JOINT EUROPEAN INVESTGATIONS OF NEW GENERATIONS OF DUST SAMPLING INSTRUMENT

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INTRODUCTION

Considerable success has been achieved in understanding the predominant relationships between the risk of coalworkers' pneumoconiosis and exposure to fine particles of airborne coalmine dust. This has led to the setting of meaningful standards and, in turn, substantial reductions in the incidence of disease by improved dust suppression. However there is still the need for further improvement to deal with a number of important dust-related health problems which remain. In order to make progress in these areas, new research questions are posed requiring more detailed information about the properties of the airborne dust which cannot be obtained just by the use of instruments like those employed in much of the previous research. A need is therefore identified for a new generation of dust sampling instrument. Various new instruments have emerged in recent years, and it is timely to critically assess some of them in relation to the current research needs. To this end a Joint Project, involving six laboratories from five European Member States, has been carried out under the auspices of the Commission of European Communities (CEC). The participating laboratories were:

- Bergbau-Forschunginstitut GbmH, Essen, West Germany (BF)
- Silikose-Forschunginstitut, Bochum, West Germany (SF)
- Centre d'Etudes et Recherche des Charbonnages de France, Verneuil en Halatte, France (CERCHAR)
- Institut d'Hygiene des Mines, Hasselt, Belgium (IHM)
- Instituto di Medicina del Lavoro, Milan, Italy (IML)
- Institute of Occupational Medicine, Edinburgh, UK (IOM)

This paper describes the project coordinator's preliminary assessment of what was achieved.

RATIONALE

The new generation of dust sampling instrument includes a range of particle size-selective devices from which information about health-related fractions of airborne dust may be obtained. The rationale against which to compare and evaluate these instruments was based primarily on the 1983 recommendations of the International Standards Organization (ISO),[1] updated where appropriate in the light of more recent experimental evidence. The dust fractions in question are inspirable (the fraction that enters through the nose and/or mouth during breathing), thoracic (that penetrates below the larynx) and respirable (that penetrates to the alveoli). Of these, it is the inspirable fraction which, when it is referred to below, has been updated from the 1983 version, thus bringing it in to line with the definition contained in the 1985 recommendations of the American Conference of Governmental Industrial Hygienists (ACGIH).[2] In addition, since it forms the basis of present sampling in some European countries, an alveolar fraction was also included, describing a fine fraction which takes account of the fact that—in actual human exposure—the finest inhaled particles remain airborne for long enough to be exhaled during the exhalation phase of the breathing cycle.[3] The important philosophy embodied in the ISO recommendations is that all the dust fractions which deposit in the regions of the respiratory tract are subfractions of the inspirable fraction. This is consistent with what happens during actual human exposure. Ideally, it should also be reflected in sampler performance; namely that the efficiency with which particles enter the sampler in the first place should match the inspirable fraction.

The information provided by the various instruments includes details not only about airborne mass concentrations within defined fractions but also about mineralogical composition (and, possibly, physical properties such as particle shape). The instruments themselves fall into two categories. In the first, dedicated instruments sample to a given, single criterion (e.g., respirable dust), although some can also provide information about 'total' dust. In the second, more versatile instruments—broadly referred to as spectrometers—can provide a wider range of information. These operate on the principle that, if a defined fraction of airborne dust can be aspirated and its particle aerodynamic size distribution subsequently obtained, then all the information is available to allow determination of the particle aerodynamic size distribution and airborne mass concentration of any health-related subfraction which can be defined numerically. If the dust thus classified can be recovered in sufficient quantities for analysis, then the mineralogical composition of such subfractions can also be determined.

THE INSTRUMENTS

During a Workshop which took place in Edinburgh early on in the project, involving all the participants, the following instruments were identified for inclusion in the study:

- The French 10 l/min CIP10 personal sampler for respirable dust, also capable of providing a measure of 'total' dust. Its pre-selector operates on the principle of filtration by porous foam filtration media.
- The Italian 2 l/min modified-Zurlo (M-Z) personal sampler for respirable dust. Its pre-selector operates on the principle of virtual impaction.
- The Italian 3.5 l/min personal sampler for 'total' dust (TD)
- The British 3 l/min static inspirable dust sampler (IOMID).
- The Italian 0.4 l/min static dust spectrometer (INSPEC). It operates on the principle of inertial classification.
- The Italian 2 l/min personal dust spectrometer (PERSPEC). This too operates on the principle of inertial classification.
- The German 40 l/min static dust spectrometer (PCI). It operates on the cascade impactor principle.
- The British 10 l/min static inspirable dust spectrometer (SIDS), also operating on the cascade impactor principle.
- The British 2 l/min personal inspirable dust spectrometer (PIDS), also operating on the cascade impactor principle.

In addition to these, various instruments from the previous generation were also included for the purpose of comparison. These were:

- The German 50 l/min cyclone-based static sampler for alveolar dust (TBF50), also capable of providing a measure of 'total' dust.
- The German 46 l/min horizontal elutriator-based static sampler for respirable dust (MPGII).
- The Italian 2.4 l/min cyclone-based personal sampler for respirable dust (CYCLO).
- The French 50 l/min cyclone-based static sampler for alveolar dust (CPM3).
- The British 2.5 l/min horizontal elutriator-based static sampler for respirable dust (MRE).
- The British 1.9 l/min cyclone-based personal sampler for respirable dust (SIMPEDS).
- The Belgian 17 l/min static sampler for total dust (STASER).

The mean features of the above instruments are summarized in Table I.

THE PROGRAMME OF WORK

The research was carried out during the 3-year period 1985 to 1988. During the Edinburgh Workshop, it was agreed that, as far as possible, each of the principal instruments identified for inclusion in the trial should be evaluated by more than one laboratory and that each laboratory should evaluate more than one instrument. Thus assessment of a given instrument is less likely to be biased by the findings of, say, just one laboratory. In addition, it was agreed that two of the instruments—namely the CIP10 and PCI—would be evaluated by all six participating laboratories.

The project called for a programme of comparative trials both in the laboratory and underground in mines (pyrites for Italy, coal everywhere else). Each laboratory developed its own experimental strategy, determined by the resources and expertise at its disposal. Thus the emphasis varied considerably between laboratories. At IOM, for example, the main emphasis was placed on the laboratory aspect, based on the extensive facilities available (notably the large wind tunnel) and associated expertise. Elsewhere, greater importance was given to the underground trials. In some, greater stress was placed on the abilities of the instruments to provide information about mineralogical composition; and, in others, on the basic performance characteristics (notably with respect to particle size-selectivity) of the individual devices. The net effect of all the complementary contributions has been to provide an overall, balanced programme of work, as summarized in Table II.

The experimental inquiry fell into three broad areas:

- Experiments to assess basic performance characteristics (e.g., aspiration efficiency, particle size selectivity).
- Measurements of concentrations of health-related dust fractions and subfractions.
- Measurements of mineralogical composition.

RESULTS

In this paper, only concise, largely qualitative summaries of the results available at the time of writing are given. Whilst most are based on information obtained directly during the Joint Project itself, some information obtained during other studies has also been taken into account in some cases. The full experimental and statistical details of the individual studies are given in the final reports of the six individual component projects, while the combined analysis and overall conclusions will appear in the synthesis report which is still in preparation.

Basic Performance Characteristics

This aspect of the work was conducted in the laboratory. One area of interest is the efficiency with which particles enter the sampler initially. For ideal health-related sampling, this should match the inspirable fraction, since any samplers for which this is true are consistent with the ISO rationale referred to above. Experiments to assess entry efficiency were performed with this in mind, mostly in the large wind tunnel at IOM. All devices intended for use as personal samplers were tested in that mode, mounted on the torso of a tailor's mannequin which, during sampling, was rotated step-wise through 360 degrees (to eliminate preferred-orientation effects). In the case of the CIP10, it was also tested as a static sampler (since it is used by some workers in this mode). The results are summarized in Table III where, here and in the following tables, the quantitative experimental information reported in the original investigations has been reduced to the qualitative form shown. At this stage, until further analysis of the data is carried out, it is possible only to place the instruments into arbitrarily-chosen broad performance categories, without reflecting the degree to which each either conforms or fails to conform. In Table III, therefore, 'YES' indicates acceptance, with more than 50% of the available data points falling within ± 10 percentage points of the definition in question (inspirable or true total dust). 'NO' indicates non-acceptance, with less than 50% of the available data points lying within the same band. In certain cases, the

Table I
The Instruments Tested and Their Main Features

Sampler	Type	Flowrate l/min	Principle of size selection	Nominal fraction	Other fractions
CIP10	Dedicated	10	Porous foam filtration	Respirable/ alveolar	'Total'
M-Z	Dedicated	2	Virtual impaction	Respirable	-
TD	Dedicated	3.5	Aspiration	'Total'	-
IOMID	Dedicated	3	Aspiration	Inspirable	-
INSPEC	Spectrometer	0.4	Inertial separation	-	-
PERSPEC	Spectrometer	2	Inertial separation	-	-
PCI	Spectrometer	40	Cascade impactor	True total + subfractions	-
SIDS	Spectrometer	10	Cascade impactor	Inspirable + subfractions	-
PIDS	Spectrometer	2	Cascade impactor	Inspirable + subfractions	-
TBF50	Dedicated	50	Cyclone	Alveolar / respirable	'Total'
MPGII	Dedicated	46	Horizontal elutriator	Respirable	-
CYCLO	Dedicated	2.4	Cyclone	Respirable	'Total'
CPM3	Dedicated	50	Cyclone	Alveolar/ respirable	-
MRE	Dedicated	2.5	Horizontal elutriator	Respirable	'Total'
SIMPEDS	Dedicated	1.9	Cyclone	Respirable	'Total'
STASER	Dedicated	17	Aspiration	True total	-

judgement may be influenced also by any obvious contradictory trends present in the data. The table shows that the PCI provides a fair sample of true total dust (not surprisingly, since sampling with this instrument is arranged to take place almost isokinetically by virtue of the choice of number of entry nozzles). So too (for similar reasons) should the STASER (although this has not been investigated experimentally). The M-Z, IOMID, SIDS and PIDS all match the inspirability criterion quite well. So too does the CIP10 in its personal mode, but *not* as a static sampler.

The basic selectivities of the two new samplers dedicated (nominally) to the respirable dust fraction (CIP10 and M-Z respectively) were also assessed at some laboratories. For the CIP10, selectivity matches the BMRC-definition (as a subfraction of the inspirable fraction) quite well except at small particle sizes where the finest particles are not collected by the porous foam final collection stage of the instrument and so are lost. However, it is noted that the proportion of the mass carried by particles lost in this way may be expected always to be very small in most practical situations. In any case, it may be argued that the dust which is lost in this way is roughly equivalent to that which is exhaled. Therefore the CIP10 selection curve has features in common with both the BMRC respirable dust definition and that for the alveolar fraction (although it matches neither perfectly). For the M-Z, agreement with the BMRC-definition is fair. For the earlier-generation instruments, selectivity is available from previously published information. For these devices, it is worth noting that the TBF50 and the CPM3 both exhibit selection characteristics which more closely reflect true alveolar deposition. The MPGII and MRE both conform closely to the BMRC-definition.

The INSPEC and PERSPEC require special comment. The performance of the first was found to exhibit effects associated in part with its low sampling flowrate; namely, biased entry characteristics (depending on the type of entry piece attached), high particle losses between the entry and the sensing region, and collected mass too small to allow gravimetric assessment. The first two effects are more pronounced the larger the particle size. Furthermore, in its present mains-powered version, INSPEC does not satisfy intrinsic safety criteria which would allow its use underground

Table II
Outline of Programme of Work Carried Out

Sampler	LABORATORY					
	BF	SF	CERCHAR	IHM	IML	IOM
CIP10	P	L,U	L,U,P,M	U,M	. .	L,P
M-Z	. .	. .	. .	. .	U,P	L,P
TD	. .	. .	. .	. .	U	L,P
IOMID	. .	. .	. .	. .	. .	U,P
INSPEC	. .	. .	. .	. .	. .	P
PERSPEC	. .	. .	. .	. .	. .	P
PCI	U,M	L,U	L	U,P,M	. .	L,U,P
SIDS	. .	. .	. .	. .	. .	L,U,P
PIDS	. .	. .	L	U,M	U	L,P
TBF50	U	U	. .	. .	. .	L,U,P
MPGII	U	U	. .	. .	. .	-
CYCLO	. .	. .	. .	. .	U,P	L,P
CPM3	. .	. .	L,U	U,M	. .	-
MRE	. .	. .	. .	. .	. .	L,U
SIMPEDS	. .	. .	. .	. .	. .	L
STASER	. .	. .	. .	U,M	. .	-

L = Comparative trials in the laboratory
U = Comparative trials underground
P = Evaluation of basic performance characteristics
M = Evaluation of instrument's ability to provide mineralogical data

in coalmines. In its present form, this instrument would seem to be more suited to fine-particle aerosol studies in the laboratory or in less ardous workplace conditions. PERSPEC, with its higher sampling flowrate does permit the collection of larger dust deposits. However the recovery of fractions classified according to particle size is difficult in present versions of the instrument since it requires precise dissection of the collection filter. For such reasons, these two instruments did not feature significantly in the comparative studies that subsequently formed the bulk of the project. It is understood that both are undergoing further development to improve performance and practical applicability.

Comparative Performances in Relation to Health-Related Dust Fractions

Large numbers of comparative trials were carried out, both in the laboratory and underground in mines. In each individual run, an instrument was identified which provided a reference for the fraction of interest. For example, for true total dust the reference was usually a thin-walled probe facing into the wind and aspirating isokinetically. For the inspirable fraction, it was the IOMID, SIDS or PIDS. For respirable dust, it was the MRE (or an equivalent horizontal elutriator-based sampler such as the MPGII), and for the alveolar fraction the TBF50 (or CPM3). For the thoracic fraction, no suitable reference sampler was available. For this, therefore, it was decided to use the thoracic sample obtained from the PCI.

For the dust spectrometers (i.e., PCI, SIDS, PIDS), the determination of the dust concentration in each fraction was carried out by first determining the particle aerodynamic size distribution for the sampled dust, and then numerically cal-

Table III
Summary of the Entry Characteristics of the Instruments Tested

Sampler	Entry efficiency	
	True total	Inspirable
CIP10 (personal)	NO	YES
CIP10 (static)	NO	NO
M-Z	NO	YES
TD	NO	NO
IOMID	NO	YES
INSPEC	NO	NO
PERSPEC	NO	YES
PCI	YES	NO
SIDS	NO	YES
PIDS	NO	YES
TBF50	NO	NO
MPGII	*	*
CYCLO	*	*
CPM3	NO	NO
MRE	NO	NO
SIMPEDS	*	*
STASER	YES	*

YES - unqualified acceptance NO - not appropriate
* - no information

culating the size (frequency) distribution of the fraction of interest. The area under this new curve gives the mass sampled in the fraction of interest, and hence its airborne concentration.

From the large body of data available from all the trials that were carried out, Table IV summarizes qualitatively how well the various instruments provide information relevant to the various health-related dust fractions. Here, as in the previous table, a fairly bland assessment of the relative performance is given. It is based on examination of combinations of the various instrument comparisons against suitable reference samplers and information about their selection characteristics. Where there are inconsistencies, the judgement is made by inspecting the total information available and, where appropriate, a qualified acceptance ('OK') is indicated. It should be noted that although the first two columns appear to be the same as those in Table III, the ratings now take into account the accessibility of the sampled dust in those fractions. Hence, for example, although the CIP10 actually aspirates the inspirable fraction quite satisfactorily, it is not so easy to recover it for gravimetric assessment. Therefore a 'YES' in Table III becomes 'OK' in Table IV.

Later, when all the results have been combined and analyzed in greater detail and have been discussed by all the participants in the Joint Project, a more detailed picture will become available.

Mineralogical Assessment of Sampled Dust

One important aspect of sampler performance is the ability to collect dust samples within desired fractions or classified size ranges in a form (i.e., quantity, accessibility) suitable for mineralogical assessment. This was studied, again both in the laboratory and in the field trials. The conclusions are summarized in Table V for typical coalmine dusts. In these studies, the main emphasis was placed on the quartz content—reflecting the general interest in health-effects associated with quartz-containing dusts.

The methods which were used for mineralogical assessment included infrared spectrophotometry and X-ray diffractometry. For both, the greater the amount of dust which is available for the assay, the better. Obviously, however, the minimum amount of dust required to carry out a satisfactory analysis depends greatly on the particular analytical instrumentation available. Within the laboratories participating in the Joint Project, such capability varied appreciably. For present purposes, the simple 'rule-of-thumb' was adopted that a minimum mass of 0.1 mg of mixed mine dust should be available in order to enable assessment for quartz content. Table V therefore indicates judgements made on the basis of estimates of amounts collected—in the various parts of each instrument as appropriate—for typical dust concentrations over typical (up to 8-hour) sampling shifts. Of the spectrometers, the 40 l/min PCI comes out particularly well since amounts of dust are provided at each of the impactor stages more than adequate for determination of the mineralogical content of the dust throughout the particle aerodynamic size distribution. The same can be achieved using the lower-flowrate SIDS and PIDS but with less sensitivity due to the smaller amounts of dust available for analysis.

CONCLUDING REMARKS

In general, the dedicated samplers were found to be generally easier and more convenient to use. Some of the ones intended for respirable (or alveolar) dust may also provide—with some additional effort—a reasonable measure of 'total' (or, in some case, inspirable) dust. By contrast, the spectrometer-type devices require more skill on the part of the operator. This is the price of the greater versatility required in some of the expected research applications.

During the Joint Project which has been described, a number of dust samplers, originating from a number of European countries, have been tested and their performances compared. From the results, it should be possible to judge the relative strengths and weaknesses of each in relation to each proposed new application and to choose the instrument appropriate to the task accordingly. Although there is no single instrument which emerges as the universal 'best', it is clear that certain of the instruments are not appropriate for certain tasks. It is recommended that, in designing new studies to further understanding of the health-related properties of airborne dusts in mines, sampling instrumentation should be chosen after careful consideration of the results of this Joint Project.

Table IV

Summary of the Performances of the Instruments Tested in Relation to the Various Health-Related Dust Fractions

Sampler	Fraction				
	True total	Inspirable	Thoracic	Respirable	Alveolar
CIP10 (personal)	NO	OK	NO	OK	OK
CIP10 (static)	NO	NO	NO	OK	OK
M-Z	NO	OK	NO	OK	NO
TD	NO	NO	NO	NO	NO
IOMID	NO	YES	NO	NO	NO
INSPEC	NO	NO	★	★	★
PERSPEC	NO	YES	OK	OK	OK
PCI	YES	YES	YES	YES	YES
SIDS	NO	YES	YES	YES	YES
PIDS	NO	YES	YES	YES	YES
TBF50	NO	NO	NO	NO	YES
MPGII	★	★	NO	YES	NO
CYCLO	★	★	NO	OK	NO
CPM3	NO	NO	NO	OK	YES
MRE	NO	NO	NO	YES	NO
SIMPEDS	★	★	NO	YES	NO
STASER	YES	★	NO	NO	NO

YES - unqualified acceptance NO - not appropriate
OK - qualified acceptance ★ - no information

Table V

Summary of the Performance Characteristics of the Instruments Tested in Relation to Their Abilities to Provide Information About Mineralogical Content of the Dust During a Typical Sampling Shift in a Mine

Sampler	Coarse fractions		Fine fractions	
	Dust accessible for analysis?	Sufficient dust for analysis?	Dust accessible for analysis?	Sufficient dust for analysis?
CIP10	OK	YES	OK	YES
M-Z	OK	YES	YES	YES
TD	YES	YES	NO	NO
IOMID	YES	YES	NO	NO
INSPEC	OK	NO	YES	NO
PERSPEC	OK	YES	YES	YES
PCI	YES	YES	YES	YES
SIDS	OK	YES	OK	YES
PIDS	OK	YES	OK	OK
TBF50	OK	YES	YES	YES
MPGII	*	*	YES	YES
CYCLO	*	*	YES	YES
CPM3	OK	YES	OK	YES
MRE	OK	YES	YES	YES
SIMPEDS	OK	YES	YES	YES
STASER	YES	YES	NO	NO

YES - unqualified acceptance
OK - qualified acceptance
NO - not appropriate
* - no information

REFERENCES

1. International Standards Organization (ISO): Air Quality—Particle Size Fraction Definitions for Health-Related Sampling. *Technical Report No. ISO/TR 7708-1983*. Geneva, ISO (1983).
2. American Conference of Governmental Industrial Hygienists (ACGIH): Particle Size-Selective Sampling in the Workplace. *Report of the ACGIH Technical on Air Sampling Procedures*. Cincinnati (OH), ACGIH (1985).
3. Stuke, J., Emmerichs, M.: Das gravimetrische Staubprobennahmegerat TBF50. *Ergebnisse von Untersuchungen auf dem Gebeit der Staub und Silikosebekampfung im Steinkohlenbergbau*. 9:47-51 (1973).

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