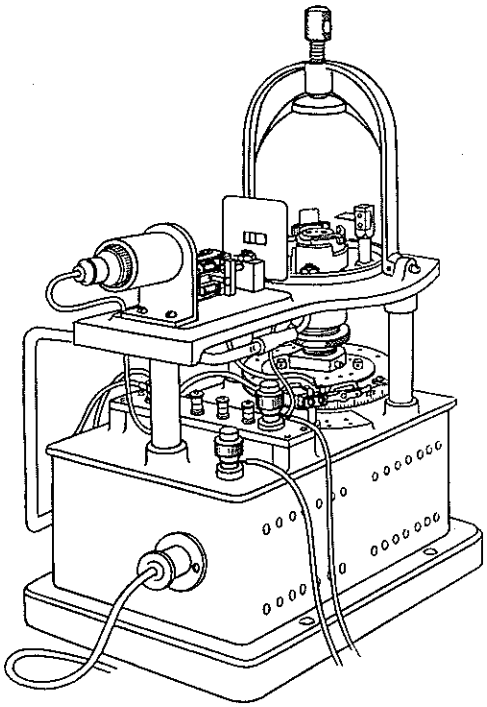


Fig. 6.—Break flash apparatus No. 3.

are removed from the gas sample by passing it through a small chemical cartridge. Underground trials are now in progress to assess their performance and to determine the degree of maintenance required in practical use. This class of instrument is relatively expensive in this country.

There is a need for a reliable and simple methanometer with low initial and maintenance costs. The accuracy should be such that 95 per cent of readings are within ±0.1 per cent methane. Development work is now in progress at S.M.R.E. on a combustion instrument using a heat catalytic element.

Electric Sparks

The methane which is often present in mine air is liable to be ignited in various ways; an important danger is a spark from electrical apparatus. Wherever possible, mine electrical equipment is designed and tested to be ' intrinsically safe '[41], that is, incapable of igniting the gas under any conditions of use, mis-use or accident. Only light equipment is amenable to this treatment; heavy apparatus, e.g., electric motors and switchgear, must be enclosed in flameproof housings.

The testing of the intrinsic safety of equipment makes use of what is called a " break-flash " apparatus[42]. There are several different types but they all provide for the interruption of an electrical circuit in a chamber filled with an inflammable gas mixture (Fig. 6). The type of instrument generally used for testing inductive circuits consists simply of a pair of contacts to which the circuit under test is connected and which are opened at a known, adjustable speed. Other forms of break-flash are available for capacitive circuits[43]. Standard electrical and electronic test-gear is used to provide information about the electrical behaviour of circuits under test.

Fundamental research on gas ignition by electric sparks necessitates, in addition to break-flash instruments, methods of observing the initiation and growth of flames in the gas. Image-converter tubes seem to offer a means of obtaining very short exposures in photographing flame kernels, and " shadowgraph " techniques [44] are used for observing the growth of the flame kernels (Fig. 7). It might be possible to measure the electrical energy in a spark by means of a very fast " micro-watthourmeter," which would integrate spark energies over periods of a few microseconds; this is being investigated. Among the more normal electrical and electronic test equipment required are fast oscillographs with high writing speeds and good high frequency response. It would be very desirable to be able to investigate the flame and spark emission spectra associated with gas ignitions but there appears to be little hope of obtaining sufficient light energy for this purpose.

Pneumoconiosis

A more serious real hazard than explosions is the disease of the chest known as coal workers' pneumoconiosis. Each year it is reported that the disease has caused or contributed to about eight hundred deaths[13], which is about twice the number due to all other underground causes, and five thousand new cases of varying degree of disability are certified. The annual cost of death grants and disablement compensation runs into millions of pounds. Nearly two million underground dust samples are taken and examined in the laboratory every year at a cost of several hundred thousand pounds.

Pneumoconiosis arises from airborne dust particles of stone or coal fine enough to penetrate into the alveoli of the lung[54], the dangerous size range being about 0.5 to 5 microns. Rock dusts cause more rapid fibrosis than the relatively inert coal dusts, though the present belief is that coal dust alone, in sufficient quantity, can cause the disease[14]. In British coal mines the conditions are regarded as " approved " if the airborne

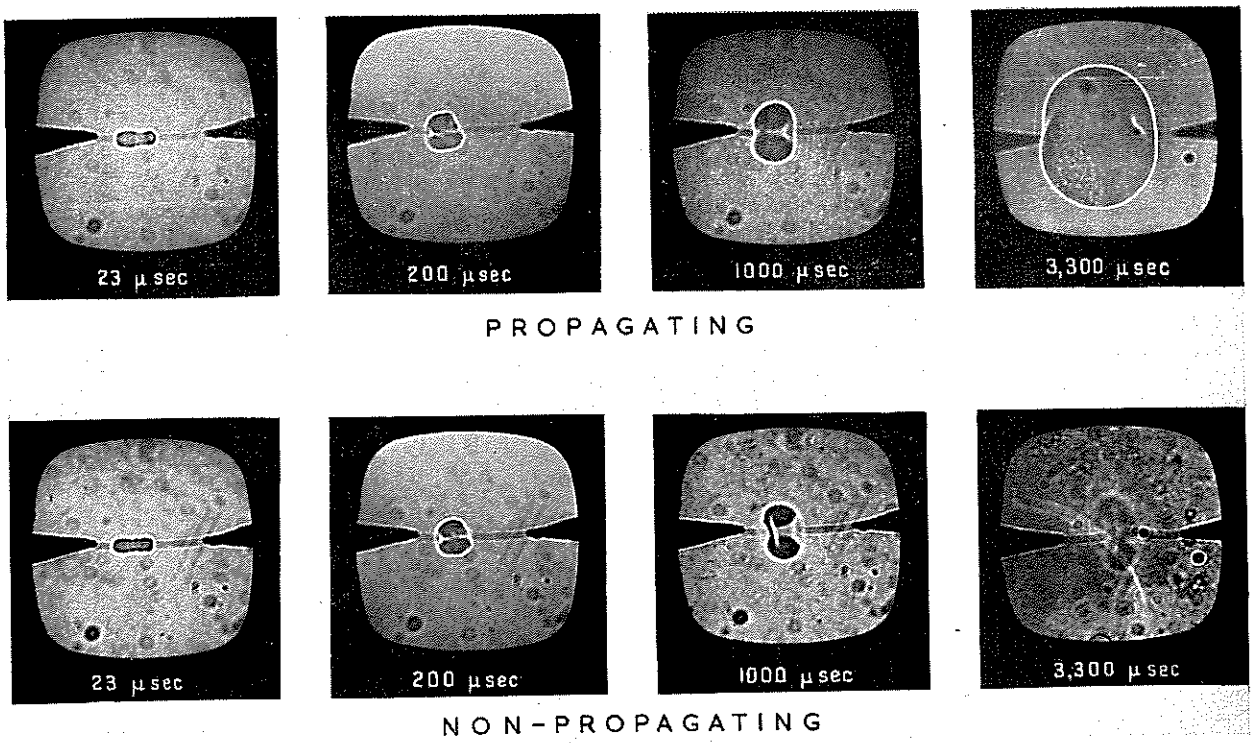


Fig. 7.—Growth of flame kernels.

dust concentrations at the periods of maximum dustiness are less than the following maxima : in bituminous coal, 850 particles per cm^3 in the size range 1 to 5 microns ; in anthracite, 650 particles per cm^3 in the size range 1 to 5 microns ; in rock, 450 particles per cm^3 in the size range 0.5 to 5 microns.

Dust Measuring Instruments

A dust sample may be taken from the atmosphere by thermal or electrostatic precipitation, inertial impaction, filtration, sedimentation or turbulent deposition, and the amount of dust collected may be evaluated by human or automatic microscope counting, measurements of optical transmission or reflectivity, Tyndall scattering, air permeability or weighing[15]. In all gross (non-counting) measurements it is essential that particles larger than the respirable sizes should be excluded from the sample. This is usually accomplished by elutriation[16, 17].

Up to the present the standard dust sampling instrument in British mines has been the thermal precipitator (Fig. 8)[18]. It has an aspirator which draws the dusty air at 7cm^3/min. for a few minutes past a hot wire in a narrow channel. The temperature gradient causes the dust particles to be deposited on the glass slides forming the walls of the channel and they are subsequently counted and sized by optical microscope. The instrument requires skilled operation.

In the konimeter (Fig. 9) 5 cm^3 of dusty air are drawn at high speed through a jet impinging on a glass plate ; the particles are deposited on the plate and are later counted by microscope. The force of impaction tends to shatter particle aggregates and even whole particles of friable material like coal, and the sample represents an even shorter period of time than that of the thermal precipitator. Nevertheless the konimeter has remained

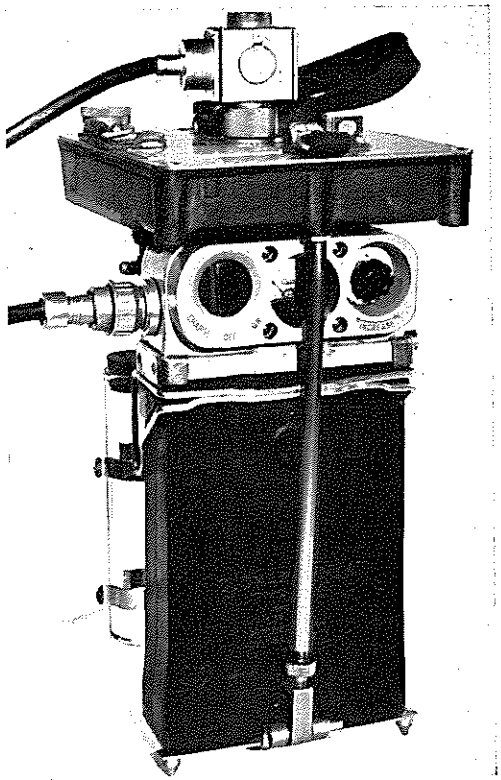


Fig. 8.—Thermal precipitator.

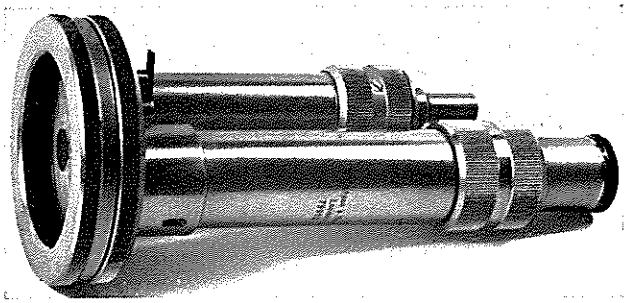


Fig. 9.—Konimeter.

in use for sampling rock dusts because of its compactness, ease of operation, and the fact that an approximate evaluation can be made on the spot.

Recent developments have indicated that for certain purposes there is a need for instruments which take samples over longer periods than either the thermal precipitator or the konimeter, and this need has been largely satisfied by the National Coal Board's long-running thermal precipitator (Fig. 10)[19]. This instrument may be taken underground and switched on by an unskilled person and it will sample automatically at a mean rate of 2cm³/min. for eight hours. The coarse particles are excluded by a horizontal elutriator while the respirable particles are deposited along a glass slide according to size. A microscope count gives the mean concentration during one working shift; in addition, the deposition of particles in different positions according to size offers the possibility of evaluation by an easier optical method.

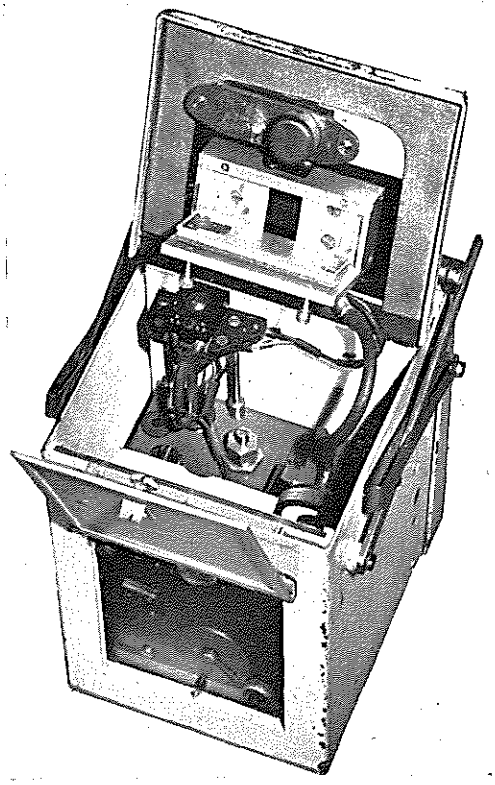


Fig. 10.—N.C.B. long-running thermal precipitator.

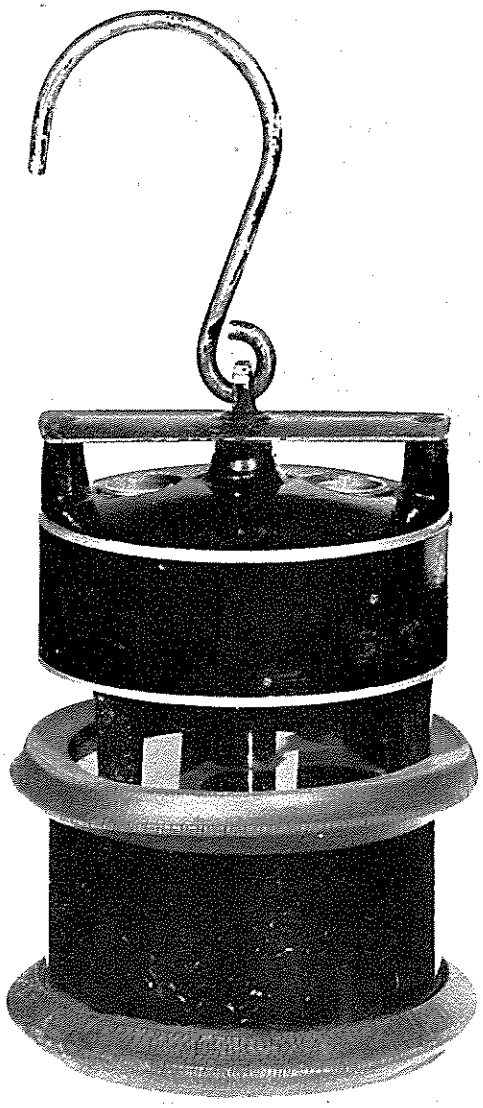


Fig. 11.—P.R.U. auto-sedimentation cell.

The Pneumoconiosis Research Unit has contributed a very compact sedimentation cell that can operate unattended for a week (Fig. 11)[20].

The advantages of automatic evaluation of dust samples on slides have been recognised for a long time[21]. S.M.R.E. is starting experiments with one of the automatic scanning machines now available in which an oscillating microscope stage of special design (Fig. 12) causes a fine pencil of light to scan the particle field. Interception of the light by dust particles is detected by a photomultiplier tube whose output pulses are counted and sized electronically (Fig. 13). The conflicting requirements of high resolution and adequate depth of focus in scanning a field of particle size range 1-10 microns may be avoided by scanning a thin metal-shadow replica of the specimen.

Some work has been done at S.M.R.E. on the refinement of the filter paper technique, in which a simple light-transmission measurement is made on the filter

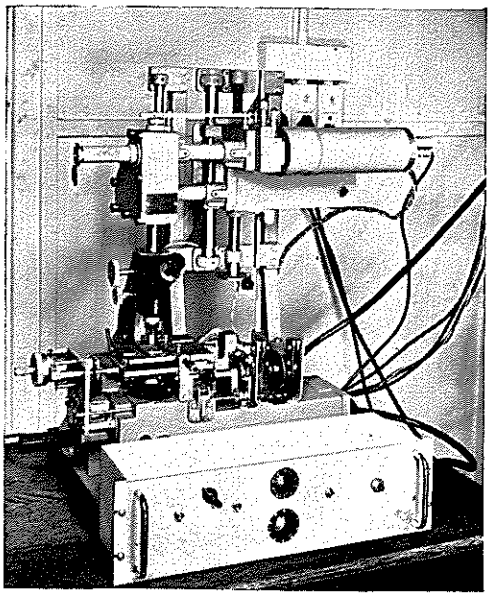


Fig. 12.—*Automatic particle counter (Microscope stage).*

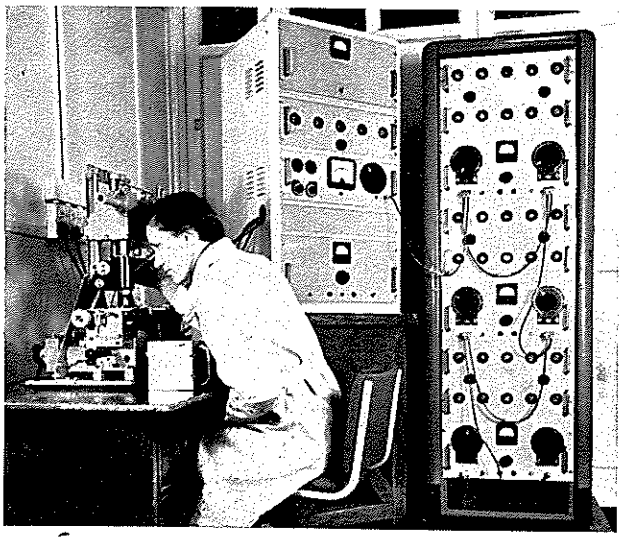
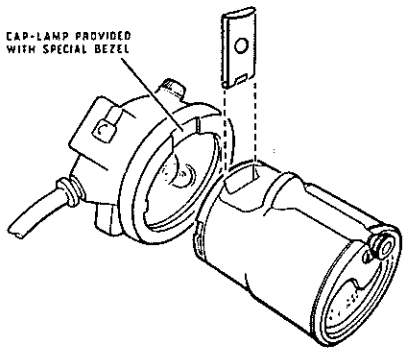


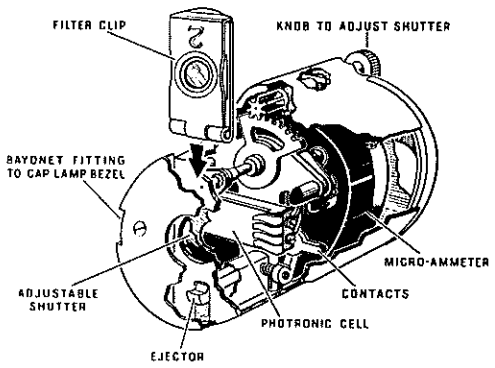
Fig. 13.—*Automatic particle counter (complete equipment).*

paper before and after the collection of the sample. A small densitometer for use underground has been developed, operated from a miner's cap-lamp (Fig. 14)[24], and the evaluation of filter-paper samples by airflow-resistance measurements is also under study.

The S.M.R.E. Automatic Handpump (Fig. 15)[23], which is a development of the Pneumoconiosis Research Unit Handpump, uses the filter paper method. A fairly constant 6-second pumping cycle is maintained by a pneumatically-controlled return stroke, and the coarser particles are eliminated during a 6-second wait in a settling chamber before the air passes through the filter paper. The S.M.R.E. Drum Pump Sampler (Fig. 16)[25] is a long-period filter-paper instrument sampling automatically for eight hours at 6cm³/min. by means of a clockwork-driven device resembling a wet-vane gasmeter. Coarse particles are excluded by



DENSITOMETER WITH CAP-LAMP HEADPIECE



INTERNAL CONSTRUCTION OF DENSITOMETER

Fig. 14.—*Cap lamp densitometer.*

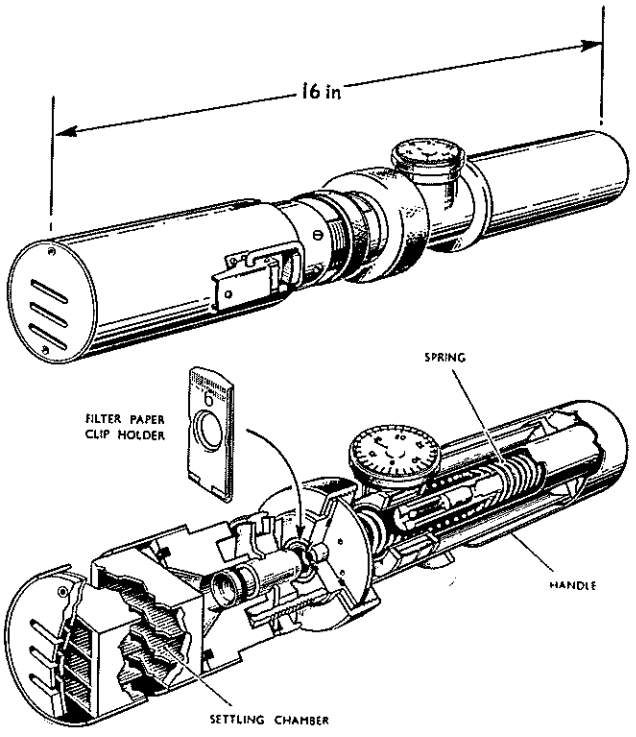


Fig. 15.—*S.M.R.E. automatic handpump.*

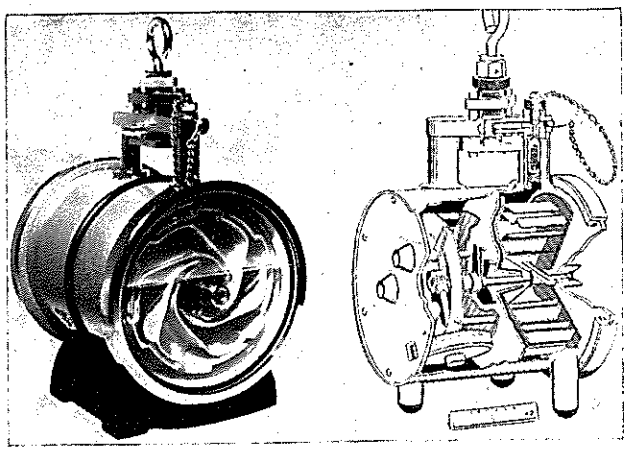


Fig. 16.—Drum-pump sampler.

vertical elutriation : the filter paper is horizontal and air is drawn up from below at a velocity of 9 cm/min. which is equal to the terminal velocity of a 7 micron sphere of unit density.

Gravimetric Sampling

Health standards have been defined in terms of particle number concentration, but a measurement of total surface area or mass of dust particles can also give an index of the health hazard. This distinction is important because particle size-distributions vary from pit to pit. Gravimetric measurements are especially attractive, but about 1,000 litres of air must be aspirated to give a weighable quantity of particles smaller than 5 microns, and so far there is no suitable self-contained instrument.

S.M.R.E. has developed a size-selecting version of the American midget impinger suitable for underground use (Fig. 17)[27].

Dust Dispersion

Radio isotope techniques are being used at S.M.R.E. to study the manner in which respirable dust is dispersed in the ventilating air, since the existence of spatial variations in dust concentration greatly influences the way in which sampling instruments should be used[26]. Time variations in concentration, during and between shifts, have been studied underground.

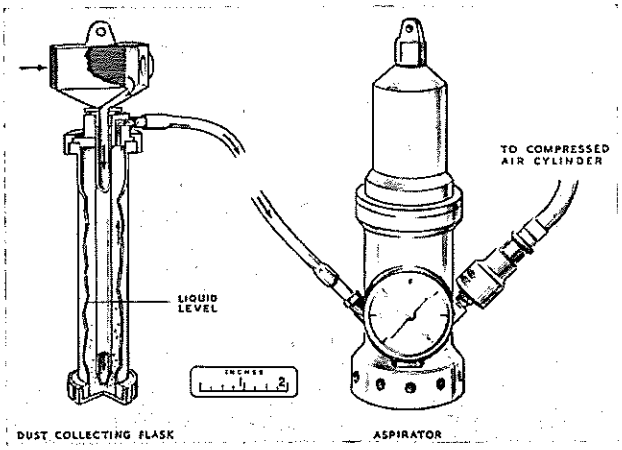


Fig. 17.—Midget impinger S.M.R.E. version.

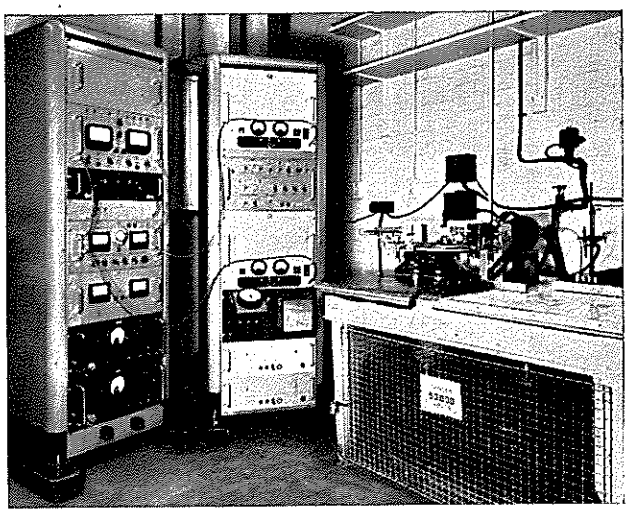


Fig. 18.—X-ray counter diffractometer.

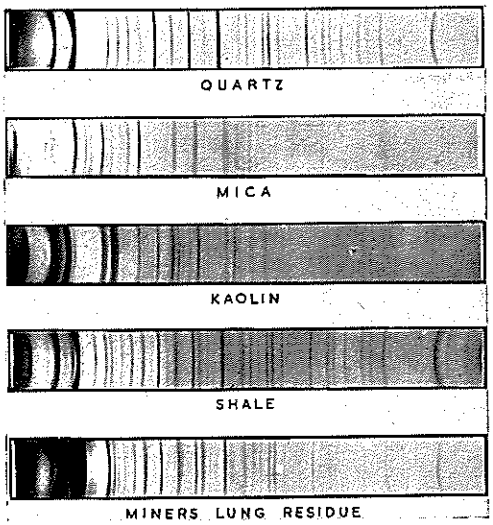


Fig. 19.—Powder diffraction photographs.

Silicosis

Another type of lung disease which mine workers may contract is silicosis, caused apparently by the presence in the lung of fine particles of silica, almost always in the form of a crystalline quartz. The dangerous size range is again about 0.5 to 5.0 microns, but the dangerous quantity of dust is much less than in the case of coal dust.

Quartz Determination

It is important to know the quartz content of various mine dusts and at S.M.R.E. 1,000 or more analyses are performed annually. Almost all this work is now done by means of an X-ray apparatus, developed at S.M.R.E. (Fig. 18), in which Geiger-Muller counters are used to measure X-ray intensities[28]. This instrument can also be used for the estimation of other constituents than quartz. For the identification of these other constituents we have more normal equipment[29], taking powder diffraction photographs (Fig. 19).

Spectrophotometry, in the visible and ultra-violet range, is used for semi-micro chemical analysis[30, 31].

The thermal balance[32] which records the loss in weight of a sample as it is heated, has been used to

investigate the properties of the kaolin family of minerals and in similar work. A somewhat similar technique, differential thermal analysis[33], provides methods for the identification of any constituent of a sample which undergoes an endothermic or exothermic change as it is heated or cooled. The technique is sometimes used for quartz determination using the (α-β) transformation of quartz at 570 deg. C.

It is often necessary to remove the combustible constituents in dust samples containing a high proportion of coal so that mineral estimations may be made more accurately. The ignition loss and the moisture content of a sample may be required in some cases. Such heat treatment demands a range of ovens and furnaces, some of them accurately temperature-controlled. For example, where a mineral analysis by X-ray methods is to follow a heat treatment this must be carried out at a temperature as close as possible to 380 deg. C. ; a lower temperature would leave a significant coal residue, while a higher temperature would partially dehydrate kaolin minerals in the sample and so make them undetectable by X-ray diffraction.

Preparation of Dust

For experiments on animals S.M.R.E. provides other laboratories with dust samples of well-defined size and composition. The preparation of these samples necessitates sedimentation and centrifuge techniques[34], and after certain etching treatments electrodialysis may be necessary ; fluorine, for example, must be removed after etching with hydrofluoric acid. Grinding of the samples requires a range of mills and mortars and a variety of sieving methods. In the preparation of fine coal samples a turbine grinder of the type developed by B. M. Wright[35] is rapid and provides a degree of size-selection of the ground samples.

Microscopy

Throughout these studies microscopy is of paramount importance. For the examination of particles bigger than 0.5 micron optical microscopes are used, but for particles smaller than 0.5 micron, electron microscopes are needed (Figs. 20 and 21). Techniques have been developed [36, 37, 38] for the combination of particle size distributions in the best ranges of each instrument to cover a final range of about 500 : 1 in particle diameter.

Special techniques are often required in the application of electron microscopy. " Heat-stable " membranes[39], to support specimens in the microscope have been developed which can be heated to 500 deg. C. or above. Thus a field of a specimen can be examined, the specimen heated to any desired temperature in this range, and the same field re-examined ; this is a considerable help in identifying various mineral particles since, for example, coal can be burned off at about 400 deg. C. while quartz particles are unaffected (Fig. 22). Impressions of " thickness " or depth in specimens can be gained by a " shadowing " technique, in which a thin metal film is deposited by evaporation at a known angle in such a way that the particles screen the membrane to their lee-side for distances dependent on their depth.

It is possible to remove quartz particles completely from the supporting membrane by means of hydrofluoric acid vapour. The previous position of the quartz particle can be located on the membrane since a carbon skin is deposited on the particle, from the hydrocarbon vapor present in the high-vacuum system, which remains behind after the particle itself has been etched away (Fig. 23).

In some dust samples, when they are received, the particles form tightly bound aggregates. An ultrasonic generator is used to break down these aggregates and disperse the sample so that its individual particles

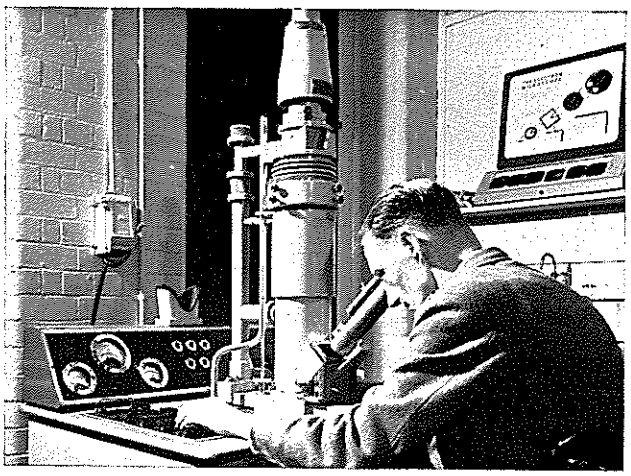


Fig. 20.—E.M.3 electron microscope.

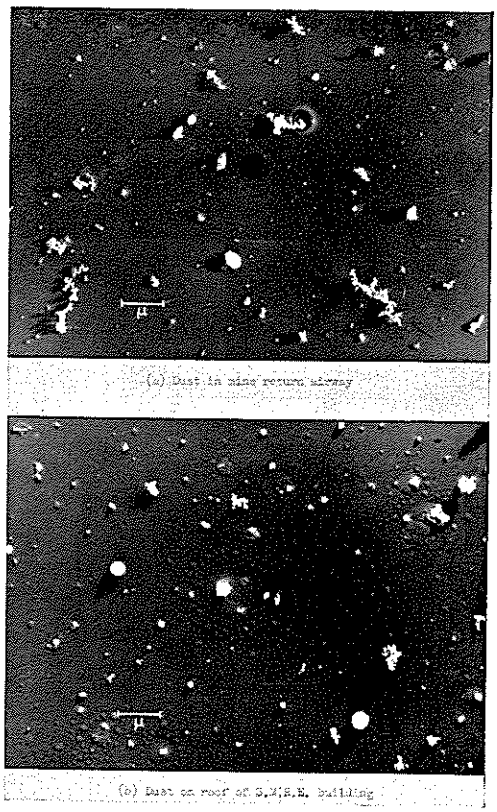


Fig. 21.—Electron micrographs of airborne dust
(a) Dust in mine return airway.
(b) Dust on roof of S.M.R.E. building.

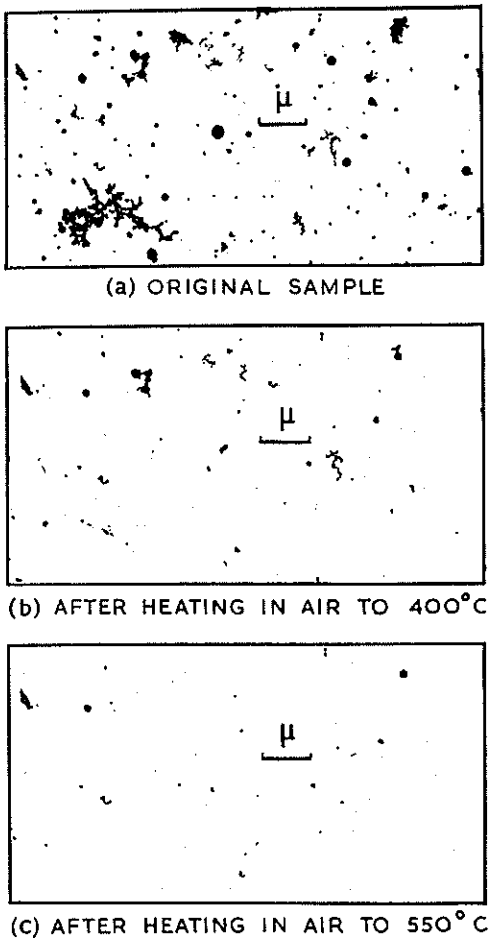


Fig. 22.— Atmospheric pollution taken on heat sensitive membrane.

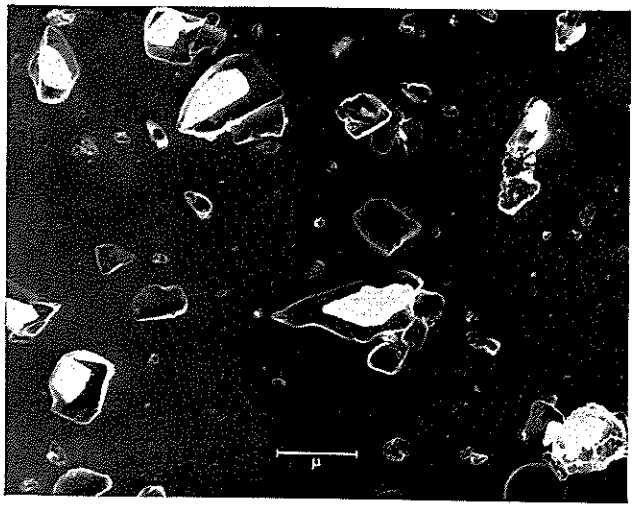


Fig. 23.—Carbon replica of etched quartz.

may be resolved.

The optical microscope is used in a technique called " dispersion staining "[40]. When dust particles including quartz are immersed in a liquid of suitable optical properties and viewed with dark-field illumination the quartz particles appear coloured and other particles appear white. The quartz particles and non-quartz particles can then be counted separately. The technique is quick, cheap, and fairly accurate for particles of diameter greater than 2 microns. Further work is needed to extend this lower size limit before the method can be considered completely satisfactory for quartz determination in silicosis research.

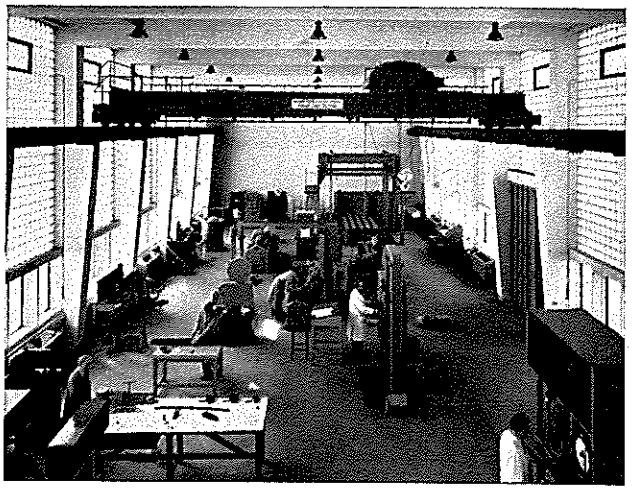


Fig. 24.— View of mechanical engineering laboratory.

Metallurgy

One of the functions of S.M.R.E. is to assist in the investigation of mining accidents, a part of which work involves the metallurgical examination of components of mine machinery and equipment. For this purpose an extensive range of instruments and testing machines is required (Fig. 24). These include bench and projection microscopes, vacuum and controlled-atmosphere furnaces, with temperature controllers and recorders, universal testing machines, ranging in maximum load from 100 lb. to 200 tons, notched bar impact machines, hardness machines, extensometers, strain gauges with associated electrical and electronic equipment, and a large 20-ton pulsation machine.

Surface Layers

Besides this standard equipment a number of other machines and techniques have been developed. Chain links and similar gear are subject to pounding and abrasion which plastically deform the surface layers. These layers become hard, and on certain types of material are sufficiently brittle to cause the link to behave in a brittle manner, even though the underlying material is still soft and ductile[45]. To measure the hardness of these thin surface layers, and of constituents of microstructures, a low-load hardness tester was developed. The first instrument[46] to be made had a maximum load of 20 gms, which was too great for some purposes since it was difficult to locate the impression on the areas selected for test. Accordingly, a second instrument has been designed to overcome these difficulties (Fig. 25). A small pendulum or arm, with a diamond-holder of low mass as a " bob " weight, is pivoted on a bracket screwed to the stationary platform

c

of the stage of a metallurgical microscope. The arm is parallel to the stage (Fig. 26) and by tilting the microscope the load on the diamond can be varied. Adjustments are provided so that the impression can be accurately located in the centre of the optical field. Fig. 27 shows impressions which indicate how the hardnesses of different parts of a metallic sample may vary.

The Detection of Manufacturing and Service Defects

Examination of broken haulage and winding gear shows that many failures are associated with impact and fatigue cracks, which develop during service, and with manufacturing defects such as weld cavities. Three methods of non-destructive testing in general use in other industries have been applied to this gear, viz. the magnetic particle method of crack detection, the ultrasonic method of flaw detection, and radiography[47].

The magnetic particle method[48] is well known. To examine haulage and winding components the gear is magnetised, either by passing a current through it or by placing it within a sufficiently strong magnetic field. An indication of the crack is obtained by applying to the surface of the gear a fine magnetic powder, either dry or in suspension in a light oil. The magnetic fluid may also contain a fluorescent compound which glows in ultra-violet light and makes detection more reliable.

The ultrasonic technique[49] is based on the fact that a pulse of sound of ultrasonic frequency (about 2¼mc/s) transmitted into a steel sample is propagated rectilinearly and is reflected by discontinuities such as cracks, inclusions and cavities. Probes containing piezoelectric crystals are employed to transmit the pulse and to receive the reflections. The sequence of events is displayed on an oscilloscope and scales are provided so that the position of the flaw can be determined. The method is most suitable for the inspection of large masses of steel such as the shaft of a winding drum. The two probes are placed on one end of the shaft and longitudinal waves are employed.

To inspect a steel chain link which may be welded at one or both sides, transverse waves are used. A perspex block with the contact surface curved to suit the link is interposed between the crystal and the surface of the sample. The block is shaped so that the longitudinal wave is totally reflected and lost within it, but a transverse wave is transmitted into the metal at a narrow angle (20 degrees) to the surface. Similar probes are placed on diametrically opposite sides of the same section, both pointing towards the weld. The wave is reflected by a defect in the weld, picked up by the receiver probe and indicated on the cathode-ray screen. The height of the peak (Fig. 28) represents the size of the defect. With a sound weld the initial pulse becomes attenuated in travelling round the link and no indication is obtained.

Radiography using X- or gamma-radiation is employed to detect internal flaws in the welds of chain links. In either case the necessity of processing the films before the size of the flaw can be assessed makes the method slow. Fluoroscopic methods employing an X-ray image intensifier are being explored to see if they can be used to speed up the inspection of such chains. Another technique has been developed[50] to inspect the

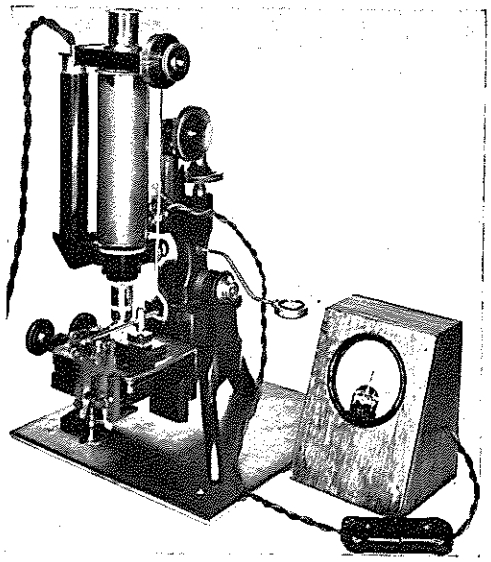


Fig. 25.—Low-load hardness tester.

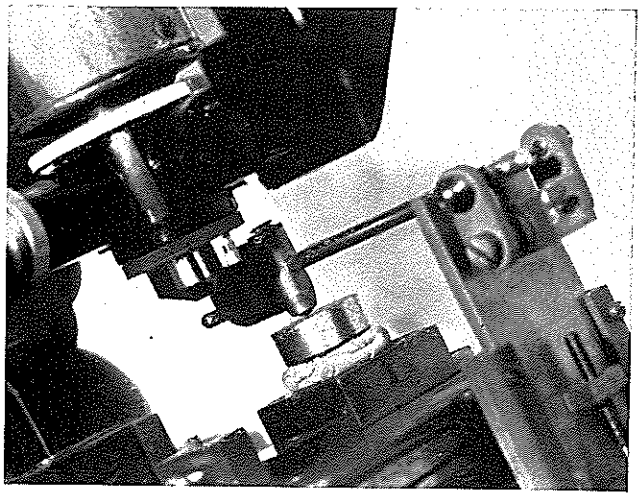


Fig. 26.—Pendulum mounting on low-load hardness tester.

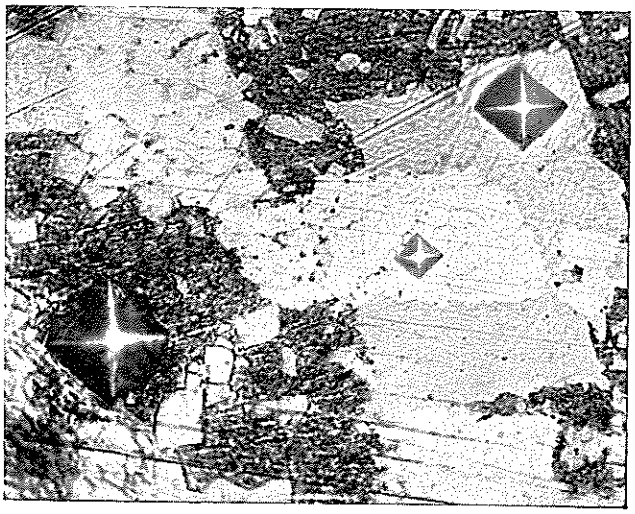


Fig. 27.—Hardness impressions on metal sample.

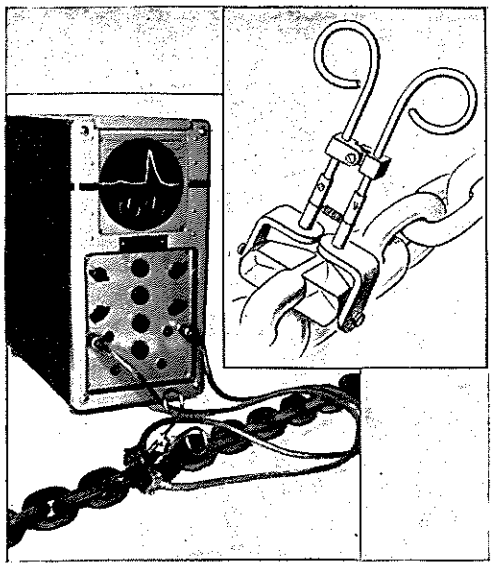


Fig. 28.— Ultra-sonic flaw detector showing (inset) probe-heads applied to butt-welded chain links.

welds of chain links. The gamma radiation transmitted through the welded section of a link is scanned by a Geiger-Muller or scintillation counter coupled to a ratemeter and recorder. This method is so far only capable of detecting large flaws. Fig. 29 shows the arrangement of the isotope (150 mC Iridium 192), the link and the counter when inspecting end-welded links, the slit in the lead shield to the counter being inclined to the angle of the weld. A scintillation counter, with a NaI crystal as phosphor, is much more sensitive than the Geiger-Muller counter and enables a low energy radioactive source to be used (5 mC Thallium 170), so reducing the radiation hazard.

Friction Props

The withdrawal of mining equipment made of

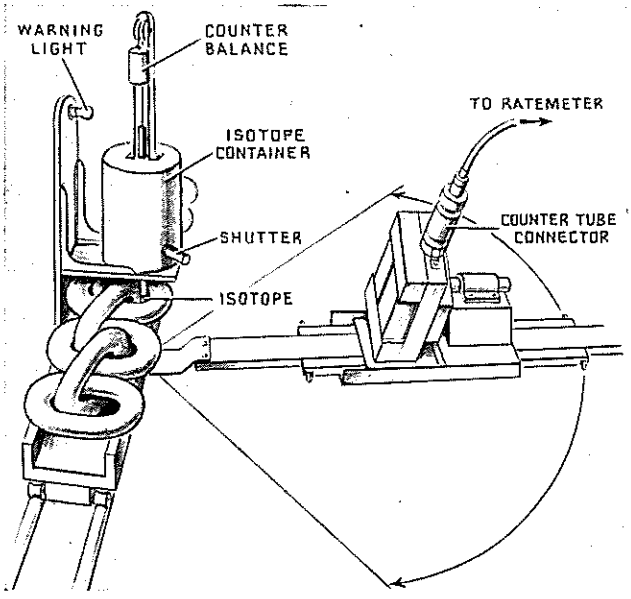


Fig. 29.— Arrangements of isotope and counter tube for chain-link examination by radiography.

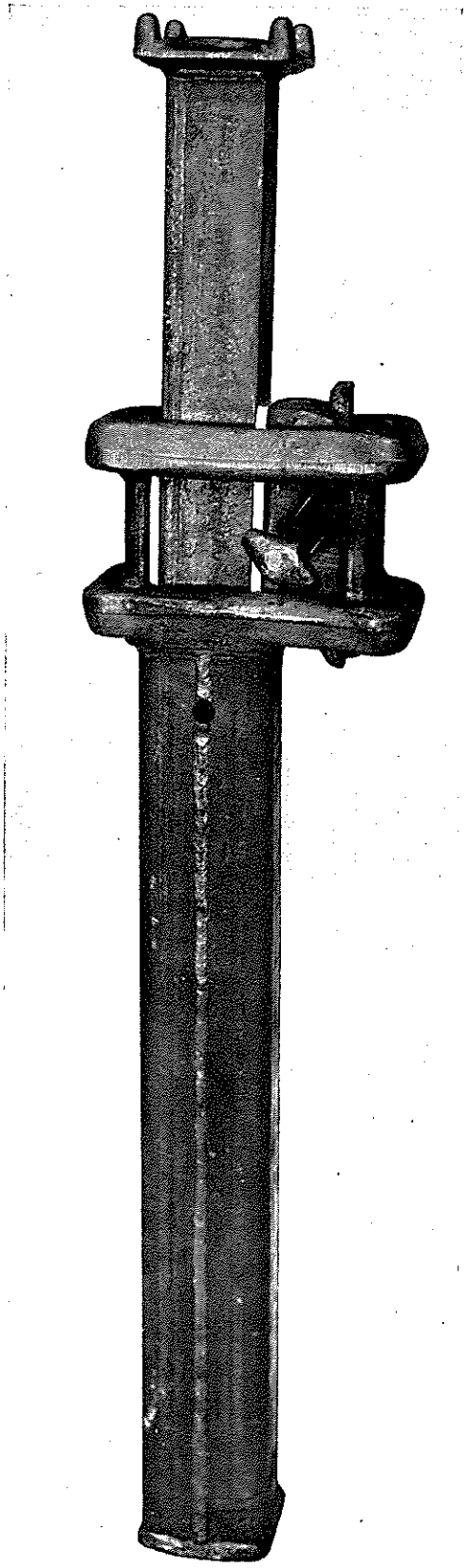


Fig. 30.— A typical friction prop.

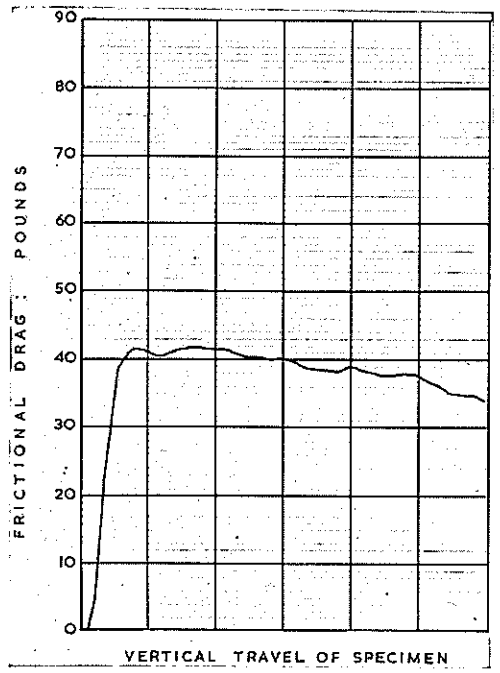


Fig. 31.—Friction load record—steel on aluminium bronze.

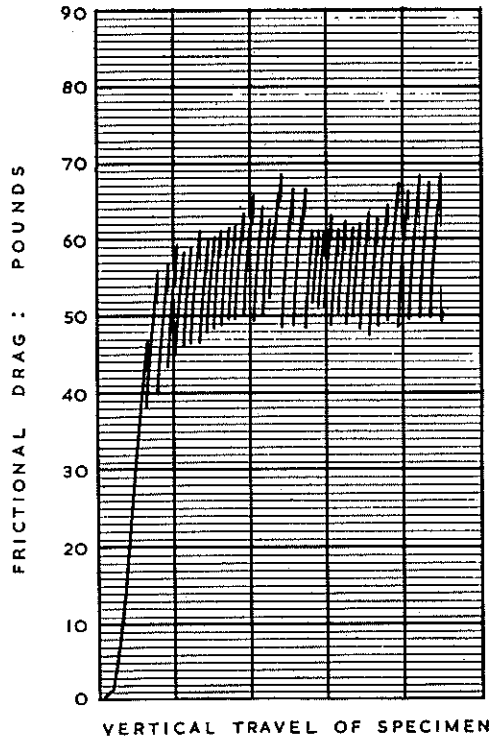


Fig. 32.—Friction load record—steel on steel.

aluminium alloys from service underground because of the frictional sparking hazard[51, 52] affected the use of friction-type yield roof supports[53]. The relative movement of the two members of a support of this type (Fig. 30) is controlled by two friction pads of aluminium alloy pressed against the upper member and held in position by a clamp fixed to the top of the lower member. In the search for a suitable alternative for aluminium it was necessary to determine static and dynamic friction coefficients at mean pressures in the range 5-20 tons per sq. in. For this purpose simple apparatus was used in which two heavily loaded hardened steel balls or cylinders were drawn across the opposite faces of a rectangular block of the metal or alloy under investigation. The " frictional " force was determined by measuring the strains induced in a strip of aluminium interposed between the specimen and the straining head of the machine. Wire strain gauges were fixed to the aluminium strip and the variations of strain were recorded on a potentiometer recorder. Fig. 31 shows a record obtained with steel rubbing on aluminium bronze. Fig. 32 was obtained with steel on steel, and shows " stick-slip " characteristics.

Acknowledgment

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DISCUSSION

Replying to a question on the effect upon haulage ropes of calcium chloride, used for floor consolidation in mine roadways with a view to suppressing dust, Mr. Wass said that galvanizing of the strands together with periodical dressing ensured a long life. Questions were asked about sampling instruments and the size of dust particles retained in the human lung. This was related to the rate of fall of a particle under gravity, a figure which was preferable to the diameter for classifying particles in respect of pneumoconiosis. Particles of high density would be incapable of reaching the lung alveoli when their sizes were considerably smaller than those quoted for coal dust.

FIELD TESTS FOR TOXIC SUBSTANCES IN INDUSTRIAL ATMOSPHERES

By B. E. Dixon, M.Sc., Ph.D., F.R.I.C.
(Department of the Government Chemist)

TESTS for the presence of toxic gases may be roughly divided into those giving immediate results in the " field," or area of suspected contamination, and those requiring the use of a laboratory and its technical services for completion of analysis. The former class has occasionally been held to include not only simple devices but also comparatively expensive instruments such as absorbtiometric equipment, interferometers, *U V* or *I R* gas analysers, which may require an electric point, but which are portable and otherwise independent of laboratory facilities. In this paper, however, the term " field test " is limited to chemical or other tests carried out with simple inexpensive apparatus requiring the minimum of skill and scientific manipulation.

According to the Reports of the Chief Inspector of Factories[1] the number of notifiable gassing accidents in industry every year varies from about 200 to 250, about 10 per cent of these proving fatal. It is obviously desirable that factory staffs should be encouraged to carry out frequent tests for the presence of suspected noxious gases in the atmosphere. The larger organisations are in any case usually well equipped with both staff and elaborate apparatus to do this. Smaller undertakings, where the risk of contamination may be greater, are much more likely to carry out tests leading to safer hygienic working conditions if methods involving little trouble and expense are available.

At the request of the Factory Inspectorate, formerly of the Home Office now transferred to the Ministry of Labour, arrangements were made by the Department of Scientific and Industrial Research, with the co-operation of the Association of British Chemical Manufacturers, for a series of such tests to be developed.

Twelve methods for the determination of low concentrations of toxic gases, for which Dr. R. B. Vallender of the Chemical Defence Research Department was mainly responsible, were published as DSIR pamphlets between 1937 and 1940[2]. The responsibility for revising these tests and devising new methods as the need arises has recently passed from DSIR to a Committee sponsored by the Ministry of Labour, most of the laboratory work involved being carried out by the Department of the Government Chemist.

Basic Requirements

Since these field tests are intended for use by comparatively unskilled operators, the results of the tests must be easily ascertainable. For this reason, and because the amount of toxic substance collected is very small, the choice of method is practically limited to colorimetric tests. The toxic substance itself or a derivative combines with reagents to form a coloured product which can be compared with standard colours. The coloured product may form in the solid phase (e.g. on test paper or on silica gel), in the liquid phase, or even in the gaseous phase (as in the case of the halide lamp).

The necessary simplicity of a field test requires that the experimental procedure shall be determined once and for all, and embodied in fairly rigid instructions when the apparatus is designed. The unskilled operator cannot be expected to use his judgment and make adjustments in the apparatus to meet exceptional conditions, nor does the nature of the apparatus in general admit of this. Hence an early review of essential requirements is desirable. An attempt has been made to list these in order of importance, which will, however, be influenced to some extent by the nature of the toxic substance and by special circumstances.

General Reliability

This requirement is more difficult to ensure in field tests than in ordinary analytical methods, since the absorbing material must either be prepared in the field by the non-professional operator or else prepared commercially and stored with the risk of some deterioration during storage. With regard to standards, if the reaction is carried out in the liquid phase it is fairly easy to manufacture permanent transparent glass colour standards. The preparation and preservation without fading of standard colour stains on paper presents some difficulty.

Sensitivity

It is desirable that the method should be sufficiently sensitive to detect at least half the toxic threshold limit, which has been defined as the maximum average concentration to which workers may be exposed for an eight-hour working day without injury to health. The expedient of improving a relatively insensitive method by taking larger samples should not be employed if this proves too lengthy.

Specificity, etc.

Since the nature of the contaminant will, in most cases, be known specificity is not usually essential. More important is freedom from interference by other gases likely to be present, or a ready means of ensuring this freedom if necessary.

Range of Tests

Once it has been shown that the threshold limit has been reached remedial measures must be put in hand and it is then of little interest from this point of view to know the exact concentration of toxic gas. Nevertheless for diagnostic purposes it is useful for inspectors and factory staff to know where and by how much this limit is exceeded, in order that the sources of contamination may more easily be tracked down. For this purpose, it is useful to be able to detect concentrations of gas up to about four times the threshold limit.

Simplification and Duration of Test

The difficulty of analysis of toxic substances differs widely in degree. The temptation to over-simplify an apparatus or to reduce unduly the time required must be avoided if there is any danger at all of lessening the reliability.

Accuracy

Accuracy as distinct from general reliability is of minor importance in these tests, especially as the threshold limit figures themselves are often approximations. An error of ±20 per cent can usually be tolerated.

Apparatus

Two forms of standard apparatus used are shown in Fig. 1 (for formation of a coloured stain on absorbent test paper) and in Fig. 2 (for formation of a coloured solution by passing the gases through an aqueous solution of reagent). The atmosphere under test is sampled in both cases by means of a standard hand exhausting pump. In Fig. 1 the air sample is drawn through a test paper clamped in a holder which can be attached to the pump. After a preliminary trial, the number of pump strokes required to produce a stain of suitable intensity is counted, and the stain is compared with the standard stain chart to arrive at the concentration of contaminent in the atmosphere. In Fig. 2, the sample of atmosphere is drawn through a reagent contained in a bubbler ; a trap is inserted between the pump and the bubbler. In this case the depth of colour obtained is compared with that of a standard solution and the concentration of toxic gas read off from a table.

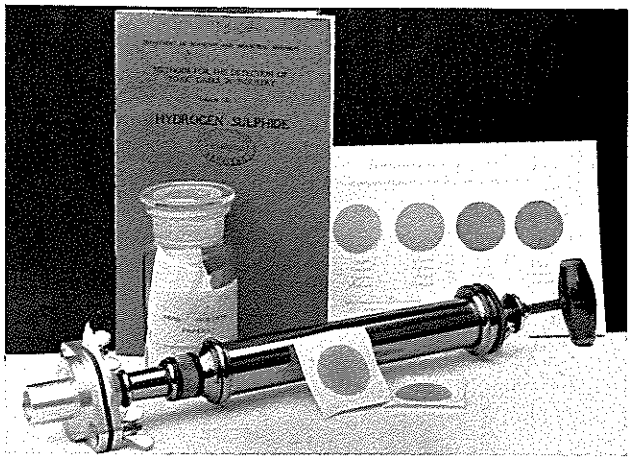

Fig. 1.—Hand pump and filter paper for stain tests (Crown Copyright reserved).

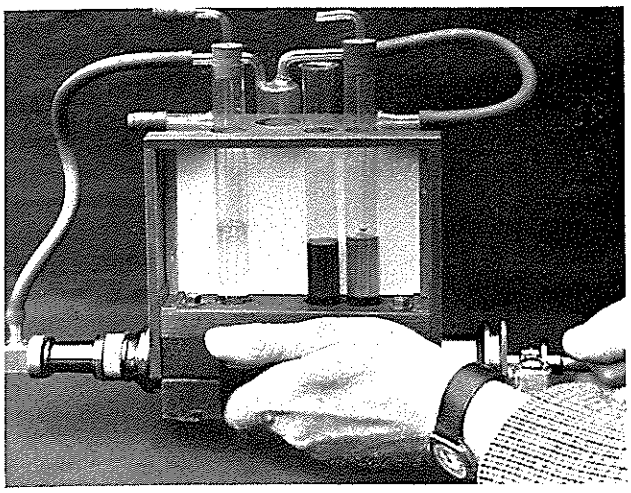

Fig. 2.—Hand pump and babblers for colorimetric estimation (Crown copyright reserved).

Silica gel can be used instead of test paper as a base on which to form a stain. The atmosphere under test is passed through a glass indicator tube containing a column of silica gel impregnated with reagent. In this case it is the length of the stain, not the intensity of the colour, that is a measure of the toxic gas concentration. This method is particularly suited for the determination of carbon monoxide.

Some toxic substances require a more elaborate apparatus, e.g. the collection and estimation of mercury and its compounds[2, 3] constitute two consecutive operations carried out in separate tubes.

Improving Performance

By definition, the field test must be simple and robust, hence the scientist is debarred from following his instinct to improve its performance by the use of more delicate apparatus and more sensitive instruments. Any improvement therefore must come by other means such as the following :

Application of Gas Absorption Theory

Most of these tests involve in the first place removal of the toxic gas from a mixture of gases by absorption in a suitable liquid or onto a solid base. The case of absorption in a liquid will be considered first. Absorption processes can be divided into two types (a) a solely physical process and (b) solution accompanied by chemical reaction, which itself influences the actual rate of absorption. Most field tests fall into the second category. The mechanism of mass transfer of solute gas from the gas mixture to the liquid is usually explained by the two-film theory of Whitman or by the more recent modifications of Higbie and Danckwerts. It is assumed that the concentration of the solute is fairly uniform in both phases owing to convection currents, and that resistance to mass transfer exists mainly in the neighbourhood of the gas-liquid interface. From the practical point of view, efficiency in absorption of the soluble constituent of the gaseous mixture will be promoted much more by devices ensuring a rapid renewal of surface at the interface than by mere vigorous mixing of the gaseous and liquid phases.

Some of the recent work elucidating absorption processes on the large scale can be profitably applied to the design of absorption apparatus for analytical purposes. For example, a study of the performance of perforated and porous plates in achieving contact between gas and liquid[4] showed that absorption at the plate surface is extremely active and is essentially complete within a very small compass. Absorption in the foaming liquor above the porous plate was found to be much less efficient per unit space. It follows that no great increase in absorption efficiency will be effected by devices frequently used in analytical absorbers, such as lengthening the path of bubbles through a liquid, or brisk stirring of absorbent liquor above the exit tube. The single jet type of bubbler is comparatively inefficient but simple and quite adequate for use with easily soluble gases. Some further improvement in absorber performance can be made by selection of the most suitable type of perforated or porous plate, since the quantitative relationship between absorption efficiency and such factors as the number, size and distribution of holes, and the gas flow rate is known.

Another type of absorption apparatus of high efficiency is the impinger, through which the air can be driven at high velocity to strike a glass plate covered with absorbent liquor[5, 6]. Here again, it is probably their capacity for promoting an extremely rapid renewal of surface at the gas-liquid interface to which these instruments owe their high efficiency.

Recent years have shown an increase in the use of silica gel impregnated with reagent as a base on which to form a coloured derivative of the toxic gas. Silica gel is a partially dehydrated form of polymerised colloidal silica having an enormous internal area, up to several hundred square metres per gram. The pores, which probably consist of connected channels, occupy a considerable proportion of the total volume of gel. It is clear that the flow of gases through this structure must be very involved, and further complicated by adsorption phenomena and chemical reaction within the pores. Some empirical information has been obtained by manufacturers but more fundamental investigation needs to be done which in turn would lead to practical information as to optimum rates of gas flow, particle size, etc. Here again, valuable guidance might be gleaned from another chemical engineering process that has recently received intensive study, viz., fluidisation.

Absorbent test paper is widely used as a solid medium on which stains are formed. Microscopic examination of a transverse section of a stained test paper shows that the stain is largely superficial, the colour falling off rapidly in intensity as it penetrates the paper to the extent of 50-100 microns. If the stain colours are examined by reflected light, it is evidently important that there should be no deterioration in the activity of the critical outside layer of impregnated reagent before use. Since this layer is also the most exposed, care should be taken to keep the unused test papers covered.

New Reactions

A large number of reactions between gases and various reagents, often uncommon organic compounds,

have been described in recent years which give rise to coloured products. A thorough study of promising reactions, particularly from the point of view of the special requirements of a field test, sometimes produces a new or improved test.

Improvement in Material

The exacting demands of chromatography have led to improvements in the range, toughness, and homogeneous quality of absorbent test paper. More varied grades of activated charcoal and silica gel are now available.

Sampling

The sampling procedure, like the analytical procedure, of field tests is hampered by their special requirements. The use of several admirable sampling instruments is excluded by reason of their comparatively complicated nature and technique. Again, the partly diagnostic character which field tests share with industrial toxicological analysis imposes problems in sampling that are absent in general analysis.

Manual Aspirators

Where the amount of sample to be taken is not too great, hand-operated aspirators can be used of which the most useful are:

1. The DSIR Hand Pump

This has a capacity of 126 ml. and can be used to suck gases through a bubbler or through a test-paper contained in a special holder attached to the pump.

2. Aspirator Bulb

This has the advantage of ensuring a slow and perfectly steady flow, which is sometimes difficult to attain by means of the hand-pump. On the other hand, there is a risk of leakage in the valve and the rubber bulb may perish with age.

A third device, the aspirator bottle, has an easily controlled rate of flow, but is in general, too clumsy for field use. Evacuated sampling vessels, which are so useful in general gas analysis, are also usually unsuitable for field tests since they require some dexterity in manipulation.

Mechanical Aspirators

For larger samples a power-driven pump must be used of which the simplest is the :

1. Water Filter Pump
2. Electric Vacuum Pump

Some types of electric pumps set up pulsations in the gas train which may interfere with the operation of the flowmeter and must be eliminated by means of a reservoir. There is some danger in using this type of pump for sampling atmospheres containing inflammable vapours.

The optimum rate of sampling for each individual field test must be ascertained. Frequently, too rapid or too uneven a gas flow rate through a bubbler will result in incomplete absorption and, in the case of absorption on a solid base, in patchy stains. In these circumstances, absorbent test paper may show intensely coloured pinholes where the gas has channelled through the larger pores.

The time of sampling and the volume of sample are often determined by the requirements of the method used and may vary from a few seconds to 20 minutes and 100 ml. to 50 litres respectively. It is usually desirable to take several samples e.g. in the vicinity of the worker, at various distances from the source of contamination etc. It is often possible to establish fairly accurately the degree of hazard associated with various phases of an industrial process by interpretation of the results of carefully timed and located sampling. Unless the field test has a small sampling period, however, it is obviously inferior from this point of view to a recording instrument. This weakness of the field test might be significant if a short period of intense contamination was repetitive and inherent in the process rather than a rare accident.

The activity of the reagent used in the test is sometimes very dependent on the humidity of the inspired air. Soda lime, for instance, shows a marked decrease in efficiency at moisture contents outside the range 10-25 per cent; active carbon is somewhat similarly affected by moisture and it may be necessary to dry the air sample. Extremes of atmospheric temperature may also affect the reaction. The danger of absorption of the toxic gas by materials in the sampling line such as rubber and metals should not be overlooked. The degree of ventilation at the sampling point is probably the most important factor to be noted at the time of sampling. If ventilation is poor the air is likely to be stratified and more samples should then be taken.

Acknowledgment

I wish to thank the Government Chemist for permission to publish this paper.

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DISCUSSION

Following Mr. Dixon's paper, reference was made to the ultra-violet absorption method of determining mercury vapour. It was emphasised that this was specific to mercury vapour and would not detect mercury present, for example, as an organic compound or as a particulate. There was a danger of cases of mercury poisoning arising after the U.V. absorption method had indicated that conditions were safe.

Mr. Dixon's suggestion that simple tests for toxic chemicals need not be specific was taken up since a factory might employ a considerable number of different solvents and lack of specificity could create trouble. Simplicity of apparatus was accepted as essential and accuracy of only ±50 per cent might often be tolerated.

INSTRUMENTS AND THEIR USE FOR THE CONTROL OF IONISING RADIATION IN LABORATORIES

By B. S. Smith
(Health Physics Division, A.E.R.E., Harwell)

Permissible Dose for Internal Radiation

THE first radiation injuries were observed within a few months of the discovery of X-rays in 1895. As a result of over 50 years study of the acute and chronic effect of X-rays and gamma-rays on the human body it is now possible to formulate the conditions of use which " in the light of present knowledge,are not expected to cause appreciable bodily injury to a person at any time during his lifetime." As used here " appreciable bodily injury " means any bodily injury or effect that a person would regard as being objectionable and/or competent medical authorities would regard as being deleterious to the health and well being of the individual(1) ". These conditions are substantially fulfilled if the weekly dose is kept within the limits given in Table I.

Table I

Basic Permissible Weekly Dose for Whole Body Exposure to Ionizing Radiation

Tissue	Basic permissible weekly dose in the organ (in mrems)
Skin	600
Blood-forming organs ..	300
Gonads	300
Lens of the eye	300

The Committee recommended certain relaxations for limited portions of the body. The most important being 1,500 mrems/week to the hands, feet and head.

Since 1954 the permissible levels of radiation have been re-examined as a result of the world-wide interest in the dangers of radioactive fall-out from weapon trials and the International Commission is expected to recommend two further restrictions on the permissible dose—a limitation of 50 r by age 30 for genetic reasons and 200 r in a lifetime as protection against an increase in the incidence of leukaemia.

Permissible Doses for External Radiation

The International Commission on Radiological Protection has also listed the values for occupational workers of the maximum permissible body burden and of the maximum permissible concentration in air and water of various radio-isotopes. The energy of disintegration, radioactive half-life and metabolism varies widely from one isotope to another with corresponding changes in the permissible concentration in air and water. It is, therefore, necessary to know the chemical nature of the activity when monitoring air and water supplies.

Table II gives some typical maximum concentrations in air and water in curies and weights of carrier free materials.

Permissible Contamination Levels

The recommendations of the I.C.R.P. are directed to the establishment of conditions of exposure which will produce no health hazard. To maintain satisfactory working conditions in a laboratory in which unsealed sources of radioactive materials are used, it is also essential to keep a close control of the contamination by radioactive materials, of floors, benches, apparatus, etc. Failure to keep contamination down to low levels by good housekeeping will often invalidate experimental work through radiation measuring equipment developing high and variable backgrounds. This danger is particularly present in tracer experiments involving large dilutions of radioactive materials. For work of this type it is preferable to have separate laboratories for the preparation of bulk materials and the counting of trace levels. Such a laboratory will have its own permissible contamination levels. It is possible to establish contamination levels, which are acceptable on experimental grounds in the average laboratory, and are sufficiently conservative to ensure that the resultant radiation exposure is well within the I.C.R.P. recommendations. Dunster (2) considered a hazardous isotope widely spread over the surfaces of a laboratory and showed that the inhalation of the

Table II

Typical Maximum Permissible Levels for Occupational Exposure (1953)

Isotope	M.p.l. in body μc	Critical Organ	M.p.l. in air μc/cc.	M.p.l. in water μc/cc.	M.p.l. in air mg/M^3
Ra^{226}	0.1	Bone	8×10^{-12}	4×10^{-8}	8×10^{-9}
Pu^{239}	0.04	Bone, Gut	2×10^{-12}	3×10^{-6}	3×10^{-8}
Sr^{90}	1	Bone	2×10^{-10}	8×10^{-7}	1.5×10^{-5}
Sr^{89}	2	Bone	2×10^{-8}	7×10^{-5}	7×10^{-9}
I^{131}	0.6	Thyroid	6×10^{-9}	6×10^{-5}	5×10^{-11}
P^{32}	10	Bone	1×10^{-7}	2×10^{-4}	3×10^{-10}
Na^{24}	15	Body, Gut	1×10^{-6}	8×10^{-3}	1×10^{-10}

c.f. Lead — 0.05 mg/M^3 (24 hour)

resultant dust in the atmosphere and the external radiation received from the radioactive material on the surfaces did not exceed the levels recommended by the I.C.R.P. provided the activity did not exceed :

10^{-5} μc/cm^2 for alpha activity

and 4 x 10^{-4} μc/cm^2 for beta activity

these figures can be relaxed by a factor of 10 or 100 where the contamination is localised to small areas and where the contaminants are not the most hazardous.

Radiation Protection Monitoring

Radiation control is never the primary object of the work of a laboratory. For it to be carried out efficiently the instruments used should be designed for reliability and ease of operation. The electrical circuits should be of the " fail safe " type so that failure of batteries or components, over estimates the radiation danger. For survey instruments and contamination probes lightness is important if they are to be used for long periods. These features and rapid response are more important than high accuracy. Measurements are often made under conditions not truly representative of the individual's exposure and the use made of the measurement obtained often precludes the necessity of high accuracy. An accuracy of 20 per cent is usually adequate and often 100 per cent error is acceptable.

Instruments for the Measurement of Radiation

The Ionisation Chamber

The roentgen, which for many years was the basic unit used in X-ray and gamma radiation protection, is defined around the " free air " ionisation chamber. This is a homogeneous chamber in which the quantum absorption and the subsequent ionisation by secondary electrons takes place in air. In practice the " free air " ionisation chamber is not a suitable instrument for general radiation protection purposes. The requirements of the " free air " ionisation chamber are closely followed in an enclosed chamber if the walls are made of a material having a mass absorption coefficient equal to that of air. Fig. 1 shows a chamber designed by Howes on this principle. It has a diameter of $3\frac{1}{2}$ in. and an effective gas volume of about 300 ccs. It is filled with air to 6.5 atmospheres pressure and for a radiation intensity of 10 mr/hr gives a current of 2 x 10^{-12} amps. The electrodes are moulded from a graphite powder designed to give air wall characteristics.

This chamber is of sub-standard quality and has a more extended energy response than is required for normal protection work. A chamber operating at atmospheric pressure and having graphited bakelite walls is adequate for protection measurements in laboratories using a limited range of gamma emitting isotopes.

Fig. 2 shows two portable radiation monitors. The 1043D has two ranges giving full scale readings of 125 mr/hr and 1.25 r/hr and weighs $3\frac{1}{2}$ lb. The survey meter type 1349A has three ranges giving full scale readings of 15, 150 and 1500 mr/hr. Errors due

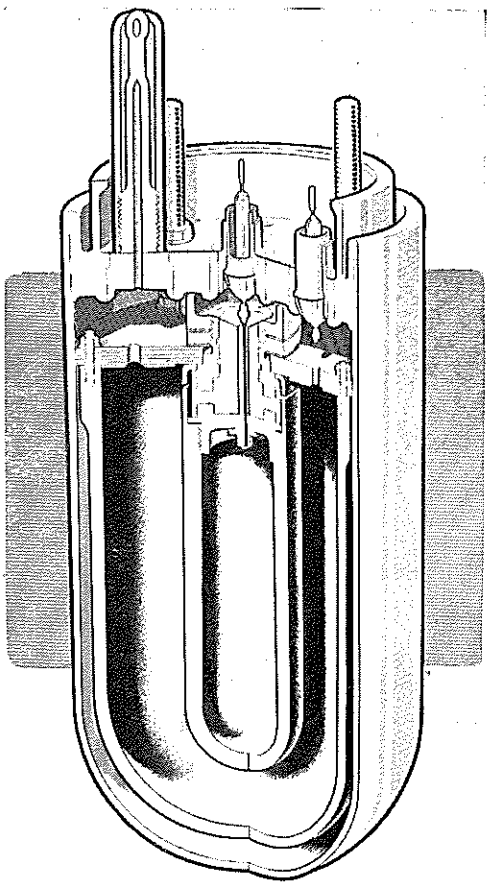

Fig. 1.—Cut away section of " air wall " ionisation chamber.

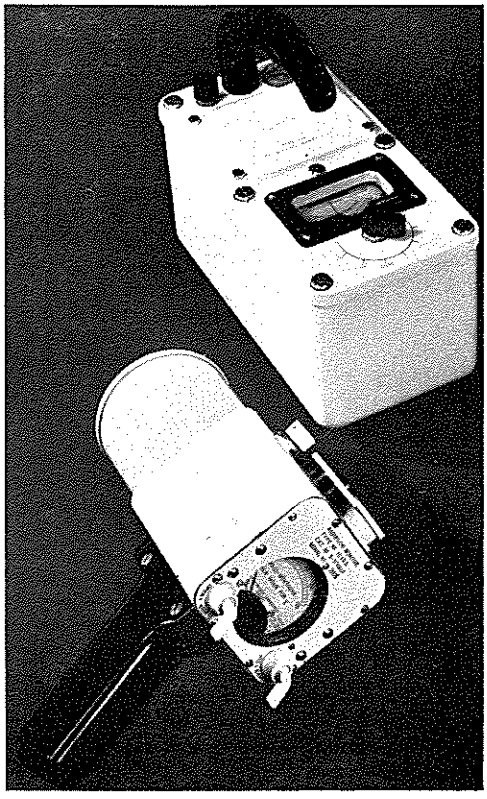

Fig. 2.—Battery operated " beta-gamma " monitors.

to mis-reading the scale multiplier are eliminated by changing the meter scale for each range. It weighs 7¼ lb. Both instruments have built in beta sources for checking their performance and their ion-chambers are provided with removable covers for use when measuring beta radiation.

The Gas Counter

In the gas counter as in the ionisation chamber, the interaction between the incident gamma rays and the wall material is controlled by the well known processes of pair production, Compton scattering and photo-electric absorption. Each recoil electron entering the gas volume ionises the gas. In the Geiger counter the collecting field is sufficiently high to produce further ionisation by collision and a single free electron initiates a discharge which produces an electrical pulse whose size is independent of the primary ionisation produced by the initial recoil electron. In the proportional counter the collecting field is only high enough to increase ionisation one or two orders of magnitude.

The efficiency of a geiger counter for the detection of photons of energy 1 MeV is about ½ per cent and if the cathode wall is constructed of materials of low atomic number (Al, Cu) it can be made approximately proportional to the energy of the incident photon over the range 0.3 MeV to 2.5 MeV. This is the approximate variation of efficiency with energy which is required to enable Geiger counters to measure milliroentgens independent of energy of the gamma rays.

Geiger counters are nearly 100 per cent efficient for beta rays of sufficient energy to penetrate the cathode wall. They are therefore suitable for the protection monitoring of beta rays since over a wide range of energies a flux of 7β,s/cm^2.sec. produces a dose of 1 mrem per hour.

Proportional counters are used in protection monitoring when it is necessary to distinguish between different types of radiation. A fast neutron proportional counter has been developed by Hurst [3]. It is filled with methane and contains an arrangement of polythene and metal radiators adjusted to give a count-rate proportional to dose for neutron energies in the range 0.2 to 10 MeV. By using the counter in the proportional region the proton recoils are counted and the electron recoils are discriminated against.

Fig. 3 shows the mains operated 1021B radiation monitor. It has interchangeable geiger and scintillation counter probes. The geiger counter is shown with the protective cover removed. The meter is connected to an integrating circuit and has four ranges 0-2, 20, 200, 2000 counts/sec. Its sensitivity to gamma rays is given in Table III.

Table III

Response of 1021A Geiger Probe to Gamma Rays Counts/Sec per mr/hr

Energy	Uncovered	Covered
1.25 MeV	107	106
0.66	70	68
0.08	60	57
0.03	106	33

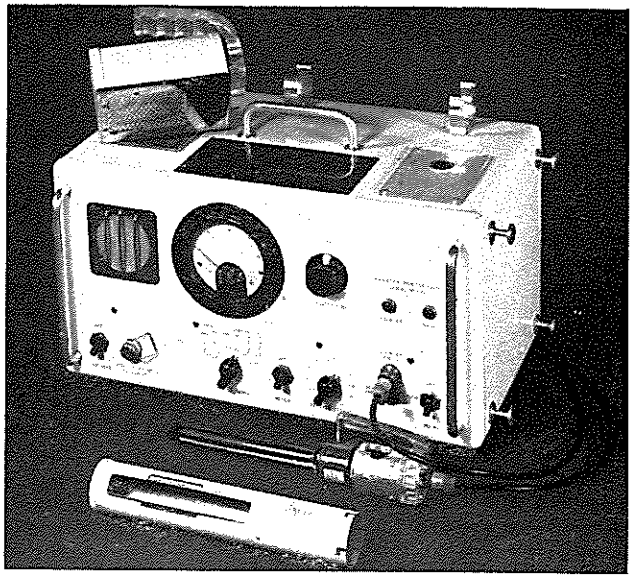

Fig. 3.—Mains operated monitor with Geiger and scintillation probes.

A contamination level of 4 x 10^{-4} μc/cm^2 of beta activity gives a count rate of 20 counts/second.

The alpha scintillation counter contains a ZnS scintillator of effective area 35 cm^2 and gives 3 counts/sec for an alpha activity of 10^{-4} μc/cm^2. This is ten times the level suggested above and shows the extreme difficulty of alpha contamination measurement.

Individual counts are also broadcast from a loudspeaker. This feature is useful when the monitor is operated as a watch dog in the laboratory and when searching for contamination.

Scintillation Counters

Many materials emit visible light when exposed to alpha, beta, gamma or neutron radiation. The most commonly used groups of scintillators are organic crystals of the hydrocarbon type and the inorganic crystals and powders of the alkali halide and zinc sulphide types. The most important are anthracene, sodium iodide (thallium activated) and zinc sulphide (silver activated). When used in conjunction with a photo-multiplier tube it is possible to detect the absorption of a single quantum or charged particle in the scintillator. Under suitable conditions the electron pulse will be proportional to the absorbed radiation energy. The zinc sulphide phosphors are mainly used as alpha particle counters. Good discrimination against beta particles is obtained because a phosphor which is thick enough to absorb most of the alpha energy will only absorb part of the beta energy. If a sodium iodide crystal is irradiated with mono energetic gamma rays the resultant light pulses contain a group having an intensity corresponding to the energy of the gamma ray and a continuous spectrum of smaller pulses produced by gamma rays which are scattered by the Compton process and only lose a portion of their energy in the crystal. Recent developments of large crystals and photo-multipliers has enabled gamma ray spectrometers to be constructed with greatly improved ratio of counts in the full energy peak to the Compton back-

ground. Spectrometers of this type are valuable analytical tools for radiation control on account of their high sensitivity and their ability to measure selectively one isotope in the presence of others.

Photographic Materials

In 1902 Rollins recommended the use of photographic materials for the measurement of "safe" intensity. Films are now universally used for personnel radiation monitoring. Ionising radiation produces a latent image in the emulsion which gives blackening on development in the same manner as visible radiation. The density, D produced by an exposure E is approximately connected by the relationship [4]

$$D = D_o + D_a (1 - e^{-SE})$$

where D_o is the base density, D_a is the maximum blackening obtainable, and S is a constant determined by the sensitivity of the emulsion. The density v exposure curve for the Ilford PM1 film is shown in Fig. 4.

The photographic blackening is proportional to the energy absorbed in the AgBr and since the photoelectric absorption of silver is much larger than that of air the blackening per roentgen increases with photon energy down to the K edge of Ag at 25.5 keV. This causes a film calibrated with radium gamma rays to overestimate the exposure at 100 keV by a factor of 3.

The film badge used in the Atomic Energy Research Establishment is shown in Fig. 5. It carries an Ilford PM1 personnel radiation monitoring film between cadmium and tin filters each 1 mm. thick. The two filters give the film an approximately uniform response to a given exposure measured in roentgens in the range 0.1 MeV to 3 MeV. Thermal neutrons are monitored by the additional blackening produced by the gamma rays resulting from the capture of neutrons in the cadmium filter. The film is identified by stamping a number on the wrapper with sufficient pressure to give a clear marking on development. To reduce errors caused by variation in sensitivity between different batches of emulsion and by differences in development, a series of control films from the same production batch are given known exposures to a radium source and developed with the monitoring films. The controls are then used to establish the roentgen scale on the photometer. The films are sorted visually into those exposed above 0.05 r and those below and it is only the former which are assessed on the photometer.

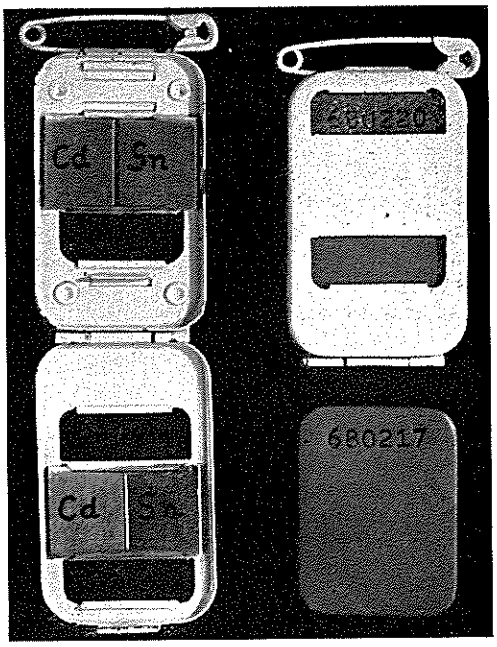

Fig. 5.—The Atomic Energy Research Establishment Film badge.

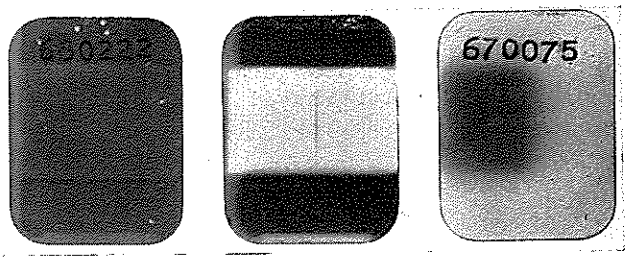

Fig. 6.—Developed films exposed to radium, soft gamma, and thermal neutron radiation.

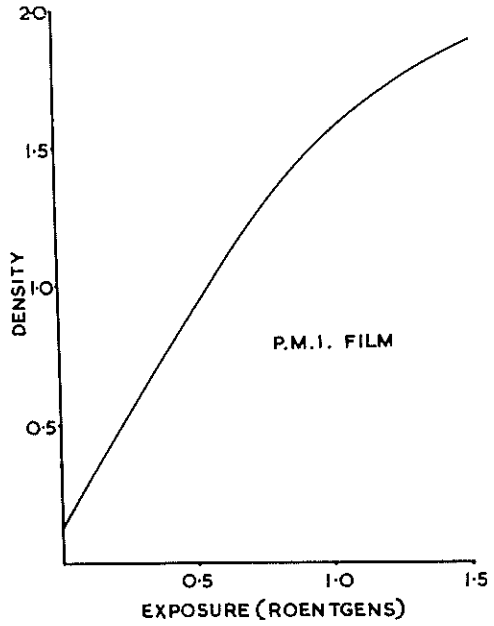

Fig. 4.—Density/Exposure curve for personnel monitoring film.

Fig. 6 shows three developed films. The film 680222 has been exposed to hard radiation from radium, 110960 has been exposed to soft radiation from xenon, and only the unfiltered portion is blackened, 670075 has been exposed to thermal neutrons and negligible other radiation.

At Harwell it is our practice to issue films on a larger scale than would be required if the issue were confined to personnel working with radioactive materials. This policy eliminates the need to make radiation surveys in many buildings and gives a permanent record of the exposures received by any individual. These records are thought to be of legal value should radiation damage be claimed at a later date.

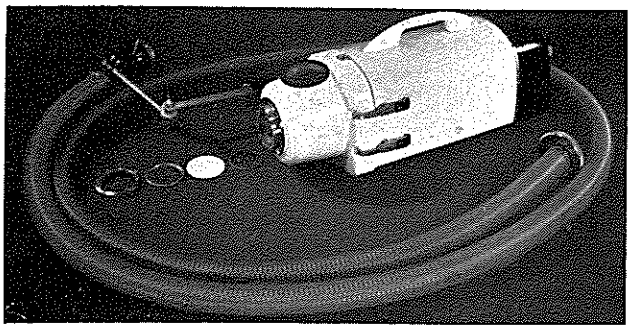

Fig. 7.—Portable sampler Type 1195.

Air Monitoring

In laboratories using unsealed radioactive materials in powder or liquid form it is also necessary to monitor and control the amount of radioactive dust inhaled. Where installed samplers are not available portable samplers of the type 1195 shown in Fig. 7 are used. They will pass 100-150 litres of air per minute through a 2 in. diameter disc of Fourstones sample A paper. The period of sampling varies from minutes to hours according to the toxicity of the material and the nature of the operation being monitored. The total air flow is integrated with a built in anemometer. The collected radioactive material is assessed in terms of disintegrations per minute per cubic metre by counting the filter paper, but to give it biological significance it is necessary to identify its chemical nature. When this cannot be done from a knowledge of the operations involved the following physical methods are used :

(1) measurement of the rate of radioactive decay,
(2) measurement of the absorption curve of the beta radiation,
(3) measurement of the gamma ray spectrum.

Assessment of the more toxic alpha emitting materials is complicated by the masking effect of the natural radioactivity in air. When measuring a maximum permissible concentration of plutonium it is not unusual to find the alpha count from radon and thoron decay products to be ten to one hundred times greater than that due to the plutonium. If the counting is delayed for two days the natural materials will have decayed and the plutonium can be assessed. Tait[5] has shown that under most laboratory conditions the plutonium is present on particles a few microns in diameter whilst the natural activity is attached to particles two or three orders of magnitude smaller. An annular impactor similar in design to that used by Tait has been used and tested by Stevens [6] over an extended period in the hot laboratories at Harwell. By using it in conjunction with the Portable Sampler Type 1195 he has obtained satisfactory monitoring samples in ten minutes without excessive interference by radon and thoron decay products.

Total Body Gamma Monitor

The normal procedure of controlling the body burden of workers using radioactive materials, depends upon monitoring the routes of ingestion and inhalation. Uncertainties of the efficiency of the various stages of the uptake route leave an element of doubt as to the degree of overall control which has been achieved. Improvements in techniques now make it possible, not only to measure the total radioactivity in the human body, but also, to measure the energy spectrum of the photons emitted and by means of phantom studies to assess the individual radioactive isotopes in the body[7]. The lower limit of measurement is determined by the gamma spectrum of the isotopes concerned and by the background of natural radioactivity in the body. This natural background arises from the potassium in the body and is about 10 per cent higher in men than women. The minimum body burden of radio-caesium which can be detected is about one hundred thousandth of the permissible body burden and is so low that the present level of radio-caesium in the population can be measured easily. This caesium background in the population arises from weapon debris taken up in the food cycle and has to be allowed for with the natural potassium when monitoring individuals. It is also possible to measure some beta emitters by the bremsstrahlung emitted from the body.

The recent improvements in body monitors have followed closely on the production of large potassium free NaI crystals and photo-multiplier.

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DISCUSSION

Mr. Smith was asked about the relative merits of film monitoring and the use of a small ionisation chamber. He said that the film system was more practical where a very large number of persons had to be watched, whereas ionisation chambers were susceptible to misuse. On the other hand, when the chamber was employed, it was possible to take readings at any moment and see how far one had gone towards getting the weekly permissible exposure.

The observation that plutonium had been located only on larger particles of the atmospheric aerosol led to the remark that this might depend on working conditions and should not generally be relied upon.

Reference was also made to whole-body radiation and the difficulty of deciding whether external or internal sources were being detected ; it was a particular problem in the case of strontium 90 since the aluminium enclosures for the sodium iodide crystals let through the beta rays.

INSTRUMENTS FOR ABSORPTION SPECTROPHOTOMETRY

By R. A. C. Isbell, A. Inst. P. (Hilger & Watts Ltd.)

ALL workers in the medical field today must have occasion to use at least one instrument for measuring selective optical absorption.

Many will, therefore, already have some knowledge of one or more of these instruments but will probably be a little hazy about the principles behind their design. This is more likely because the instruments must have entirely different components depending on the region of the spectrum they cover. Briefly, we may define our fields of use as Ultra-Violet 200-400mμ (2000-4000A) ; Visible 400-700mμ; Infra-Red 700-40,000mμ (.7μ-40μ).

It would not be appropriate here to deal with the many applications of these instruments. Suffice it to state that most organic chemicals such as drugs, dyestuffs, proteins, hormones, etc. absorb energy in one or other part of the spectrum and may be identified and even estimated by using this property. Furthermore, use is made of spectral absorption by reacting on samples without specific absorption in the visible region to produce a compound or complex which may be coloured, i.e., absorbs a specific colour or wavelength in the visible region. This latter technique, known as colorimetry or absorptiometry, is conveniently employed in the estimation of inorganic anions which may occur naturally in body fluids or tissues.

In all of these instruments there are three primary sections namely (a) light source giving a continuous spectrum throughout the region : (b) some means of isolating one particular wavelength or a narrow band of wavelengths : (c) a detector and associated means of measuring the unabsorbed light.

Dealing with the simplest instruments first we should mention the abridged spectrophotometer or absorptiometer which can be used in the visible region only. Here the light source is a simple tungsten filament lamp operated from battery or mains supply through a voltage regulating transformer. For many measurements where the absorption band is fairly broad it is sufficient to isolate a narrow waveband only. For example dyed gelatine colour filters isolate a band between 10-50mμ.

The simplest form of light detector is a barrier layer photocell which does not require any external e.m.f. to operate it. This consists of an iron plate on which is deposited a layer of selenium and a transparent metallic film. A Woods metal ring above this acts as one electrode and the iron back plate the other. When light is incident on the surface a current flows into a galvanometer connected across it. The deflection gives an indication of the intensity of light and hence the transmisison of a sample placed between the light and the photocell. Some form of control either optical or electrical is used to adjust the deflection to full scale with blank sample so that the reading with sample is in percentage transmission. There are many such instruments available, all suitable for work where highest accuracy is not required.

As an extension of this type of instrument are those employing simple monochromators in place of the colour

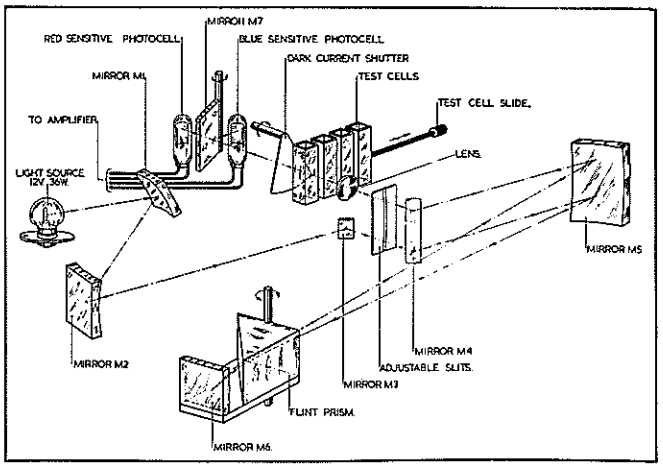

Fig. 1.—Optical System of Unicam SP600 Visible Spectrophotometer using a glass prism monochromator and vacuum type photocells (by courtesy of Unicam Instruments Ltd., Cambridge).

filters. Replica diffraction gratings are sometimes used to provide a continuous choice of waveband but owing to considerations of sensitivity it is not possible to isolate a narrower waveband without using a more sensitive type of detector.

A vacuum type emission photocell with electronic amplifier is capable of giving greater sensitivity. This photocell consists of an evacuated glass envelope containing a metallic plate (cathode) which emits electrons when light impinges on it. These are collected by a ring or grid held electrically positive. The passage of electrons thus constitutes an electric current which is proportional to the intensity of incident light. The spectral response of such a photocell depends on the type of metal surface of the cathode. The photo-current may be amplified electronically without difficulty. The high sensitivity makes it possible to use a more monochromatic beam but the amplifier and extra stabilising circuitry puts the instrument in a higher price range. However, where it is desirable to obtain the complete spectral absorption curve instead of spot readings such an instrument giving continuous choice of wavelength is very useful. For more accurate work still, where a much narrower band width is required, it is usual to employ a monochromator with a glass prism. It is thus possible to attain a minimum bandwidth of only 3mμ (30A). Higher grade optical components are necessary and as every step in narrowing the band width means less energy at the detector it is necessary to use greater amplification of the photocell output with more effective stabilisation of supply.

The barrier layer photocell has the advantage of cheapness and simplicity not only in itself but in associated equipment. However, it has the disadvantage that unless the intensity of light incident on it is kept low and the electrical resistance of the measuring instrument is not greater than a few thousand ohms the response to varying light is not linear. In designing such a simple instrument, therefore, the

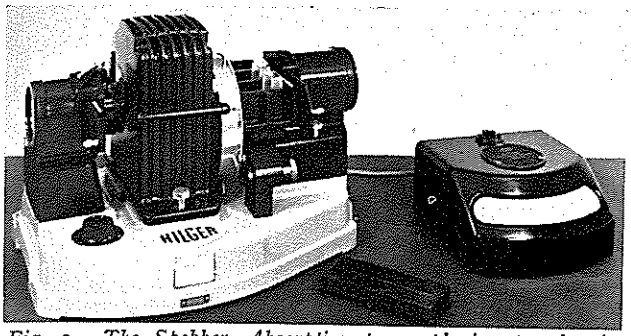

Fig. 2.—The Spekker Absorptiometer employing two barrier layer photocells in balance. The reading is taken on the calibrated shutter operated by the circle on the right of the lamphousing (By courtesy of Hilger & Watts Ltd.).

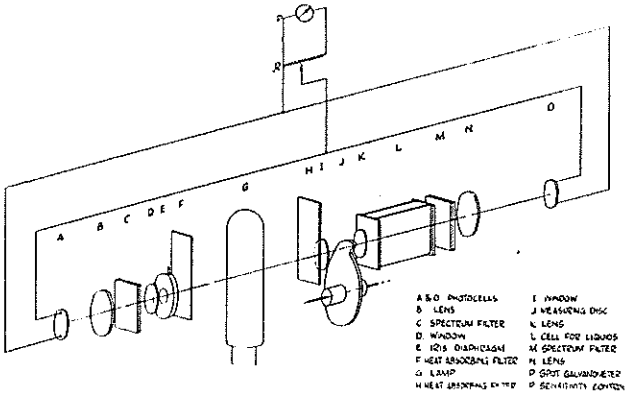

Fig. 3.—Diagram of Optical System and Photocell Circuit of Spekker absorptiometer (by courtesy of Hilger & Watts Ltd., London).

power of the lamp and associated system must be limited to restrict the intensity of light on the photocell. Further difficulties are encountered in choice of measuring instrument. In order to register the low output obtained from the photocell a sensitive galvanometer is required which must have a low resistance. From the point of view of the galvanometer the parallel resistance of the photocell cannot be less than 10,000 ohms or the movement of the galvanometer coil will be over-damped and sluggish. Although barrier layer photocells can be selected with a higher resistance one must also watch for fatigue and development of dark current to which some photocells may be subject. It will be seen, therefore, that although very much cheaper than any other type of detector, considerable care must be taken to ensure satisfactory performance. However, bearing in mind these limitations many such simple instruments have been produced.

It is not surprising, however, that other types of absorptiometer have been designed which in one way or another overcome these disadvantages. One way is as mentioned above, namely, by using a different type of detector. Another way is to arrange by using a balance circuit that the barrier layer photocell is not the ultimate measure of intensity.

In one well known instrument two such photocells are connected to a null point galvanometer in such a manner that their outputs are in opposition. The beam falling on the measuring photocell passes through an accurately calibrated shutter. With the coloured sample in this beam the current from the other or compensating cell is regulated also optically so that the galvanometer is undeflected. When the blank replaces the coloured sample more light falls on the measuring cell so that the galvanometer is deflected until the calibrated shutter is closed a suitable amount. The reading of the scale attached to the shutter gives directly the transmission or optical density of the sample referred to the blank. As the output from the measuring cell is at the time of reading equal to that at the moment of initial balance the linearity is unimportant. Such a design immediately opens up the possibility of using higher light intensity. The fact that two photocells are connected in opposition also reduces effects of photocell fatigue and dark current drifts.

Although in this instrument one is still limited to isolation of a waveband with filters a more precise reading is obtained on the shutter scale than could be obtained even on a linear galvanometer. Perfectly monochromatic light may be obtained on this instrument at certain wavelengths by substituting a mercury vapour lamp for the tungsten filament. With suitable filters which need not be very narrow it is possible to select one line at a time.

While on the subject of filters and other means of selecting a narrow wavelength band, mention should be made of interference filters which have been expected to give a band width as low as 1 mμ (10A) or even less. Such a filter is in effect a Fabry Perot etalon consisting of two partially metallised glass plates separated by a transparent medium also deposited in vacuo. White light is effectively filtered into a series of orders at various wavelengths depending on the separation of the plates. It is necessary to use a supplementary filter to remove unwanted orders. It is difficult to produce interference filters in quantity absolutely free of pinholes caused by specks of dust being present on the plate during metallising. These pinholes give rise to a white light " background " which although it may have a level of only $\frac{1}{2}$ per cent. in comparison with 25-30 per cent at the peak, will have a measurable effect on a photocell. Although the peak transmission is high the band width is so narrow that only a very low intensity reaches the photocell. Furthermore, to reduce the stray light background it is necessary to employ a narrow band supplementary filter which will of necessity have a low peak transmission. It will be seen, therefore, that such filters are not readily fitted to existing simple colorimeters. Therefore, where a narrow band is essential a monochromator with prism is required.

Passing from instruments for the visible region employing a glass prism, we consider similar instruments for the ultra violet region. The tungsten filament lamp with glass envelope is of no use below 350mμ and it is necessary to employ a special lamp with a hydrogen arc in a fused silica envelope. If hydrogen is arced at a suitable pressure a continuous spectrum is produced over the region 200-350mμ. The glass prism must be replaced by one made from the more expensive quartz or fused silica. Alternatively, a high quality original grating may be used. An emission photocell with a quartz window or silica envelope is also required. As the cost of the associated electronic amplification and stabilised power supply represents a major part of the total price of the instrument, it is usual to extend

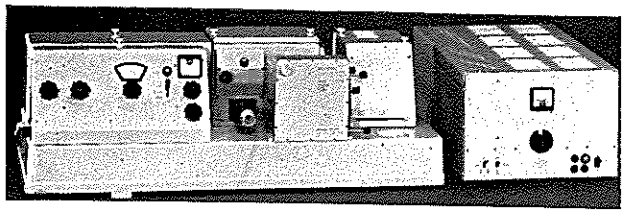

Fig. 4.—Uvispek Photoelectric Spectrophotometer for Ultra-violet and visible (by courtesy of Hilger & Watts Ltd., London.)

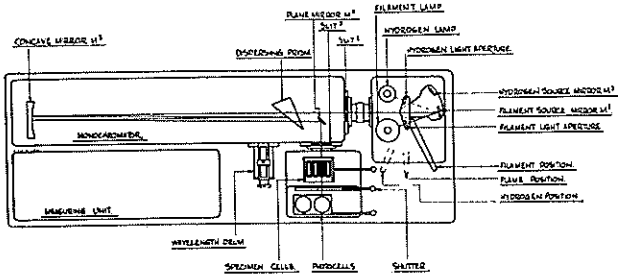

Fig. 5.—Diagram of Optical System of Uvispek Spectrophotometer (by courtesy of Hilger & Watts Ltd., London).

the range of the instrument to cover the whole of the visible region by including an interchangeable photocell suitable for this range. There are, therefore, two lamps covering 200-250mμ and 350-1000mμ and two photocells covering 200-600mμ and 600-1000mμ respectively. One instrument manufacturer has also included an optional glass prism as an extra which provides greater dispersion than that of quartz and hence gives an even narrower band within the visible region. Some instruments operate from batteries except for the stabilised power supply for the hydrogen lamp. At least one other operates entirely from the mains supply with suitable stabilisation to allow for voltage variations. Such instruments readily lend themselves to the fitting of attachments for various purposes such as flame spectroscopy. The simplest consists of a flame unit with sprayer tube placed alongside the existing lamphouse. By selecting an intermediate position of the reflecting mirror system in the lamphouse light from the flame may be directed straight into the entrance slit of the monochromator and the measuring set is used in a similar manner to evaluate the relative intensity of spectral lines in the flame due to the element in the sprayed sample. Such an arrangement makes use of oxygen and hydrogen and is most convenient as it is possible to change from absorption to flame in a few seconds.

The instruments described are non-recording and the reading is obtained on a calibrated potentiometer used to back off the potential difference developed across a high resistance grid leak when the photocurrent passes through it. This is the only type at present available in this country but it is understood that two British manufacturers are well advanced in the development of recording models. Here a chart is obtained representing a plot of the transmission versus wavelength and this provides a considerable saving of time when a complete curve is required for identification purposes. Several instruments of the recording type are made by American manufacturers and others.

In a short talk such as this it is not possible to cover the whole field in detail. There is perhaps some justification for spending more time on the more commonly used instruments for the visible and ultra-violet regions. For the sake of completeness, however, at least a short resume should be given of the type of instrument used in the infra-red. Although widely used in industry for the routine testing and research on samples as widely different as explosives, fuels, plastics, rubber and drugs, it is already finding its way into medical research, particularly into the causes of cancer. Although recording infra-red spectrophotometers are priced much higher than their counterparts for other spectral regions, it is beyond all doubt that in a short time they will be widely used in more routine applications in the medical field.

Infra-red spectra are in general more complicated and the absorption bands are much narrower than are encountered in the ultra-violet. Furthermore the wavelength of a band may shift according to general configuration of the molecule as a whole, although caused by the same group or branch of the molecule. It is, therefore, essential to obtain a complete picture of the spectral absorption and a recording instrument must be used. Apart from other difficulties the atmosphere itself produces a series of absorption regions each consisting of many fine bands which completely blanket any other bands due to samples. This means that the record must be double beam, i.e. a ratio of the intensities of two monochromatised beams, one with the sample and the other a blank. As the atmospheric absorption is equal in both beams the resultant curve of the sample only is shown.

Considering now the general design ; all previously mentioned light sources are unsuitable as their infra-red emission falls off very rapidly. A nernst filament consisting of a thin porcelain-like rod containing rare earth oxides conducts an electric current when raised to incandescence and it can be maintained in this condition by the passage of the current. It acts as a suitable emitter for the region. Coming now to the monochromator, quartz and glass are unsuitable except for the very lowest wavelengths and other materials are employed for the prism. The most commonly used is sodium chloride which transmits out to about 16μ. Other materials such as potassium bromide, calcium

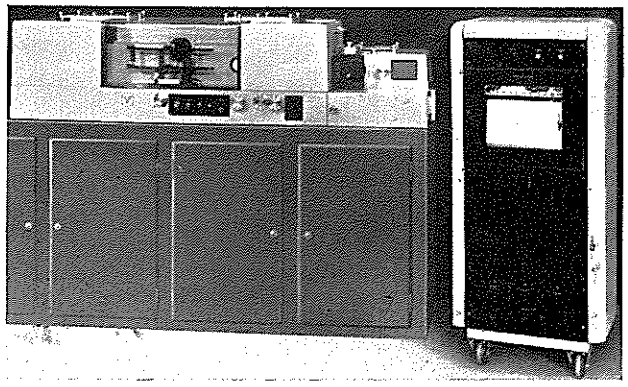

Fig. 6.—Recording Infra-red Spectrophotometer (by courtesy of Hilger & Watts Ltd., London).

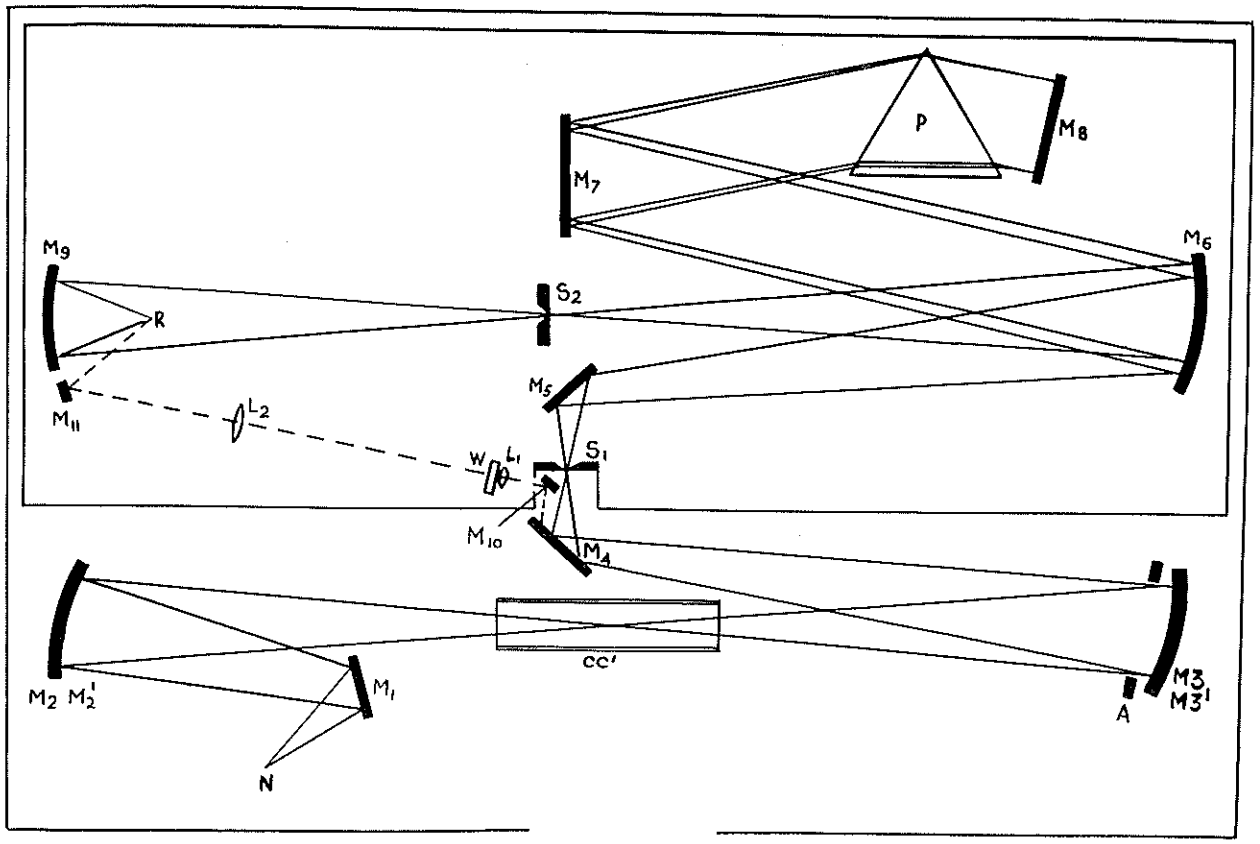

Fig. 7.—Optical diagram of Hilger Infra-red Spectrophotometer (by courtesy of Hilger & Watts Ltd., London).

or lithium fluoride or caesium bromide are sometimes used according to the range and dispersion required for the analysis. Apart from being very expensive they are in general more difficult to work and polish, being much softer than quartz or glass. In addition some materials are hygroscopic and readily deteriorate if suitable precautions are not taken against surface condensation. In the last year or two some manufacturers have made available alternative diffraction gratings which provide a very high dispersion usually over a short wavelength range. None of the radiation detectors such as photocells described are suitable for the infra-red, although for instruments limited to the range up to 6μ or 7μ a type of semi-conductor photocell of lead telluride is used. More usually a thermoelectric detector is required. The most common is the thermopile consisting of a number of thermocouples fitted with receivers which are black to the infra-red wavelengths. These in general have low impedence and do not readily lend themselves to electronic amplification. Fast thermopiles with a speed of response of about 30 milliseconds are now available and by "chopping" the light at about 12 cycles per second an alternating output can be produced which may be amplifed electronically using circuits resembling conventional types.

In a typical spectrophotometer light from the source N is divided into two beams passing respectively through sample and blank. These beams are reflected alternately into the entrance slit $S1$ of the monochromator whose prism P is slowly rotated, thus steadily progressing through the spectrum. Monochromatic radiation emerging from the exit slit $S2$ falls onto a fast thermopile R, the output of which is amplified. Obviously, if the transmissions of the blank and sample are unequal the thermopile 'sees' an alternating radiation pulse which is thereby translated to an alternating e.m.f. This after amplification operates a servo motor driving an optical attenuator in the blank or reference beam until the beams are equalized.

Coupled to the attenuator is a potentiometer driving a pen-recorder. Thus the movement of the pen follows accurately the attentuator and hence indicates the transmission of the sample relative to the blank.

Samples of gases, liquids or solids may be examined by this instrument. A recent trend has been to develop reflecting microscopes to be used with such an instrument. One such has a double beam microscope by means of which infra-red transmission of two narrow fibres may be compared. Such a valuable accessory readily lends itself to use with microcells for liquid samples of the type encountered in medical research.

In this brief review it has not been possible to describe all of the instruments available and one does, therefore, tend to give more detail of those with which one is more familiar.

It cannot be emphasized enough, however, that although there are very few cases of instruments of different makes covering the same specification, one

must distinguish between true advantages and plain differences in design.

Thus one may have a choice of apparently similar instruments one of which has a particular feature, which may appeal to a prospective user. It should be borne in mind that such a feature more than likely involves a deficiency in some other respect and it may be necessary to have several different instruments to cover all requirements.

DISCUSSION

Comments on Mr. Isbell's paper included a reference to gross errors in ultra-violet spectrophotometry which resulted if fluorescence was induced in the specimen. The trouble could possibly be avoided by placing the monochromator between the sample and the photocell, though, it was pointed out by the author, this involved irradiation of the sample at high intensity with the attendant risk of photochemical decomposition which was lessened when the monochromator was used between the light source and sample. Answering a question on diffraction gratings, Mr. Isbell said a replica gave a fair percentage of scattered light and a reduced intensity of dispersed light. Increase of slit width was therefore compelled and about 35 millimicrons was the best one could achieve. With a prism instrument a band of only 3-10 millimicrons could be utilised. The new plastic grating replicas were an improvement on the original collodion films.

Referring to Beer's law of absorption, he said that this would hold unless there were chemical effects in the solution, provided that the band width employed in the measurement was smaller than the absorption band of the liquid being tested.

SOME ANALYTIC AND CLINICAL METHODS IN THE STUDY OF ATMOSPHERIC POLLUTION

By P. J. Lawther, M.B., M.R.C.P.

(Medical Research Council Group for Research on Atmospheric Pollution)

THE presentation of this paper at a conference on the use of instruments in occupational hygiene can be justified only by the acceptance of wide definitions of terms. The Shorter Oxford English Dictionary defines an *instrument* as "a thing with or through which something is done or effected; a means; a person made use of by another person or being for the accomplishment of a purpose," and *occupation* as "the taking up of space and time; the being occupied with or engaged in something." This essay can be submitted in the light of these definitions.

The object of the use of instruments in air pollution research must next be considered. We are ultimately concerned with the investigation of the clinical consequences of contaminated air and this great problem may be broken down into several parts, each requiring the application of different techniques. This clinical aspect of air pollution is reviewed more fully elsewhere (Lawther, 1956). Low-grade chronic urban pollution is suspect as a possible aetiological factor in the production of chronic bronchitis and lung cancer, and the severe acute pollution experienced during temperature inversions is known to have a harmful effect on patients whose respiratory function is impaired by pulmonary or cardiac disease. Obviously the proper investigation of the clinical effect of dirty air necessitates detailed knowledge of the chemical and physical nature of urban pollution which varies greatly both in quantity and quality. The character of polluted air must be studied concurrently with the health of susceptible patients in order to seek some association between specific pollutants and clinical deterioration. While these analytical and epidemiological aspects of the problem are being studied, suspect pollutants are being tested for possible physiological effects; volunteer patients and normal subjects are exposed to gases and aerosols in a chamber and any effects, particularly on pulmonary function, are measured. The importance of the analytical and epidemiological methods may be emphasised by consideration of some of the limitations of the experimental exposure technique; experiments must be confined, especially when the subjects are patients, to attempts to produce only effects which are rapidly reversible, such as bronchospasm; exposures are necessarily of relatively short duration and are properly limited to the application of selected isolated factors. The results of such experiments cannot safely be used to predict the behaviour of man when exposed to complex urban pollution over long periods; they will tend to produce negative results which will exonerate rather than incriminate individual contaminants. Linear relationship between cause and effect is rarely seen in biology and extrapolation is fraught with academic peril. The time taken for a guinea pig to die when exposed to 500 p.p.m. sulphur dioxide is of strictly limited relevance to the plight of an old man with emphysema who is laid low with bronchospasm on a smoky day when the concentration of sulphur dioxide reaches only 1 p.p.m. The study of the patient in this polluted environment is to be preferred to the direct experimental approach though the latter method is obviously of great complementary value.

Our use of instruments is directed, therefore, mainly to the determination of the nature of the patient's environment and to the assessment of his clinical status. This task requires the use of a host of instruments from stethoscopes to spectroscopes and in a paper of this size only a few can be selected to the exclusion of many. For a clinician to embark on a catalogue of complex physical instruments would be impertinent and for comprehensive reviews of the

subject reference should be made to the excellent papers given to the Instrumentation Panel of the U.S. Technical Conference on Air Pollution (Proceedings edited McCabe 1952) and to the recently published Air Pollution Handbook (Magill, Holden, and Ackley, 1956).

The degree of air pollution throughout the country is approximately indicated by the measurements of smoke and SO_2 made under the auspices of the Fuel Research Station of the D.S.I.R. (The Investigation of Atmospheric Pollution, 1955). Monthly averages of sulphur dioxide concentrations are determined by the lead perioxide method which depends on the fact that SO_2 reacts with lead peroxide to give sulphate which is readily determinable. This method was originally developed to give estimates of the effect of polluted atmospheres on buildings but the results have been used to derive approximate figures for SO_2 levels in the 1952 smog (Wilkins, 1954). There are 1,042 peroxide instruments in Great Britain.

Of much greater value are the daily " volumetric " smoke and SO_2 instruments of which there are 130 in operation at present. (There are, in addition, 44 instruments which measure smoke alone.) By means of a small electrically operated pump air is drawn at a rate of about 50 cu. ft. per day through a Whatman No. 1 filter paper, a Dreschel bottle containing hydrogen peroxide, and a domestic-type gas meter. The air enters through an inverted funnel and is led to the filter through hard glass tube of internal diameter $\frac{3}{16}$ in. It is claimed that the linear velocity of entering air is about 0.1 ft./sec. from which it is calculated that particles up to about 20μ diameter are being sampled. The smoke produces on the filter paper a black stain the density of which (measured either by photoelectric reflectometer or by comparison with a scale of shades) is translated into terms of milligrams per cubic metre. The sulphur dioxide is oxidised in the bubbler and the resultant sulphuric acid is determined by titration. This method of assessing air pollution has many limitations some of which are discussed by Parker and Richards (1952) but the data it produces are the most valuable at present available over wide areas.

There is a danger in accepting the results of 24 hour mean values as indicating a true hazard to health; peak concentrations may be of much greater toxicological significance and the enormous variations which can occur over short periods are shown in Fig. 1. (Waller and Lawther, 1955.)

Obviously such observations cannot be made routinely and continuous automatic recording instruments are of value on such occasions; but it will be noted that their range needs to be great in order to cope accurately with such large variations. The automatic SO_2 recorder recently described by Cummings and Redfearn (1957) seems to meet these requirements.

It must be emphasised here that the measurement of smoke and SO_2 does not imply that these pollutants are necessarily specially injurious to man; they may indeed be harmful but at present it is wiser to regard them as indicators of particulate and gaseous pollution.

Any belief that the ill effects of air pollution may be simply ascribed to smoke and SO_2 is dispelled by contemplation of the wonderful complexity of particulate

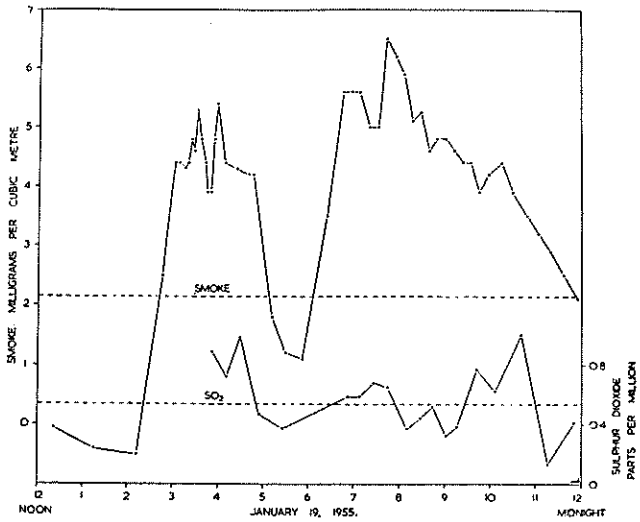

Fig. 1.— Variations in concentrations of smoke and sulphur dioxide on the roof of St. Bartholomew's Hospital. E.C.1 on Jan. 19, 1955. (Daily mean figures shown by dotted lines.)

contaminants revealed by the electron microscope. (Figs. 2a and b.) This instrument is surely the most powerful which has yet been brought to bear on the analytical problem and the pioneer work of the Safety in Mines Research Establishment is producing exquisite techniques by means of which the nature of minute particles may be studied (Cartwright, Nagelschmidt and Skidmore, 1956, and Nagelschmidt, 1957). Samples are collected with the thermal precipitator in which a known volume of air is drawn slowly through a narrow gap past a heated central wire. On each side of the gap are mounted two microscope cover slips on which the thermal gradient deposits the particles from the air as it passes through. The cover slips are coated with films of Formvar about 200° A thick and these, on which the particles have been deposited, are stripped off and mounted on specimen grids for examination in the microscope. Cartwright *et al.* (1956) have developed a new technique using heat-stable membranes of aluminium oxide which permit the observation of the effect of heating the particles to known temperatures. Much is thereby being learnt of the composition of urban smoke.

The fate of these particles on inhalation and the effects they have on the lung are of prime interest. Most of the existing knowledge of the penetration and retention of particles in the lung has come from work on dusts and aerosols in connection with the pneumoconioses. These experiments and calculations have been mainly concerned with idealised spherical particles and reference to the electron micrograph of the smoke aggregate in Fig. 3 shows how different is the problem set by urban pollution. It may be truly said that the electron microscope has opened up a new world from which it can be seen how sadly inadequate were previous concepts of particulate pollution in crude terms of smoke and grit.

At the present time, when physical instrumental techniques are developing with bewildering rapidity, it is easy to forget that the object of our studies is biological, and that a direct approach to the problem

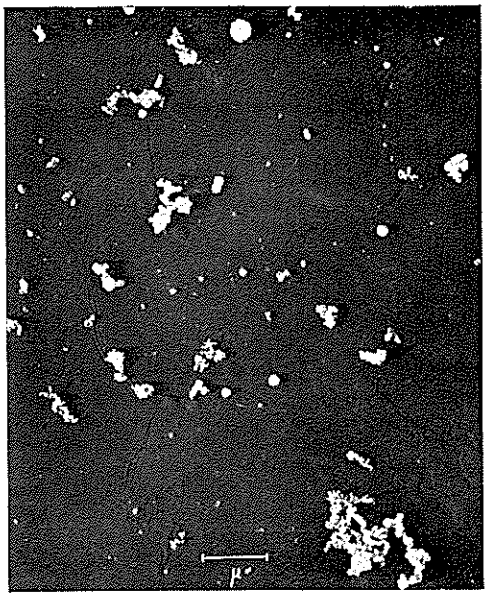

Fig. 2(a).—Electron micrograph of thermal precipitator sample of air taken on Holborn Viaduct E.C.1, 1 March 25, 1955. (Crown copyright, S.M.R.E.)

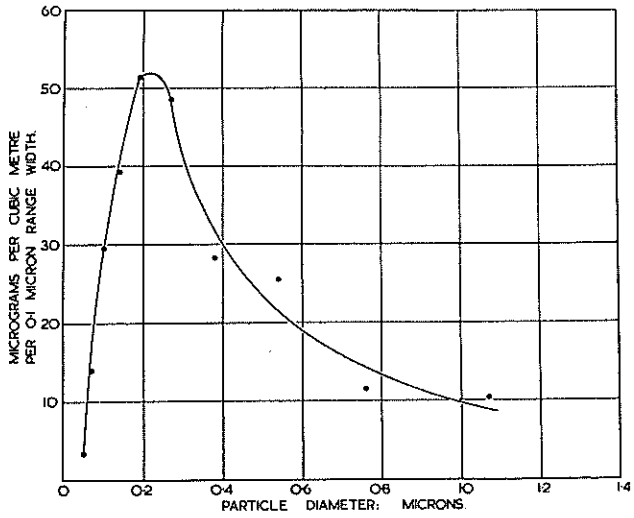

Fig. 2(b).—Graph showing mass distribution of particles in sample shown in Fig. (2a). The diameters are those of equivalent spheres.

is preferable to one involving intermediate measurements; the object of our tests must be used, when possible, as indicator and assessor. Thus, in California air pollution can cause severe damage to spinach crops, and so the spinach plant is properly used as an instrument for the estimation and study of specific pollutants. Sulphur dioxide produces damage in different plant species which is histologically distinct from that caused by Los Angeles " smog " and by fluorides; plants may thus be used as delicate and specific instruments in research work which has their salvation as its primary object. (Thomas and Hendricks, 1956.) Likewise, Los Angeles " smog " is a great nuisance because it causes lachrymation; despite an enormous amount of analytical work the compounds responsible for the effect have not yet been identified with certainty and it is refreshing to see that, amidst complex analytical machinery, the human subject, the proper object of the work, is used as an instrument to assess lachrymatory properties of suspect compounds. The principle is again well illustrated by consideration of the problem of pollution in streets by carbon monoxide from petrol vehicles. One may sample the air instantaneously at a time of peak pollution and analyse it; or one can take a large sample slowly over 12 or 24 hour periods and then determine an average concentration; with an automatic recording infra-red analyser a record can be obtained of the precise manner in which the concentrations fluctuate. Air samples may be taken in evacuated bottles or collected by bubbling the air through blood. Any of these results must then be translated by reference to graphs and tables derived from the research work of others to provide ultimately an estimate of a possible hazard to men of such a size engaged in a specific activity for a specific time. It is sometimes forgotten that man himself is the best CO sampler and that by determining the CO content of his blood after he has performed a stated task in the environment in question much speculation and difficulty may be avoided. That is the method we are using in our study of pollution in London streets. Man is better than an evacuated bottle. Haldane was applying the same principle when he took canaries down mines; the bird is a most valuable instrument supplying vital information and if it is subject to error, the error is always on the safe side.

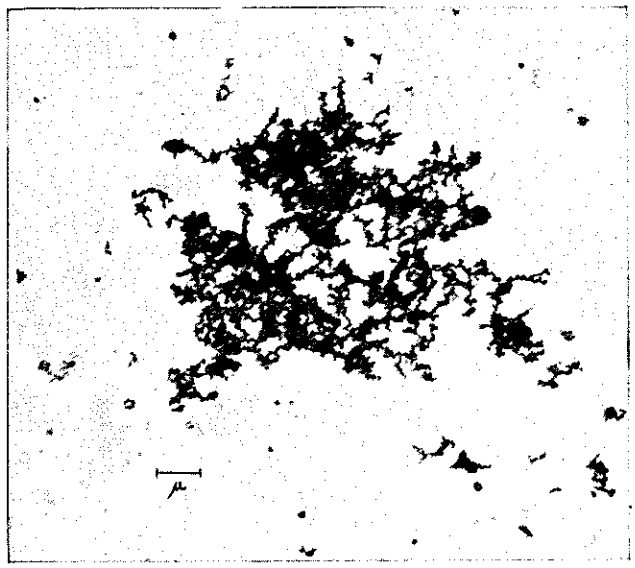

Fig. 3.—Electron micrograph of smoke aggregate in sample of air taken on the roof of St. Bartholomew's Hospital. (Crown copyright, S.M.R.E.).

Nearly three years ago we started a crude biological experiment using patients with chronic bronchitis as our instruments in an attempt to determine the circumstances responsible for their clinical deterioration. We were fortunate in having a well controlled group of patients at St. Bartholomew's Hospital whose clinical condition had been carefully followed for several years (Bates, Knott and Christie, 1956). They were the first to take part in the investigation. Later (in the winter of 1955-56) about 150 patients

from four other clinics in London and from clinics in Manchester, Sheffield and Birmingham, joined in the experiment. Commonly, patients with chronic bronchitis maintain that certain types of weather or different kinds of fog make them worse and they vary in their dislikes. A visit to a clinic at intervals of a month or so does not permit this valuable information to be elicited with any great degree of accuracy since remembrance of individual days is often vague. Therefore it was decided to ask the patients to write in a diary their own assessment of their condition according to the following simple code and instructions which were pasted inside the diary :—

Bronchitis Investigation Instructions

Please write a letter in the space for *each day* as follows:—

A. If your condition is better than usual
B. If your condition is the same as usual
C. If your condition is worse than usual
D. If your condition is very much worse than usual.

It is important to write one of these letters in the diary every day

If you are ill or have to go into hospital please ask your closest relative to fill it in for you until you are well again.

In addition to the above write:—

F. If there is a fog some time in the day
X. If you have head or chest cold that day
H. If you stay indoors all day.

If you want to make any special note, please do.

The simplicity of the instructions will be noted; it was felt that any attempts to elicit more specific information (such as various symptoms of chest trouble) would render the results invalid by overburdening the patients' powers of categorisation and clinical classification. In fact the experiment was remarkably crude in conception and was designed as an alternative to monthly questioning. As the results came in an attempt was made to correlate the " degree of illness " of the patients as a group in Greater London with meteorological factors and with pollution (smoke and SO_2) measured on the roof of St. Bartholomew's Hospital. The " degree of illness " of the group has been calculated after allotting a " score " to each diary entry as follows :—

$$A = -1$$
$$B = 0$$
$$C = +1$$
$$D = +2$$

$$\text{Then Mean Score} = \frac{\text{Sum of scores for all patients}}{\text{Number of patients}}$$

The mean score provides a measure of the " degree of illness " of the group as a whole, ranging from 0 to 1 in winter and below 0 in summer.

There remains to be done an immense amount of analysis but some preliminary results from 180 patients in Greater London are shown graphically in Fig. 4.

From a preliminary examination it seems that a close correlation exists between " degree of illness " and air pollution (smoke and SO_2); the correlation is closest in mid-winter and ceases to exist by the time

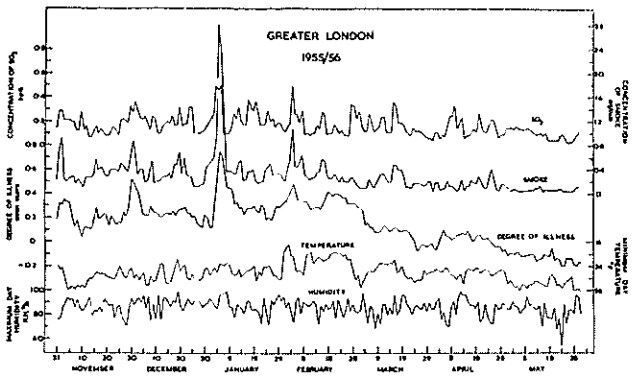

Fig. 4.—Graph showing " degree of illness " of 180 patients in Greater London with chronic bronchitis plotted with smoke and SO_2 concentrations, temperature, and humidity. (Diary experiments.)

spring comes by which time temperature and other factors seem to assume some control; whenever pollution becomes severe, clinical deterioration occurs. These results are not merely a reflection of visibility because the variations in pollution recorded cannot always be detected visually. It might be that certain combinations of conditions are particularly injurious or that " threshold " levels of pollution are required to produce ill-effects, and, if so, the harmful conditions could be quantitative or qualitative variations of " normal " urban pollution and weather. Manifestly, the analysis of these results is in its very early stages; earlier it has been said that individual patients react differently to apparently similar and synchronous conditions and it is hoped that further detailed analysis might reveal some individual consistency of response which will contribute to our better understanding of this problem.

So far the diary experiment has been valuable as a probe technique in that it has indicated the need to give attention to pollution as distinct from fog. Usually wet fog does not seem to have marked ill-effects on patients whereas the diaries showed that a

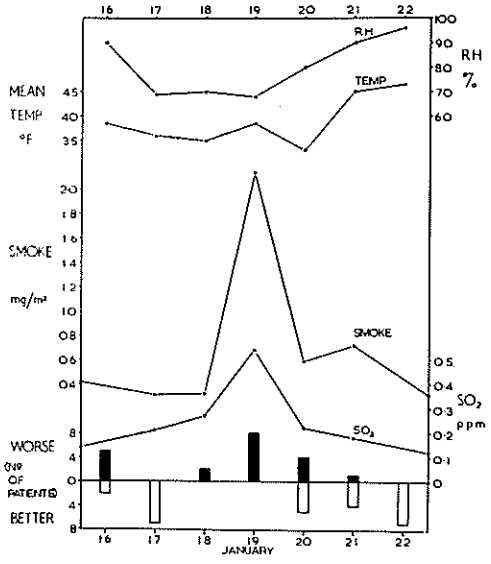

Fig. 5.—Graph showing effect on bronchitic patients (Bart's) of high pollution without fog.

period of sudden high pollution with low relative humidity had a bad effect on the Bart's group on January 19th, 1955 (Figs. 1 and 5, Waller and Lawther, 1955).

We hope that this use of the patient as an instrument for the investigation of air pollution will bear fruit. The crude humble approach must not be scorned because it looks inadequate beside modern complex methods. Frequently the complex methods are designed specially to discover the truth when it is deeply hidden —to distinguish the trees in the wood; but, though some of us stand in awe of Science, we must keep our eyes open wide, even naïvely, lest we miss seeing the wood before us.

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DISCUSSION

The effects of atmospheric pollution on plant growth were referred to in the discussion on Dr. Lawther's paper. Typical smog damage was the silvering of leaves, due to necrosis, which was seen in susceptible species in various urban localities. An outstanding difficulty was the separation of SO_2 and SO_3; the latter in the form of droplets of sulphuric acid, was of greater pathological significance, although men working in accumulator factories in an atmosphere of sulphuric acid spray apparently suffered no harm beyond dental erosion. There was doubt as to whether atmospheric SO_2 was a factor in causing discomfort to bronchitis patients.

DIAGNOSTIC AIDS IN RADIATION MEDICINE

By T. E. Graham, B.Sc., M.B., Ch.B., Senior Medical Officer, U.K.A.E.A., Industrial Group (Northern Area)

Biological Effects of Radiation

THE previous speaker has described the principles by which ionizing radiations are detected and measured. We have seen examples of the great variety of instruments which have been evolved to meet practical needs. All this is necessary because radiation is not detectable by the human senses. Without instrumentation we could not hope to control the environment of people who work with radioactive substances or radiating equipment.

Before discussing instrumentation in further detail it might be helpful to consider some generalities.

Already the concept of a Maximum Permissible Level is a familiar one in industry. In radiation work, this concept is perhaps of more pressing importance than elsewhere, because of the insidious nature of the hazard. There are no early warning symptoms such as are met with, for instance, in the better-known chemical hazards. Radiation-induced disease has a latent period of many years. It is irreversible and malignant in character. At low levels of instantaneous exposure recoverable blood changes may occur while, at the other end of the scale, grossly excessive exposure of the whole body produces an acute illness—the " Acute Radiation Syndrome "—which could well be fatal. Between these two extremes—the first of academic interest only, the second a disaster—lie possibilities for chronic disease to be caused over long periods of time, by doses of radiation which are not only unnoticed by the patient but could escape detection altogether if rigid control were not excercised. Table (1) shows a brief summary of radiation pathology, also a rough guide to the severity of selected dose levels. It should be noted that these levels would not apply to children nor to persons suffering, for example, from blood disorders. Individual variations in sensitivity must be great but, as yet, we have no method of assessing these

Table I

RADIATION INDUCED DISEASE

ORGAN	DISEASE
Skin	Erythema, blistering, baldness, pigmentation, hypertrophy, ulceration, cancer and other tumours.
Eyes	Burns, cataracts.
Bones ..	Inflammation, sarcoma.
Bone marrow	Destruction of cells and disruption of the blood-forming system. Aplastic anaemia and leukaemia.
Lungs ..	Cancer.
Genitalia ..	Impaired fertility, sterility, changes in heredity.
General ..	Many types of malignant disease especially of lymphoid tissue.

ACUTE DOSE (R)	EFFECT
0-25	No obvious injury.
25-50	No serious injury.
50-100	Blood changes.
100-200	Injury and possible disability.
200-400	Death possible.
400	Minimal lethal dose in 50 per cent of cases.
600+	Fatal.

in advance. In the matter of variations in senstivity iit is, of course, also true that some tissues are more vulnerable than others—a fact which is of great importance to radiotherapists. In general, the cell is in its most radiosensitive phase when it is undergoing growth changes. The actively growing tissues of bone marrow and reproductive organs come at the top of the list.

Maximum Permissible Levels

Such human data as we have to support the validity of present M.P.L's come mainly from a large series of patients who suffered fatal disease from the effects of X-rays and radium. They sustained overexposure many years ago, before the dangers were recognised. The martyrdom of the X-ray pioneers and the tragedy of the "radium dial-painters" of the 1914-18 war are by now too well-known to describe here. To these must now be added the recent statistical information on the incidence of leukaemia among American radiologists, the M.R.C. inquiry into the connection between leukaemia and X-ray treatment of Ankylosing Spondylitis and of course the long-term studies on the Japanese people who survived the raids on Hiroshima and Nagasaki. Animal data of all kinds, are abundant—so plentiful, in fact, that the real problem is to discern simple principles amongst the wealth of detail.

The M.P.L's of "external" radiation—that is electromagnetic radiation mainly—are much better known than those of "internal" radiation. Radioactive substances absorbed into the body can have many effects which depend, not only on physical, but largely on metabolic criteria. In humans we know a lot about absorbed radium, but the other elements, such as Plutonium, have M.P.L's which are calculated from that of Radium. No human case has yet arisen, so far as I know, of disease caused by the absorption of any artificially made radioisotope. But then less than twenty years have elapsed since these new substances were first discovered. Plutonium^{239} itself was first made in microgram quantities in 1942, so there has not been enough time.

Maximum permissible levels have varied a good deal over the years, but modern view is that 0.3 röntgen per 7-day week is a safe working level. For planned exposure over many years however, such as might be expected in a full-time atomic energy worker, this is really too high because of considerations which will be apparent from Table (2). From a lifetime point of view a kind of sliding scale is to be applied so that the total lifetime dose from conception to age 60 should not exceed 200 r. A bar, at age 30, of 50 r as a maximum is put up on genetic grounds. The lifetime maximum of 200 r is related to leukaemia: this figure is now agreed to be capable of causing leukaemia.

In the same table will be seen only a few of the "internal radiation" elements expressed in terms of lifetime M.P.L. The figures shown incorporate all known considerations: metabolic characteristics, physical half-life, energy of radiation. In addition, there is a small factor of safety—an ignorance factor, if you like.

The foregoing sketch gives an idea of the demands which the doctor has to make on the ingenuity of the physicist and the electronic expert.

Table II

PERMISSIBLE EXTERNAL RADIATION EXPOSURES FOR FULL TIME RADIATION WORKERS

Week	Month	Quarter	Year	Lifetime
0.3 r	1.0 r	3.0 r	5.0 r	200 r

Some Maximum Permissible Body Burdens

	By Radioactivity	By Mass (approx.)	Significant Radiations
Radium^{226}	0.1 μc	0.1 μg	α, β, γ
Natural Uranium	0.04 μc	60.0 mg	α, β, γ
Plutonium^{239}	0.04 μc	0.6 μg	α
*Polonium^{210}	0.04 μc	0.000001 μg	α
Strontium^{90}	1.0 μc	0.0075 μg	β

* A short-lived element (138 days) and readily excreted, this case permits a continuous "topping up" dose, also mitigation by radiation-free time.

Control of External Radiation

Fig. 1 shows the commonplace devices used for measuring external radiation. This type of radiation hazard is perhaps the most readily controllable.

The instrument in the centre is a 1030C Portable Gamma Monitor (the "coffee-pot" monitor). It consists of a battery-operated ion chamber which registers a cumulative total in rontgens up to a maximum of 0.12 r. It is useful in cramped places for timed jobs. It is also used for gauging the radiation field when timing a job. This type of instrument could be elaborated into a mains-operated, built-in version which would be like a clock on the wall in a place of work. In practice, however, this has not been found very useful. If the radiation field is fairly constant,

Fig. 1.—Instruments used for measuring external radiation.
Left: Pocket dosimeter.
Centre: Battery operated portable gamma ray monitor.
Right: Film badge.

a short period of routine measurement would give enough data for planning and the instrument then becomes unnecessary. If the field is very variable it is unlikely that a stationary instrument would be flexible enough to use for measuring the dose sustained by individuals. There may, of course, be important military applications, for instance in vehicles, ships and aircraft.

The film-badge, of which you have already heard, is universally worn in radiation areas. Different emulsions can be selected to suit the energy range. The small metallic instrument is a Pocket Dosimeter. It is a Quartz Fibre Electrometer, which is charged beforehand and worn like a fountain pen during special jobs. A direct reading of the body dose in röntgens is obtained by looking through one end of the device. This is used as a cross-check on the film (or films) which are worn at the same time. Quite often the two stories do not agree. When this happens the worker is given the benefit of the doubt and the higher reading is accepted. The Q.F.E. fails to safety—like all good protective devices—and its reading can be increased by dropping it or shaking it: a disadvantage not shared by films. On the other hand films are subject to spoilage by heat, light and moisture.

Film-badges are assessed by a photoelectric Densitometer. Control films, exposed to standard radium sources, are first tested and the arbitrary units on the galvanometer are thus calibrated in terms of röntgens. The unknown films, from exposed persons, are then measured and the exposure calculated. Here, again, heavily blackened films do turn up and an explanation cannot always be found. The worker is, again, given the benefit of the doubt. He is transferred to non-radiation work until his average is brought down to M.P.L.

By means of simple devices like these control can be exercised even on special jobs (such as repairs and maintenance to Atomic Reactors). Many of these operations can be timed to the minute and rotation of personnel is practised, saving the few skilled men for the skilled jobs and using unskilled men from non-active areas as labourers.

Various other types of instrument are employed—both static and portable which give a very accurate picture of the radiation field in which men are working. Nearly all depend on the ion chamber principle.

It must be remembered, however, that radiation falling upon a worker is not necessarily χ- or γ-radiation. High energy β-radiation (i.e. fast-moving electrons) is another aspect of the problem. All the radioactive Fission Products are β-emitters (most have γ-activity also) and some of them are very active. The Geiger-Muller tube will record β plus γ rays and allowance has to be made for the proportions. Radiation from β-particles of lower energies is not important to the clothed worker but becomes a consideration when it is necessary for him to *handle* sources. Special types of film holder for fingers and wrists are often used.

Neutrons

Perhaps the most subtle and least controllable of the external radiation hazards is that associated with neutrons. These particles, having no electrical charge, are difficult to detect and measure. Neutrons can have a wide range of energies and their damaging effects depend on how fast they are travelling. M.P.L's for neutrons are reckoned in terms of the number per second per square centimetre and the higher the energy the lower the M.P.L.

To count a neutron you have first to make it cause some electrical disturbance the effects of which will register electronically. If the particles are travelling slowly (i.e. at velocities in the region of 2000 metres per second) they can be absorbed into certain substances with a high " capture cross section." The most notable element of this class is Boron and several devices use this as a counting medium. A proportional gas-counter containing the gas BF_3 has been successfully designed. The isotope B^{10} has an avidity for neutrons. The captured neutron forms an unstable nuclide which gives off an α-particle and the atom becomes Li^7. The α-particles are absorbed by a scintillating medium, such as zinc sulphide, giving off light flashes which can be picked up by a photomultiplier and thence counted.

Taking the principle somewhat farther, plastic materials such as Perspex, can be used for slowing down neutrons of medium energies and the Boron, with zinc sulphide, can be embodied in the plastic.

For the counting of very fast neutrons a different principle is employed. Hydrogen, and substances rich in hydrogen (e.g. paraffin wax), emit recoil protons when irradiated by fast neutrons owing to direct collisons between the latter and the hydrogen atoms. The protons can be counted either by a scintillation or an ion chamber assembly.

To find some simple device for a man to wear like a film badge is a matter of great difficulty. Two types of detector are made for this purpose. The first is a photographic plate coated with a nuclear emulsion loaded with Boron. After exposure this has to be developed and the α-tracks counted visually. This is time-consuming and laborious. The second type embodies the principle of radioactivation, whereby the stable isotope of certain elements will capture neutrons and turn into the appropriate radioactive isotope. Indium is such an element, and a foil made out of Indium metal will become β-active when exposed to neutrons. Unfortunately the In^{114} is rather short-lived and counting has to be done immediately to be of much value.

From this very superficial account of the neutron monitoring problem it will be seen that there are great difficulties in applying such indirect techniques to give reliable results in practice. The fact that fast neutrons behave differently to slow, makes it necessary to have a whole battery of detectors of different types to assess and measure a flux of mixed energies.

It is fortunate that in practice, barring accidents, the neutron hazard takes the form of discrete beams emerging from expected places e.g. out of an open channel of a reactor during discharge operations. In other words it is usually possible to know in advance where the neutron beams are going to be and thus avoid them. Even so, in research work, observations by direct vision are sometimes necessary in a neutron field and the eye is, unfortunately, specially prone to neutron damage in the form of cataract. Perspex goggles are useful only for moderate and low energies.

Reactors are not, of course, the only source of neutrons. Some light elements, when bombarded by α-particles give off large numbers of neutrons, the best-known being a Radium-Beryllium neutron source. There are also particle accelerator machines which can generate high energy neutrons and collimate them into a beam.

Criticality

Spontaneous emission of neutrons occurs in a few radioactive elements. If it were not for this phenomenon no chain reaction would be possible and hence no atomic energy. This brings us now to consider what is certainly the most dangerous kind of hazard in radiation work. Fissile elements—notably Pu^{239} and U^{235}—have what is known as a *critical mass*. A piece of a fissile element has a maximum size. A point is reached when even a few atoms more will cause an uncontrollable disintegration to start. Geometrical shape, chemical form, surrounding materials, purity—all these are factors which help to determine the critical mass. Criticality is achieved when enough neutrons are produced to cause a constant number of fissions while any neutrons in excess of this number can escape capture. When there are neutrons to spare i.e. to cause more and more fissions, the assembly is said to be supercritical. In a time which is measured in microseconds the supercritical assembly gives off great and increasing, heat, light and radiations of all kinds. It will melt, vapourise or explode depending on circumstances and part of it will shatter into Fission Products. In much less time than it takes to tell, balance will be restored, the excess mass having been thrown off as energy. Properly controlled by means of moderator, reflector, coolant and adjustable neutron-absorbing devices, a system like this would be an Atomic Reactor. But experimental reactors and assemblies have been known to " run away " and, if this happeus, persons in the vicinity may receive damaging or fatal doses of radiation. It is in such a situation that the doctor needs all the evidence he can get from instruments.

Our information about such accidents is not merely theoretical. Detailed accounts of at least three have been published in America and I have heard of one Russian episode. In all 16 people at least have suffered radiation exposures in this way and two of them died. There has not been a British case so far, and I am leaving out, of course, the Japanese bomb casualties.

In situations where an experimental critical assembly is being used on a laboratory scale one would expect suitable precautions to be built in: shielding, remote-handling machinery, wide dispersal of personnel. There would be static monitoring instruments—either for neutrons or for γ-radiation, so that if a person did sustain a heavy radiation dose this would, at least, be measured with some accuracy. The situation is much worse when there is no direct information about dosage. The ordinary film badge would be blackened beyond the scope of a densitometer and only a rough idea of the dose would be got from chemical analysis of the film. All ordinary instruments would go " off-scale." To estimate the dose by measurement very indirect methods would be necessary, such as measuring induced activity in the surrounding structures of the apparatus.

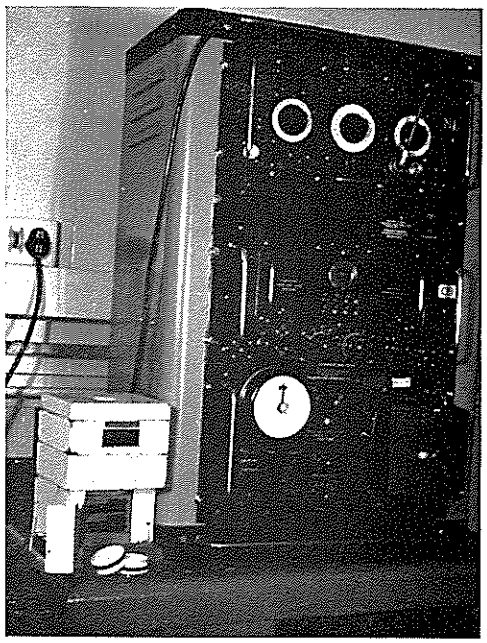


Fig. 2.—" Infinite depth " counter for Beta emitters, showing the lead castle on the left.

The patient himself might provide a lot of information if the neutron flux at the moment of the " flash " were high enough. Perhaps the most useful index is the Na^{24} formed in body fluids by neutron capture in natural Na^{23}. Serum sodium and urine sodium are the obvious choices.

Fig. 2 shows an assembly for counting β and γ pulses. The lead castle (on the left) contains a G.M. tube and an amplifier circuit the pulses from which are fed into the discriminator which eliminates valve noise, etc. The selected pulses are then fed to the scaler which embodies a number of 2-way valves by means of which pulses are carried on to a battery of lights, registering units, 10's and 100's. From there the pulses are recorded on a clock and an integrator which are mechanical. You can have the total in terms of number per given time—i.e. counts per hour—or else you can have the time taken for a given number of counts to occur.

The counter itself has an efficiency of 100 per cent. In the model shown, however, the sample is contained in the lead castle in solid form and is counted and calculated according to the " infinite depth " principle, where an answer is obtained in dpm/gm. Standardisation is attained by using a standard of pure potassium chloride the K^{40} content of which is accurately known. Dried serum residues (or urine residues) can be used here. A variation of the technique calls for an M6 liquid counter in which the treated urine is poured into the glass cylinder along whose axis is a G.M. tube. Calibration is again reckoned by means of Potassium Chloride solution of known strength. The Na^{24} content of the body fluids bears a direct relationship to the neutron flux, although it is doubtful whether enough cases have occurred to make rules about this.

The contents of the victim's pockets may reveal valuable clues. Gold and silver articles are the best because they capture enough neutrons to give a

strong β-radiation for counting by means of a G.M. tube. Copper is good enough but iron, nickel, chromium, sulphur and phosphorus are rather poor. One reported American case (a fatal case, as a matter of fact) actually had a β burn of his gum resulting from radioactivation of a gold inlay on a tooth.

Haematology

A patient who has suffered severe exposure in a criticality accident would get his greatest dose from γ-radiation. Of all the bewildering variety of radiations, hard γ-rays probably figure most largely. His skin, in due course, would show burns from β-radiation but for γ-ray damage the evidence would be sought in the realms of clinical pathology. His blood-picture would rapidly show a severe leukopenia followed by the changes associated with aplastic anaemia. Relating degree of exposure to degree of blood disorganisation is an extremely difficult exercise and one should not dwell too long on this aspect in a lecture of this nature. The relationship could not be an exact one, obviously, and clinical judgment is essential.

It is pertinent, however, to talk of blood-counting techniques and there has been, of late, much attention to automation. Apart from the drudgery of blood-counting, there is an enormous (though natural) variation in the skill and accuracy of the technician. In a criticality accident, many blood counts would be wanted, and automatic instruments would be invaluable. A counter developed at Harwell, with optical equipment by Baker and electronics by Dynatron will perform marvels of speed and accuracy in Red Cell counting. Unfortunately it can only be used for red cells and not for white (a fact which makes it really unsuitable for routine blood counts on radiation workers). It works on the photoelectric principle. A precision-built, mechanically-moving stage is scanned by a narrow light beam which is interrupted by the shadows of individual corpuscles. Each shadow registers on the scaler as one unit. Allowance is made in the calculation for overlapping and the actual count is reckoned from a graph prepared beforehand. A more elaborate version of this is available also for particle size analysis. A very interesting departure from the scanning principle is this EEL Blood Cell Counter. In this machine, a constant large volume of circulating water is employed, the pressure of which is used to make a monocellular column interrupt a light beam. A capillary tube of known capacity is interposed between the light source (with optical system) and the photoelectric cell. When everything is ready, the diluted blood is injected into the system and the circulating current carries the fluid through the capillary at a fixed and rapid rate. The corpuscles are counted one by one as they interrupt the light beam. The electronic gear is reliable up to 500 cells per second or more and thus encompasses pathological bloods such as are found in leukaemias. Counts can be done in a matter of moments. Many samples can be fed into the capillary tube and simply read off in turn. The scaler gives a direct reading in multiples of 100. Using two different diluents, red and white cells can be counted with equal ease. In my opinion this represents an enormous advance on microscope scanning methods.

Unfortunately all such automatic counters have two inherent drawbacks: first, their accuracy depends on accuracy of dilution—a human problem, and second, none are capable of doing a differential leukocyte count.

Returning to the Criticality Accident, there are three other subtle biochemical changes which are capable of measurement. Their diagnostic value is doubtful except in cases destined to be fatal. The Sodium : Potassium ratio in the blood is altered, the plasma proteins change and the urine contains unusual amino-acids in abnormal amounts. For serum-alkali metals flame photometry is the technique of choice.

There are simple flame photometers which employ a system of filters and a reading is obtained on a galvanometer which can be calibrated against known standards.

The serum sodium falls in radiation sickness: the urinary potassium rises. This may be of academic interest only.

With regard to plasma proteins, one cannot read too much into experimental findings. Decreased albumin and increased α-globulin have been noted in heavily exposed cases. Electrophoresis techniques are used for the determinations. As a diagnostic procedure this is rather unrealistic.

Amino-aciduria is assessed by means of paper partition chromatographic techniques. Two factors render the picture abnormal in irradiated patients: defective utilization of dietary amino-acids and degradation of protein from degenerated cells. This phenomenon is, again, difficult to relate to exposure quantitatively—especially in the lower doses.

Another criterion is available in males, which does not however involve special instruments, namely sperm counts. The sperm count falls drastically after high radiation doses.

It will be seen that assessment of dose, in the doubtful case, is a matter of great difficulty. The main sources of information would be physical and mathematical rather than medical. In a criticality accident the best that one could hope for is a broad decision as to whether a patient will live or die. If he is to live, one can say whether his illness will be slight or severe. The rest is not well understood. Negative findings have great reassurance value.

Having discussed External Radiation at some length, we now have to consider Internal Radiation—that is to say the effects of radioactive substances taken into the body. Closely associated with this are problems of skin contamination. We have also to give thought to Radioactive Effluents, gaseous, solid and liquid. It is impossible at present to deal in detail with all aspects of this great subject. Protective clothing alone, for instance, is too large a topic for this lecture. Since our subject is Instrumentation, the rest need only be mentioned.

Fundamental to any discussion of internal radiation is the concept of Standard Man. There is an internationally agreed model on which calculations are based and his vital statistics are shown on table III. On these agreed figures are based the M.P.L's for a host of radioactive substances, not only in the matter of maximum permissible body burdens but also in connection with tolerable air content and drinking

Table III

STANDARD MAN

Total body	70 kg.
Muscle	30 kg.
Skin	2 kg.
Skin and subcutan. ..	6.1 kg.
Fat	10 kg.
Skeleton	7 kg.
Bone and marrow ..	10 kg.
Liver	1.7 kg.
Lungs	1 kg.
Total water consumed per day	2500 ml.
Total water excreted	do.
Water excreted in urine	1500 ml.
Air inhaled per 8-hour day	10 m^3
Total body water ..	50 l.
Average life-span ..	70 years.

water content. The International Commission on Radiation Protection has published its recommendations on these topics and they embody the essence of extensive experiments with animals and all the human information which I mentioned at the beginning of this talk. In an individual case the doctor has to weigh the pros and cons of the measurements he can make and apply the yardstick to his individual patient.

The instruments used for this part of the work are basically simple. The air-sampling device consists merely a vacuum cleaner into which is built a gauge to measure air flow (in cubic meters per hour). A filter paper at the intake end catches atmospheric dust and this can be counted in one of the standard counters which will record α, β or γ radiation as the case may be. Thinking now of surface contamination—another dust problem—instruments like the 1021 type portable counter are universally used at Windscale Works. It is essentially a power circuit (to provide EHT) plus an amplifier which leads the magnified pulses into a ratemeter. It records electrical pulses per second—either in units, 10's or 100's depending on the activity of the specimen. Two " probes " can be fitted : the $\beta\gamma$ probe, a G.M. tube with a gas-gain of X 10^8, or an α-probe scintillator to which is coupled a photomultiplier valve with a gain of X 10^7. A small speaker is built-in which is useful for rough checking. The efficiency is in the region of 5-7 per cent. This type of instrument, with or without simple modifications, can deal with most contaminated surfaces, ranging from floors and walls to clothing and even human skin. For more exact localisation of activity special probes are used. The very thin α-probes are used for monitoring in confined spaces, e.g. between teeth or in a small wound (Fig. 3). I should mention at this point that α-activity, such as is given off by plutonium, has a very short range—less than 1 cm. The probe has to be very close to record the α-particles and a very thin layer of water, or blood or a single layer of gauze will blot up the radiation giving a false reading.

Contamination

Skin decontamination is something of a problem in places where radioactive chemicals are handled on a large scale. At Windscale Works we have a special room for this purpose. Fig. 4 shows the irrigation of a tiny contaminated puncture wound with a thin jet of water. The puncture wound is to be excised. A 1027

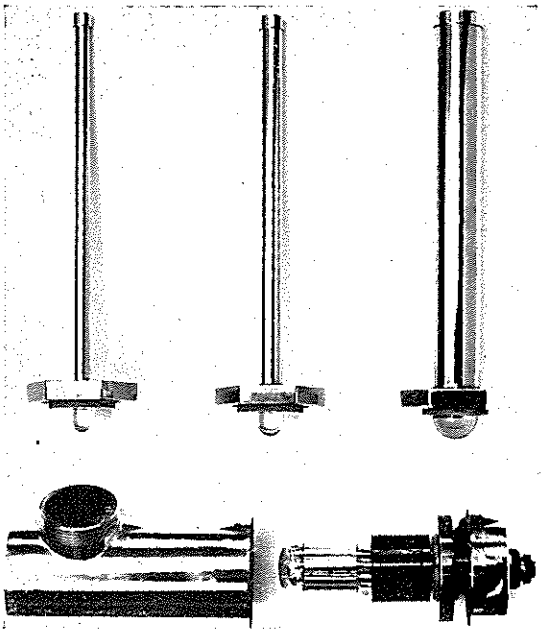


Fig. 3.—Wound probes for X-activity used with a 1021 mains-operatedmonitor. Three sizes : $\frac{3}{16}$ in., $\frac{1}{4}$ in., $\frac{1}{2}$ in. The photomultiplier tube (both left) in its protective case (upper left) collects light flashes through the perspex prism in the stem of the probe, emitted by the small zinc sulphite screen at the end of the probe. To protect the screen there is a tiny piece of aluminium foil at the very end.

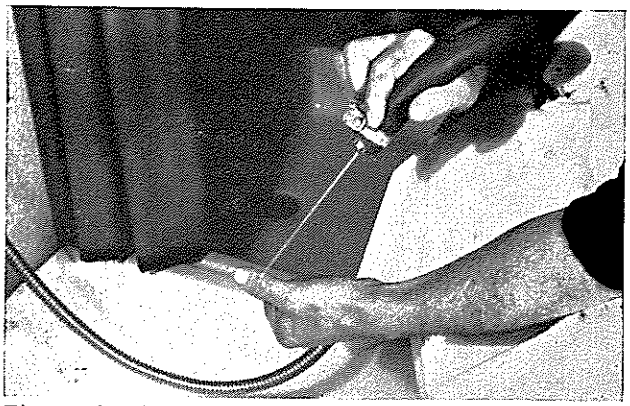


Fig. 4.—The irrigation of a small contaminated puncture wound with a jet of water.

Hand and Foot Monitor is standard equipment in changerooms ; it has two pairs of slots, one for α- and one for $\beta\gamma$-radiation, into which the hands are thrust. The instrument, which has an efficiency of about 5 per cent, consists of the power pack, discriminator and ratemeter which were described previously. The " probes " are novel in that they interpret hot spots on the fingers as being spread over the whole hand, i.e., the dose is integrated. Also they run for a fixed time ($\frac{1}{2}$ minute) at the end of which the whole mechanism switches off. The dials read in M.P.L's and are, in fact, ratemeters. A bell rings if a hand is contaminated above M.P.L. At present the M.P.L's for hand contamination are 10 counts per minute α and 600 c.p.m. $\beta\gamma$. Feet and clothing are monitored by means of standard probes hung on hooks near the foot of the instrument.

Absorption

We now turn to the question of absorbed radioactive substances. A certain amount of information about intake can be inferred from knowledge of the external circumstances. For instance you can make a shrewd guess at the body burden if you know that the worker has breathed air containing 1 M.P.L. (6×10^{-12} μc/cc.) of soluble Plutonium for exactly 8 hours. This should be 0.6 μg—provided that this particular man has inhaled exactly 10 cubic meters of the contaminated air, and provided that his skeleton weighs 10 kilos. In other words he would have to be a " Standard Man." Plainly this is not good enough. Two other lines of approach are possible.

The first approach has already been discussed by the previous speaker, namely the measurement of radioactivity emanating from the body. This is best provided that the material you are seeking gives off penetrating radiations. Ra^{226}, Cs^{147} and Co^{60} are obvious ones: they are comparatively easy because each emits energetic γ-rays which can be readily discriminated from natural background. Even so there is a lower limit to the body burden detectable by this means, and detailed localisation would not be easy.

The whole-body monitor at Harwell works on the scintillation principle using large thallium activated sodium iodide crystals as the source of light photons. Another type of instrument, developed at Leeds University, employs the ion chamber principle. Each has its technical advantages. An interesting variant of the scintillator for use with humans is the instrument developed at Los Alamos, New Mexico. This is a large double-walled cylinder into which the patient is slid. The cavity wall is filled with 140 gallons of one or other of those organic liquids with scintillator properties, e.g., terphemyl or phenyloxazone or mixtures in suitable diluents. " Watching " for light flashes in the solution are 108 photomultiplier tubes arranged in 9 radial banks of 12. It is claimed that very rapid measurements of body activity could be carried out on big numbers of people with an instrument like this. Admittedly, however, fine discrimination of energies could never be easy.

These instruments have proved up to the present, to be disappointing when tried for elements with little or no γ-radiation, notably Pu^{239}. This very important isotope is a strong α-emitter but its γ-ray has an energy of only 17 Kev. This is too weak to be discriminated from the mixed natural background and the K^{40} of the body. Similarly Sr^{90}, the second of our most worrying long-lived isotopes, has no γ-emission at all and a β-emission of only 0.54 Mev—only $\frac{1}{3}$ as strong as that of K^{40}. So that with the two elements in which the doctors have the greatest interest, these counters are at their least efficient. It should be added that heavy shielding and complex electronics are essential, also they all require the services of an expert scientist to be properly operated.

The alternative approach to the measurement of radioactivity inside the body depends on the fact that no matter how well-retained these materials are, a certain amount of the body burden is always excreted. We measure, in fact, the radioactivity which leaves the body in the urine and faeces. (I ought to mention the special case of radium: the daughter product, radon gas, is excreted in the breath and this can be measured with some accuracy by means of an ion chamber.)

Noxious materials in general can gain entry to the body in three main ways. They can be breathed into the lungs, swallowed into the alimentary canal or absorbed through the skin, especially if the latter is unhealthy or broken. Many radio-active materials have an affinity for specific organs: radioiodine comes to mind as having almost an exclusive preference for the thyroid gland. A very important group seeks the skeleton as a " critical organ." Plutonium and Uranium (like lead) do this. Strontium also is a bone seeker. being mistaken, as it were, for Calcium by the body. The avenue of entry determines the metabolic course of the element and different fractions appear in the urine. The time of intake is also crucial, especially with bone seekers. The problem for the doctor is to assess a body burden using the excretion figures obtained by urine analysis. Most of the information available refers to animal experiments and it is not easy to reply to humans.

Biological Monitoring

To do systematic " biological monitoring," as it is called, a considerable laboratory is necessary. Part of the Windscale laboratory is shown in Fig. 5. This laboratory is not, of course, exclusively medical. Other samples of an organic nature are analysed here—for instance vegetation.

Uranium is the easiest analysis to make. Assay is done by Photofluorimetry (Fig. 6). The U.V.L. fluorescence of the prepared residue is compared with known standards. Counting techniques are unnecessary, even with highly enriched uranium. Plutonium, an α-emitter, is difficult because we seek such very small quantities. After complex chemical treatment the urine residues are counted. A small platinum disc on which the treated urine deposits its few Pu atoms, is slid in on a drawer, and a scintillator counts overnight. A similar instrument is used for Po estimations but, of course, the chemical preparation of the sample

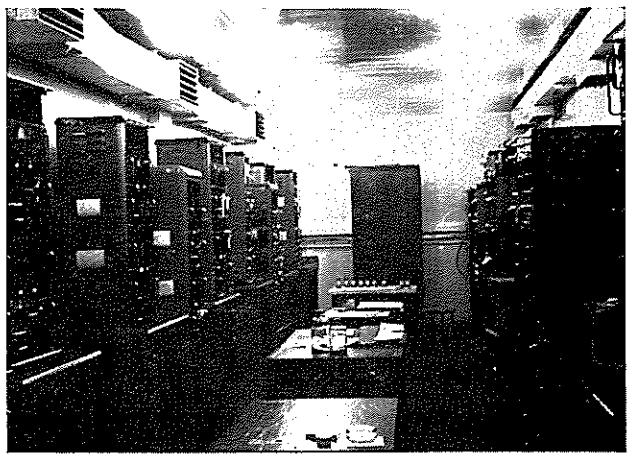
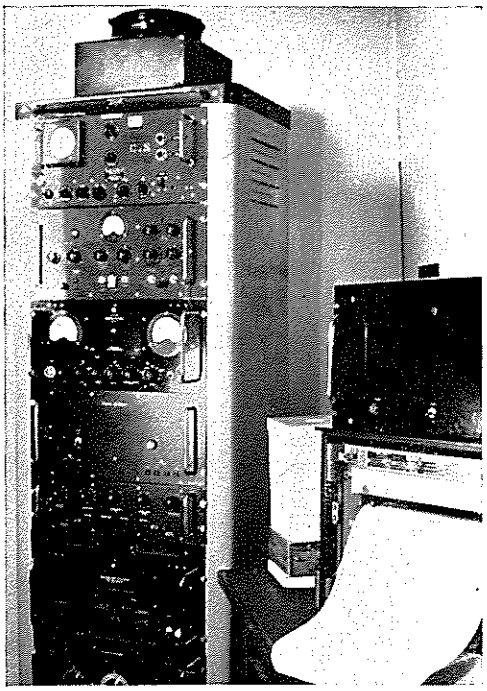


Fig. 5.—The counting room of the Windscale laboratory where biological samples (fish, vegetation and samples of human origin) are dealt with.



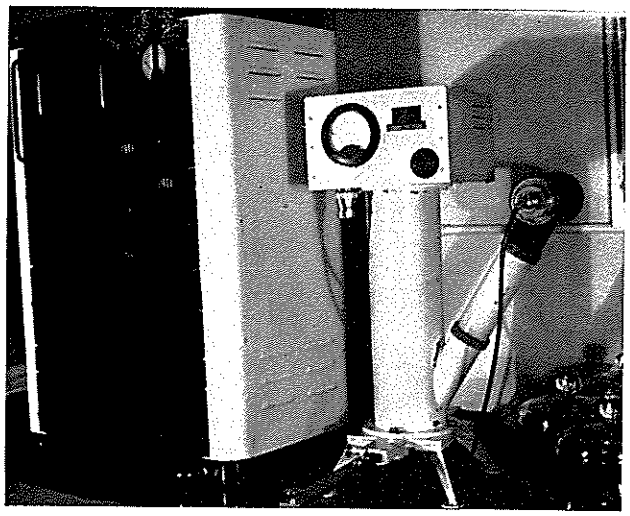


Fig. 6.—Photo fluorimeter for the analysis of uranium.

Fig. 7.— Apparatus for measuring tritium in urine.

is quite different. For unknown mixtures of α-emitters a 100-channel α-spectrometer is necessary. The metal sample chamber contains Argon plus 10 per cent Methane. This mixture is found to give higher efficiency than plain air. The α-pulses are collected in a special kind of ion chamber which is coupled to a linear amplifier. This instrument contains some hundreds of valves. Each channel counts pulses in its own very narrow energy-band, and complex mixtures of α-emitters can be quickly assayed by this remarkable device. Its capabilities are more useful in general chemistry than in biological assay. It is a foretaste of things to come.

For $\beta\gamma$ work, with mixed fission products for example, a modified version of the 100-channel instrument is necessary. It can be used with an " infinite depth " feeder (as we saw before) or else a liquid counter.

For special purposes (e.g. samples of very high activity), a single-channel γ-spectrograph is preferable. In this instrument all energies are registered at once and a scanning arrangement counts the " peaks " at selected amplitudes. The results can be drawn on a graph. The great advantage here is that chemical preparation is not essential. Such an instrument could be induced, for example, to give a quantitative analysis of the mixed fission products on a man's socks if he had contaminated them after a spill in the chemical separation plant.

The final exhibit in this array of fantastic instruments is an apparatus for measuring tritium in urine. (Fig. 7). The urine generates acetylene from calcium carbide in the glass apparatus. This acetylene passes into an ion-chamber, the current from which is fed into a Vibrating Reed Electrometer and thence to a Kent Recorder where the output is drawn in millivolts. When the ion chamber is completely filled with acetylene, the recorder pen comes to its peak. This peak reading in millivolts can be converted by simple arithmetic, to μc of tritium per ml. of urine. The calibration is done with known tritium solutions.

In this age of great scientific achievements we have learned to accept the fact that no member of any profession can afford to ignore the activities of his fellows in other professions. No biologist, for example, can be really good if he does not understand some physics and mathematics. Chemists must know something of engineering and the engineer cannot afford to be ignorant of chemistry.

Doctors are no exception. If we want to know facts about our patients which only an electronic engineer can supply, then we must have sympathetic understanding of his difficulties and he of ours.

Acknowledgments

My thanks are due to the Directorate of the Industrial Group, U.K.A.E.A., for permission to publish this lecture. I would like also to thank Mr. F. Woodman and Mr. H. Howells who allowed me to photograph their equipment, also Mr. R. Diggle who answered many questions on electronic theory.

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DISCUSSION

Dr. Graham was asked whether radiation received during pregnancy might increase the liability of the children to leukaemia. He replied that the U.K.A.E.A. did not employ pregnant

women in radio-active areas and that it was considered a bad thing for an embryo to receive even diagnostic doses of X-rays.

The keeping of records was very important in this and other matters because a 20-year latent period for radiation effects was by no means long. The pre-entry record of exposure of persons newly joining the staff was checked, and staff who left were given a final test.

The use of calcium E.D.T.A. for removing radioactive substances that had been taken in and were stored in the bones was raised. Dr. Graham said it was of no value for strontium, but only for plutonium and perhaps uranium. Prevention was the correct way of tackling this problem. Other questions were asked relating to the treatment of contaminated wounds and the disposal of effluents.

MEDICAL INDICES OF COAL WORKERS' PNEUMOCONIOSIS

By P. J. Chapman, M.B., Ch.B., M.R.C.S., L.R.C.P.

THE institution of rational programmes for the prevention and control of disease and disability is an essential part of occupational hygiene. Such measures imply not only a knowledge of the circumstances likely to produce such effects but also information about their relative importance, one to the other, in the production of disease. The existence of a hazard or circumstances likely to cause ill effects may be well appreciated but, as has been pointed out by Gilson (1951), its assessment in objective terms by engineers, physicists and doctors may be dependent on the devising of some relatively simple measuring instrument. The importance of objective methods of quantitative and qualitative measurements in describing the nature and magnitude of changes in environment and their resultant effects upon disease cannot be overemphasised. Such objective assessments are probably of greatest value in the investigation of those diseases, the occurrence and severity of which may well be affected by a multiplicity of factors. In such circumstances a programme of prevention directed at controlling the wrong variable may bring about little or none of the improvement which was anticipated.

It is now generally agreed that the most important factor in chest disease of coal workers is the dust within the respirable size range to which the workers are exposed. If a medical index representing dust disease can be related to the quantity, or type of dust to which the population under investigation has been exposed, a measure of the importance of variations in the dust can be obtained.

The insidious onset and relatively slow course of coal workers' pneumoconiosis makes the choice of an entirely satisfactory medical index difficult. Although many cases have been described and investigated during the past twenty or thirty years, changes in the methods of detection and standard of diagnosis over this period make conclusions from such observations of limited value.

Coal mining is an extractive industry and great variations in both the quality and quantity of dust may be found from mine to mine and perhaps between different parts of the same mine. It may, therefore, be unwise to extend the findings at one mine or group of mines to another area, unless there is reasonable certainty that the environmental conditions are, or have been, comparable. Only in comparatively recent years has detailed information about dust concentrations at different mines been available. In the absence of such information comparisons of the prevalence of pneumoconiosis in different areas sheds little light on the effects of different levels of dustiness in causing this disease.

The most useful index would be one related to the natural course of the disease so that the relative positions of individuals or groups of individuals (in the sense of whether they are in more or less advanced stages of the condition) can be appreciated. Indices based on the time elapsing from when the disease was first diagnosed to the time of death (Martin and Roche, 1941) or the onset of grave disability (Stewart, 1948) have been used. These have been related to the period spent in a dusty atmosphere or the age when pneumoconiosis was first diagnosed, but such correlations give little information of use in devising preventive measures. Investigations of the relationship between changes in the blood sedimentation rate (Cochrane *et al.*, 1956a) or the plasma proteins and cell constituents of the blood (Vigliani *et al.*, 1950) and the presence and progress of pneumoconiosis have also been undertaken. Results obtained by such investigations can, however, be effected by the presence of conditions other than pneumoconiosis, e.g. tuberculosis, which makes their exact significance difficult to interpret. Investigations of this type have not proved very successful in defining different stages of the disease and their use in assessing progression in the sense of worsening of the disease is limited.

In 1916 the Miners' Phthisis Prevention Committee at Johannesburg propounded the axiom that " the radiographic appearances in cases of silicosis afford the most reliable single piece of evidence in establishing the existence and the actual stage of the disease in any particular case." It is now generally recognised that this also applies to coal workers pneumoconiosis and the radiographic appearances of the chest have been used by many authors as the criteria for the presence or absence of pneumoconiosis. The variety of methods used to classify the radiological appearances often make comparisons between different reports difficult and many of the systems used took no account of very early radiographic changes. In addition none of them made any distinction between what is now termed simple pneumoconiosis and progressive massive fibrosis (complicated pneumoconiosis).

In an effort to surmount these difficulties and to make results obtained by different investigators comparable, the Medical Research Council's Pneumoconiosis Research Unit in South Wales described a method of classifying the radiographic appearances of coal workers' pneumoconiosis. The suggested classification made the distinction between "simple" and "complicated" pneumoconiosis and was founded on the principles of simplicity, the necessity of distinguishing changes occurring only in those exposed to dust, and repeatability. Details of this classification have been published on many occasions and it formed the basis of the International Roentgenological Classification of Pneumoconiosis, published by the International Labour Office in 1953.

The consistency with which films can be classified using such a system has been investigated by Fletcher (1955a). When used for routine reading, Cochrane *et al.* (1956b), have shown that differences in the classification of the same film on two separate occasions are small. These findings were based on the same two readers classifying the same films after an interval of approximately three years. Recently it has been possible to make comparisons between different observers after a slightly longer interval.

Table I

FILMS TAKEN 1949

Reader X 1956

Readers A. & B. 1952	0	1	2	3	A	BCD	Total
0	195	10	1	—	—	—	206
1	5	15	2	—	—	—	22
2	—	5	7	—	—	—	12
3	—	—	4	16	—	—	20
A	—	—	—	—	2	—	2
BCD	—	—	—	—	—	1	1
Total	200	30	14	16	2	1	263

Readings in agreement: 236
=89 per cent

Reader Y 1956

Readers A. & B. 1952	0	1	2	3	A	BCD	Total
0	193	13	—	—	—	—	206
1	4	16	2	—	—	—	22
2	2	3	7	—	—	—	12
3	—	—	6	14	—	—	20
A	—	—	—	—	2	—	2
BCD	—	—	—	—	—	1	1
Total	199	32	15	14	2	1	263

Readings in agreement: 233
=88 per cent

Table II

FILMS TAKEN 1952

Reader X 1956

Readers A. & B. 1952	0	1	2	3	A	BCD	Total
0	320	9	—	—	—	—	329
1	11	28	2	—	—	—	41
2	—	1	21	—	—	—	22
3	—	—	6	15	—	—	21
A	—	—	—	—	4	—	4
BCD	—	—	—	—	—	2	2
Total	331	38	29	15	4	2	419

Readings in agreement: 390
=93 per cent

Reader Y 1956

Readers A. & B. 1952	0	1	2	3	A	BCD	Total
0	314	15	1	—	—	—	329
1	8	29	4	—	—	—	41
2	—	8	13	1	—	—	22
3	—	—	5	14	2	—	21
A	—	—	—	—	3	1	4
BCD	—	—	—	—	1	1	2
Total	322	52	23	15	6	2	419

Readings in agreement: 374
=89 per cent

In Table 1 the number of films assigned to each category by two observers reading together in 1952 is compared with the results of two different observers reading independently in 1956. The number of identical readings in each category is shown in the outlined square. The result is influenced to some extent by the number of films classified within normal limits (Category 0) but the overall consistency of classification appears reasonable. These films were originally taken in 1949 and classified in 1952. Table 2 shows a similar result for a series of films taken and classified in 1952. The differences in consistency on the two groups of films are small, suggesting that the interval between taking the film and classifying it has little effect.

Investigations of coal workers' pneumoconiosis often involve comparing the radiographs of the chest taken with perhaps intervals of some years between them. Any differences that are found should be indicative of a real change and not due to alterations in the method of classification. The International Classification as used by these different observers, therefore, seems to fulfil the requirement of comparability in time and provides justification for assessing the amount and severity of coal workers' pneumoconio-

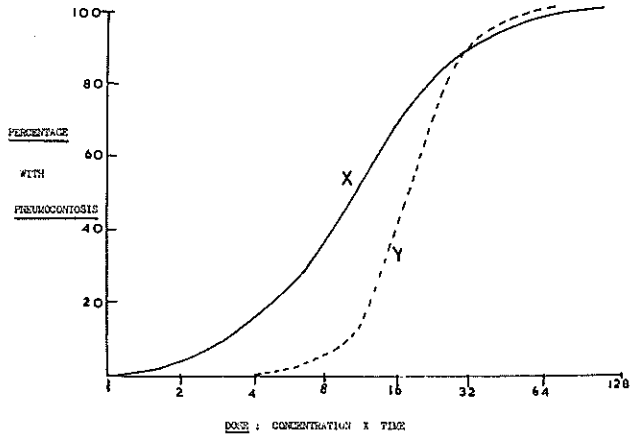

Fig. 1.—Dose-response curves for coalminers pneumoconiosis. Curves X and Y relate to different types of dust. (After Roach.)

sis using a radiological index based on this classification.

One method of using a medical index of this nature to investigate the dust hazard in a mine can be based on the dose response method employed in toxological research as suggested by Roach (1953). He visualised a normal probability-response curve, as in Fig. 1, where the logarithm of the total dust dose (concentration X time) is plotted against the percentage of individuals with pneumoconiosis in each of the categories of exposure. Such exposure response curves have been plotted by Hatch (1955) for South African gold miners. Here it was found that at probability levels of below 1 : 100 the number of known cases (of silicosis in this particular instance) exceeded the number predicted from the log probability line. Three reasons were suggested for this, firstly—hypersensitivity of some individuals, secondly—errors in estimating the dose, or thirdly—they may have been wrongly diagnosed and the changes seen in the chest radiograph may not have been related to dust exposure.

The number of times such errors of diagnosis can occur is partly influenced by whether the system of classifying the radiographs enables a distinction to be drawn between changes due to dust exposure and changes not so caused. Investigations of the validity of the classification in this respect by Fletcher (1955 b) showed that whilst the inexperienced readers may misinterpret variations in normal X-ray appearances and regard them as indicating pneumoconiosis, this is not so with experienced readers.

Radiographic technique may affect the category to which a reader assigns a film. If films are taken with low penetrating power X-rays, then the resulting film is liable to be classified, even by experienced readers, as showing more disease than a film of the same person taken with a more nearly correct X-ray technique (Fletcher *et al.*, 1949). A comparison of two films to determine whether there is any difference in the amount of disease shown by them may thus be invalidated by technical differences. Basically the problem is to ensure that if a radiograph of a man's chest is taken on two separate occasions several years apart, then radiological readings for change will not be biased in any way by technical differences between the two films.

To minimise this source of error the radiological technique employed must be carefully controlled. Although the ideal technique has not yet been achieved some progress has been made towards the production of comparable radiographs. When using the International Classification for films of pneumoconiosis it is recommended that Standard Films exemplifying the lower limits of the categories should be used, and compared side by side with the film to be classified. In addition to the aid they give in assigning a category of pneumoconiosis to the film they can also be used as a standard of comparison for radiographic technique. Complete technical comparability of films has not yet been attained, but improvements in methods of controlling the exposure and the processing of exposed films have helped considerably and some of the instruments and techniques for so doing will be described.

The amount of blackening produced on the sensitive emulsion of the X-ray film for any given quality of X-radiant energy is directly proportional to the quantity falling upon it. Radiographically this is usually expressed as the product of the tube current in milliamperes and the time for which it flows, in seconds. Both of these can be varied independently but in chest radiography the more common practice is to vary the time. This method only controls the quantity of radiation reaching the patient and takes no account of that which actually passes through him to fall on the film. A system which controls the amount falling on the film and producing blackening has obvious advantages.

Two methods of such control are practicable. One is based upon the light intensity produced in a fluorescent screen between the patient and the film and the other on the degree of ionisation produced by the X-rays in a chamber placed in the same position. In the first method photo-electric cells are used to monitor the light energy produced by the X-rays falling on the fluorescent screen. When this has reached a certain quantity the exposure is terminated. This is the basis of the photo-timer methods used in Mass Miniature Radiography Units.

The second method using an Iontomat as described by Clarke (1953) will be considered in more detail. The apparatus comprises a chamber exposed to the ionising effect of the X-rays, a device for measuring the ionisation and a method of terminating the exposure when the ionisation produced has reached a predetermined level. It is important that the wavelength of the radiation producing the ionisation effect should be similar to that affecting the sensitive emulsion of the film. For this reason the ionisation chamber is placed between the patient and the light-proof container of the film (cassette).

The plastic or aluminium walls of the ionisation chamber are fixed to a metal frame and held 1 cm. apart. The inner sides are coated with vaporised lead and mounted between the walls is a well-insulated electrode metalised on one side only. This forms the measuring area and is sufficiently radiolucent not to cast a shadow on the film. A highly insulated coaxial cable leads out through one corner of the chamber—the core is connected to the central electrode and other connections are to earth and the outer walls

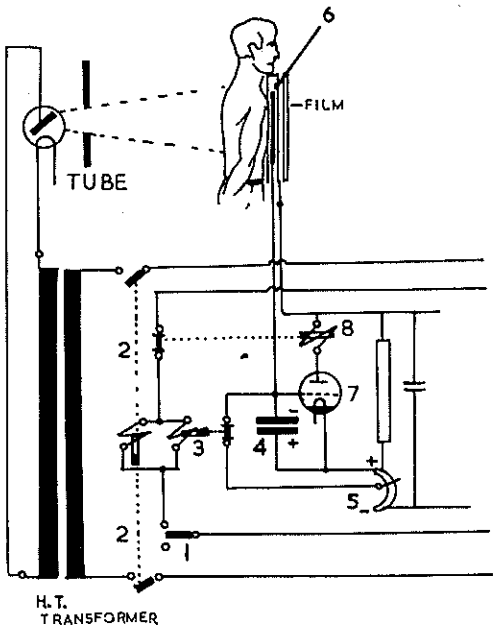

Fig. 2.— Ionisation chamber systems for control of exposure time. (Acknowledgments, Sierex Ltd.)

of the chamber. Only radiation actually passing through the patient falls on the measuring area represented by this central electrode.

The simplified diagram (Fig. 2) shows the operation of the Iontomat in conjunction with an X-ray apparatus such as a four-valve full wave rectification set, with rotating anode, maximum rating of 90 kV at 400 mA and a 2 mm. square focal spot.

Closing the operating switch (1) operates the contactor relay (2) energising the high tension transformer and so starting the exposure. The relay (3) connecting the iontomat with the X-ray set is in parallel with the contactor relay. This relay pulls up and disconnects the measuring condenser (4) in the grid circuit of the relay valve (7), from the charging potentiometer (5). The X-rays from the tube pass through the patient and fall on the ionisation chamber (6) and an ionisation current passes to the negative plate of the measuring condenser so gradually decreasing its charge. When the charge falls to a certain value the thyratron valve (7) fires and the relay (8) becomes activated. This breaks the contacts in the operating and connecting circuits cutting off the H.T. transformer, thereby ending the exposure.

The time taken for the measuring condenser to discharge depends upon the strength of ionisation current which is influenced by the degree of ionisation produced in the chamber; the amount of ionisation produced in the chamber varies with the X-ray energy falling upon it. The less energy that falls on the ionisation chamber the smaller is the degree of ionisation produced and the ionisation currents are weaker. The discharge of the measuring condenser takes a longer time and the duration of exposure is thereby increased.

A switch at the side of the control box enables a range of density settings to be selected. The desired density of the films can then be determined by adjustment of the potentiometer which alters the charge on the measuring condenser. With a particular charge on this condenser variations in the chest thickness of the subjects being X-rayed should produce little alteration in the degree of blackening of the films. Patients with large chest diameters or thickening of the lung structures cause less energy to fall on the chamber; automatically they receive longer exposure times than thinner patients. In both instances the same charge on the condenser has been dissipated but because of the weaker ionisation currents induced when the larger patient is in front of the chamber, this has taken a longer time than with the thinner person.

The use of such an exposure control presupposes that every sensitive emulsion will react in an identical way to the same amount and type of radiation. The effects of radiant energy falling upon a sensitive emulsion are conventionally described in terms of the degree of blackening produced after processing. The performance of an emulsion is given by its characteristic (H. and D.) curve where the logarithm of the exposure is plotted against the density produced by that exposure. The density is calculated from the expression Density = log 10 I/T where I = incident light and T = transmitted light. Clarke (1955 a) has investigated the characteristic curves for different batches of X-ray film of the same type and found that differences between them can be an important source of variation when endeavouring to produce comparable radiographs with these films. The benefits of exposure control can only be fully realised if precautions are taken against wide variations in the emulsion characteristics of the films used. In certain circumstances it may be possible to arrange that only emulsions within a speed range of ± 5 per cent are used, but even then it is desirable to test representative films under actual operating conditions as suggested by Clarke.

The essential requirement for such tests is a method of producing a graduated series of exposures of the emulsion. A simple way of doing this is by means of a metal step wedge made from a number of aluminium sheets of equal thickness. These are placed together in such a way that the thickness of aluminium between the X-ray source and the film to be tested increases in steps from one border to another. When an exposure is made with such a step wedge interposed between the X-ray tube and the film, then a series of strips of increasing density are produced from the same exposure of the film. The sensitivity of the different emulsions in different batches of X-ray films can be tested by exposing them through a step wedge and comparing the densities on corresponding steps in the two halves. A simpler test capable of a direct interpretation is to take a trial exposure with a human subject using two portions of film each with a different emulsion. Provided it is known that there are no gross differences between the right and left side of that person's chest, then the two portions of film may be visually compared. The objection to this method of testing is that of subjecting someone to a dose of radiation which is not strictly justified on medical grounds. For this reason the possibilities of constructing a "synthetic chest" are being considered. The aim is to reproduce an image which is reasonably comparable with that

produced by X-raying the chest of a living person, and to use this test object in the manner just described.

Chest radiography necessitates the use of short exposure times to minimise the effects of movement. The beating of the heart within the chest and movement in general produce blurring of the finer details of the radiograph. So that the maximum effect can be produced in the shortest time the action of the roentgen rays on the sensitive emulsion is intensified by the use of various materials which fluoresce when X-rays fall on them. These materials are coated on a cardboard base and for chest radiography calcium tungstate is very suitable. Only a small fraction (about 3 per cent) of the X-ray energy falling on these intensifying screens is converted into fluorescent light but this is sufficient to cause a marked reduction in the exposure time compared with that necessary when they are not used. The screens are used in pairs mounted in the cassette holding the film (which nowadays has the sensitive emulsion on both sides). The latter is placed between the two screens like the filling of a sandwich. The amount of fluorescence in the screens is proportional to the intensity of the incident radiation, but the contribution of this screen fluorescence to the resulting X-ray image may differ from one pair of screens to another even though they are made of the same fluorescent materials. For the same duration of exposure to the same type of X-rays one pair of screens may produce more blackening on one film than another. Such variations may well cancel out the advantages to be expected from a system of exposure control such as the iontomat. The step wedge can again be used to compare different screens by exposing portions of the same film simultaneously between different screens. Using this method Clarke (1955 b) has shown variations of as much as 20 per cent in the speed of the same type of screens.

So far only the production of the latent X-ray image has been considered. Before the radiograph can be interpreted the results of the X-radiation falling on the sensitive emulsion must be made apparent and permanent by the process of development and fixation. Uncontrolled and unknown variations in the conditions of development may again offset any of the advantages brought about by the use of an automatic exposure control. Two factors having a great influence in development are the time for which the developing agents are allowed to come into contact with the exposed film and the temperature at which this takes place. It was recommended in 1953 by the Joint Committee on Standardisation in Chest Radiography that 68 deg. F., should be adopted as a standard temperature. Variations of as little as 2 deg. F., can make an appreciable difference in the films. A development time of five minutes at this temperature was also recommended and standards such as these should be adopted to ensure uniformity of results.

Time and temperature can be more readily controlled by the use of a mechanical processing unit as human errors can be reduced to a minimum. Hills (1951) described such a unit based on the usual principles of placing the film first in a solution of developer, washing it, passing it through a bath of fixing solution and then a final wash. Films are transferred mechanically from developer through the wash to the fixer and so to the final washing. The films are carried in specially designed hangers resting on an endless belt. The rate of travel of the endless belt is controlled by a synchronous electric motor which gives uniformity of developing time for each film. As they reach the end of the developing bath a micro-switch is tripped which sets in motion the transfer apparatus. This consists of two cylinders worked by compressed air—a long vertical lifting cylinder and a shorter traversing cylinder to carry the film forward.

The operation of lifting films out of the developer and allowing time for excess fluid to drain off is again standardised and takes eight seconds. In the traversing motion from developer to fixer another microswitch is activated, which turns on a water spray directed on the film. This removes all traces of developer and each film is washed for ten seconds in this spray rinse. It is then lowered mechanically by the descent of the lifting cylinder arm into the fixer bath with the hangers once again resting on the endless belts. A similar transfer mechanism, without an interposed water rinse, transfers the films from the fixer to the final washing tank. After adequate washing in running water, the films are dried in a hot air cabinet and are then ready for viewing.

With this apparatus the time of development for each film can be kept uniform. By means of a thermostatic control linked to the motor driving the belts, the machine stops automatically if the temperature of the developer fluctuates beyond a pre-arranged setting. The temperature used is 68 deg. F., and is controlled to within $\pm\frac{1}{2}$ deg. F. The time and temperature are frequently checked using a stop watch and a dip thermometer. As a further check, a recording thermograph with a quick acting sensitive bulb in the developer has been installed giving a continuous record of developer temperature. This has not shown any appreciable fluctuations and time and temperature of development when using such a machine can be made uniform for each film.

Exact repetition of processing is essential if different films exposed to similar amounts of radiation are to be technically comparable. The diagnostic usefulness of an X-ray depends upon the differences in density between different areas and the intensity of the blackening produced by the exposure. Although Hills' original account does not stress the possibilities of such a machine for exactly repetitive processing, it is possible for this to be attained; particularly is this so if only one type of radiograph, e.g. chest X-rays, taken on a standard size of X-ray film, is being handled. Even with these standardised conditions the densities seen on finished films can be affected by alterations in the activity of the developing solutions. A method of assessing developer activity to control variations within certain limits should, therefore, be used.

The activity of developers can be tested by comparing the densities produced after development when films coated with the same sensitive emulsions are exposed to the same amounts of radiant energy. Developing conditions must, of course, be standardised, particularly for time and temperature in such tests. In practice, successive portions of a strip of film are exposed to a constant source for different times thereby pro-

ducing a graded series of exposures. The densities resulting from processing such sensitometric strips in different developers or in the same developer at different times, can then be compared. In the practical application of such tests two difficulties may be encountered—firstly, relating changes shown on such strips to effects on the finished radiograph and secondly, changes in the radiographs may occur without any marked effect on the strips, i.e. the test may not be sufficiently sensitive for use in conjunction with chest radiography.

The sensitivity of the test has been investigated using actual chest radiographs in conjunction with wedges. The method was to take a number of chest radiographs of a subject known to be normal. One half of each exposure was then processed and the other halves were processed at succeeding intervals. At corresponding intervals sensitometric strips were processed and difference between these related to differences detected on corresponding halves of the same chest exposure. Significant differences were seen which were not detectable by comparison of the sensitometric strips.

These findings were obtained using sensitometric strips exposed to a light source. The use of a radiographic exposure and a wider range of densities could result in greater sensitivity. Sensitometric strips can be prepared by using the step wedge previously described and exposing films through the wedge to an X-ray source. If this is done with the films, cassettes and X-ray tube in use for taking the chest X-rays then a closer approximation to actual working conditions is obtained.

A large area of X-ray film—say, 14 in. x 14 in.—is exposed to a source of X-rays through the step wedge. This wedge is so designed that if using a kilovoltage and time commonly used for taking chest X-rays, the resulting densities are similar to those seen on a chest radiodgraph. The exposed film is then kept under suitable conditions and a strip about 1 in. wide cut off it from time to time. These strips are developed at intervals under standard conditions of time and temperature. Differences on comparing the densities on corresponding steps of different strips could indicate changes in the activity of the developer solution. An examination of the changes in density across the width of a complete film before cutting it into strips, however, showed a range of variation from the periphery to the centre. These were marked in the higher densities—which are not particularly applicable to chest radiography—but were still apparent in the lower densities. Similar films exposed on other X-ray units and developed in non-automatic units showed similar variations, as did a wedge of different construction and a less marked range of densities. In the latter case the variation was less, but was still present. These variations across a complete film could be due to lack of uniformity in development across the width of the film or lack of uniformity of intensity of radiation across the width of the beam as well as variations in developer activity. It is not yet clear which is the most likely cause of such variations but an alternative method of testing can be used.

The difficulty of translating differences seen on sensitometric strips into the likely effect upon the finished film has already been mentioned. A test film which incorporates a reproduction of a chest X-ray as well as density strips may have certain advantages. Stanford and Hills (1955) published an account of such a test film, which was produced by exposing the test film to a constant light source through a master negative incorporating the reproduction chest X-ray and the density strips. With the co-operation of these authors a further series of trials has been carried out on a unit concerned only with chest radiography on a standard size of film. The possibilities of standardisation in these circumstances are greater than in a general department. It is, for instance, practicable in these circumstances to adopt a method of replenishment (for pro-longing the useful life of the developer) related to the total area of films processed. Because of the variety of film sizes and types of radiograph which may have to be processed the more usual method is based on a volumetric system. Examination of the results so far gives some further evidence that variations about an average level of developer activity should be rather less in chest radiography than in more general work if good comparability of films is desired.

So far attention has been directed towards a radiological index for disease but it is equally important to measure the effects of radiological changes in terms of physiological disturbances causing disability. Commonly, the first symptoms complained of by men with pneumoconiosis are shortness of breath and a feeling of tiredness after what was previously regarded as a reasonable period of exertion. Measurements of the occurrence and severity of breathlessness among those exposed to dust in coal mines are, therefore, relevant to the problem of pneumoconiosis.

The most direct method of assessing breathlessness is by questioning but the validity of the answers obtained may be open to doubt particularly if questions of compensation are involved. An objective measurement which is related to the symptom is of greater use. One of the oldest objective measurements used in assessing respiratory function is the vital capacity—the volume of air which can be expelled from the lungs following the deepest possible intake of breath. Such a measurement takes no account of the time involved and assumes, wrongly, that the effectiveness of breathing is solely dependent on the volume of air which can be expelled from the lungs by a single maximal effort of all the muscles of respiration. A misleading impression of respiratory efficiency is often given by this method.

The advances in the understanding of pulmonary physiology in the past twenty years have made it apparent that the effectiveness of breathing depends not so much on the volume of air which can be moved by a single maximum effort but on the volume moved in a given unit of time. If breathing is regarded as a process of pumping air in and out of the lungs an analogy can be drawn between the stroke volume of the pump and the minute-volume—the latter being a more important factor in determining the efficiency of the respiratory pump. Investigations by Gilson and Hugh Jones (1955) have shown that it is a reduction in the quantity of air passing in and out of the lungs in a given time rather than a true increase in demand

for air which is responsible for the exertional dyspnoea in coal workers pneumoconiosis. In other words it is the pumping or bellows action of the lungs which are most affected and tests of this function of the lungs can yield useful information in this condition.

A number of methods for measuring the volume of air passing in and out of the lungs in relation to time are available. Results obtained from such tests correlate well with independent clinical assessments of the subjects' breathlessness. The use of such tests is, therefore, justifiable in the objective assessment of breathlessness in relation to radiological changes. Tests of time-volume relationships in respiratory physiology often require complicated apparatus and are most suitable for laboratory use. They may also be time consuming and fatiguing both to the subject being tested and the observer, and only rarely are they readily transportable. A test which can be performed in a short space of time, with simple apparatus readily transportable from place to place, is required to measure objectively the occurrence and severity of breathlessness in large groups of people. Various types of apparatus of a less complex and more transportable form have been described and those based on the use of a single forced expiration are very suitable for field tests on large numbers. Comparisons of the results obtained using less complicated apparatus with more complicated and time-consuming laboratory tests show that they correlate well (e.g. Kennedy 1953, McKerrow 1955). The use of more simple tests on large groups who have also been examined radiologically considerably enlarges the scope of investigations to relate breathlessness to the presence or progression of radiological change.

A method using a single forced expiration has been described by Gaensler (1951). The general appearances of a modified form of the apparatus necessary for this method are shown in the illustration (Fig. 3). A low inertia vital capacity spirometer with a light weight counterbalanced bell has a detachable arm on one side carrying a timing and measuring device. This enables both the total volume expired (vital capacity) and the volume exhaled in any pre-set time (up to three seconds) to be measured utilising only one forced expiration of breath.

The subject takes a deep breath in and applies his lips around the mouthpiece at the end of the wide-bore side. He exhales as fully and as quickly as he is able and the expired air is led into the spirometer bell under a water seal. The bell travels upwards and the cord of the counterweight causes a perspex wheel, acting as the support of the bell, to rotate. On the back of the wheel is a small perspex block which at the commencement of the test is in contact with a micro-switch. The movement of the wheel causes the block to move away from the switch and so initiates the timing cycle. Mounted on the pivot of the perspex wheel is a light metal pointer projecting slightly beyond the border of the wheel on the same side as the microswitch. Connected to the timing circuit is a small solenoid mounted just below the microswitch which controls a small metal stop. The start of the timing cycle activates the solenoid so that the metal stop arrests the movement of the pointer for the pre-

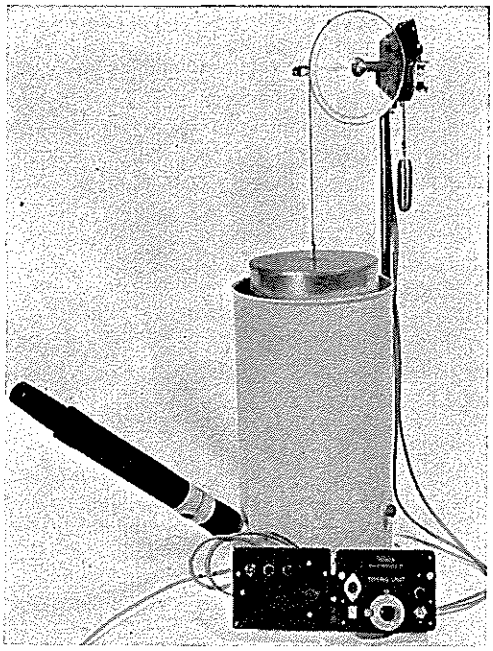

Fig. 3.—Gaensler spirometer for measuring rate of air flow in a single forced exhalation.

determined interval of time. When this has elapsed the solenoid ceases to act and the pointer is free to rotate with the perspex wheel. The wheel continues to rotate as long as the spirometer bell rises. When it has reached its maximum excursion the bell and wheel are held momentarily motionless by the counterweight. The results of the test are read from the two graduated scales mounted on the perspex wheel. The position of the pointer gives the reading of the inner scale and the outer scale is read by reference to a fixed point. The scales can both be calibrated to read the volume directly, in litres, or the inner one to read litres/minute and the outer one total volume (in litres).

The results can be expressed in two ways either as :-

(a) Rate of air flow in a given time and the total volume expired ;

(b) The volume expired in a given time can be expressed as a percentage of the total volume expired.

A distinction can be made between those whose breathlessness is due to a " restrictive " insufficiency, e.g. due to disease of the lung tissue or injury to the chest wall, and those with an " obstructive " deficiency brought about by, say, asthma, or obstruction of the air passages. In the latter cases the total volume expired is not reduced but the rate of air-flow and the percentage of the total volume expired in the given time are markedly reduced. In the former type of case the percentage of the total volume expired in the given time interval is not reduced, but the total volume of air exhaled is diminished. The distinction between these two types of respiratory insufficiency is often of great assistance in deciding the most likely cause of a patient's breathlessness.

Because this particular apparatus is to be used in connection with coal miners' pneumoconiosis where observations of the time-volume relationships are

likely to be most useful (see above) the inner dial is calibrated in litres/minute and the time interval has been set to 0.75 seconds. Actually, to avoid difficulties connected with the initial force of the expiratory breath the first 100 c.c.s. of air expires are not measured and the instrument is calibrated to allow for this.

Another instrument using the single breath method is an air flow meter designed by Dr. B. M. Wright of the Pneumoconiosis Research Unit, Llandough. This air-flow meter has a high frequency response and little inertia due to the use of a light weight vane. It is fitted with a dial and a pointer which is held in the position of maximum deflection by a ratchet mechanism. In use a person holds the body of the instrument in such a way that the dial is facing to the right, and applies the mouthpiece between his lips. After taking in as deep a breath as possible he then blows into the mouthpiece as hard as possible. The exhaled air passes through the flow meter and moves the pointer over the dial where it is retained at its maximum deflection. Pressing a button near the inlet nozzle returns the pointer to zero.

The dial is graduated in degrees up to 300 and a calibration chart is supplied with each instrument. The airflow can then be read in litres per minute, giving a figure which is closely related to the peak rate of expiratory flow during a forced expiration. Although results obtained may be a little more variable than those from the instrument previously described, it has many practical advantages from the point of view of simplicity and great portability.

In using both these instruments it is suggested that the subjects should be allowed one practice blow in each case to familiarise themselves with the procedure. Thereafter, three observations might be made which could either be treated separately or the mean of them used as the final result.

In conclusion it should be emphasised that the instruments described for assessing breathlessness are not intended to replace more complicated and possibly more exact methods of measurement. They are intended to give an indication when examining large groups of subjects of those cases where more complicated techniques will lead to a better understanding of the likely causes of breathlessness.

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DISCUSSION

A plea for a standard specification of diagnosis was made in the discussion on Dr. Chapman's paper. About 5,000 people annually were being diagnosed for pneumoconiosis and the number was likely to increase. Many of these diagnoses were not made under the excellent conditions described by the author. Attention was drawn to the risk of operators of X-ray apparatus from an overdose of radiation, and it was stated that film badges were always worn. The advantages of special techniques designed to reduce dosage to the operator were mentioned.