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 1/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 1/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 1/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
CIPI0	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 1/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
OK - qualified acceptance
NO - not appropriate
* - 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

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COMPARATIVE MEASUREMENTS WITH VARIOUS INSTRUMENTS: PROBLEMS IN THE EVALUATION OF DUST EXPOSURES IN THE HARD COAL MINING INDUSTRY

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Dust measurements with the tyndalloscope for the evaluation of dust exposure in the mining industry were performed from the middle of the fifties until 1973. Threshold values based on this measuring procedure. For the introduction of measurements, the tyndalloscope was at first the suitable device since it obtains data per minute about time-referred concentrations. Measuring values could therefore be allocated to a defined working process, thus indicating priorities of dust development and introducing measures of dust suppression. The disadvantages of the tyndalloscope were the dependence of scattering light intensity not only on concentration but also on particle size.

Realizing that the evaluation of dust conditions according to mass concentrations of fine dust results in a more suitable risk evaluation than other measuring parameters had, in connection with the establishment of mass-referred maximum workplace values for the whole mining industry, the consequence of converting the whole measuring and evaluating system. Thus the tyndalloscope was no longer suitable for the general occupational medical assessment of workplaces since the allocation of intensity values could not be realized in individual cases (Figure 1). Due to conversion to gravimetry, partly very different, evaluations of dust conditions in comparison with tyndalloscope assessments could be observed. Including tyndalloscope measuring data in epidemiological studies raised therefore many uncertainties about earlier critical dust conditions.

In the FRG, maximum workplace concentrations are derived from the Johannesburg Convention fine dust definition. The MPG II equipped with a horizontal elutriator (Figure 2) theoretically meets this defined fractionation. In the following time, it served as reference instrument in the German mining industry. When using devices with other separating functions comparative measurements with the MPG II are obligatory to determine whether conversion relations with a sufficient statistical significance are present. The TBF 50 (Figure 3), a double-cyclone instrument, used in routine measurements without follow-up filter behind the second cyclone, was tested in 180 comparative measurements. Concentration levels are compared in Figure 4. Because of the formerly supposed global connection between ash proportion and dust particle size, a correction of TBF 50 values with regard to ash proportion was tried. Based on these calculations, a corrective diagram was made (Figure 5) which was referred to for the indication of concentration-equivalent values for the MPG II. Obviously, alterations of mining and support techniques as well as of mine layout have increasingly blurred the connection between ash proportion and dust particle size. Thus, a correction via ash proportion is questionable at present. According to recent research findings, the conversion factor between these two instruments is independent of this parameter (Figure 6). The individual registered measuring positions represent mean values of 3 to 4 measurements at the same positions over a whole shift. Any position reflects various faces with different coal types and different mining techniques.

Relating the results obtained by the TBF 50 instrument with and without filter, a dependency of dust retained in the second cyclone on dust particle size is still present (Figure 7). However, distributions are also enormous when referring to dust particle size so that further influences are supposed to play a role. They might occur due to concentrations considering that cyclone efficiencies in addition to the particle size of dust to be collected also depend on concentrations. Furthermore, aggregates of suspended dust may be destroyed in cyclones. This factor has also an effect on dust masses separated in individual stages, thus being able to falsify the reference to primary conditions of airborne suspended dust. Dust may show various aggregation degrees which could not be correlated to defined workplace atmosphere parameters up to now.

The dependence of cyclone efficiencies on suspended dust uptake is also revealed in a comparison with the personal dust sampler Simpeds 70 MK II. In case of high concentrations, the throughput decreased which had the consequence that less dust was separated on the follow-up fine dust filter (Figure 8). In addition, varying flow velocities had a substantial effect on the collecting capacity of the intake. When performing alternating measurements with both instrument types, these parameters should be considered for concentration determinations.

Different conversion factors had to be taken into account, too, in a comparative test using the French device CIP 10 (Figure 9). Applied at the same position and at the same time hitherto obtained test results of instruments show a de-

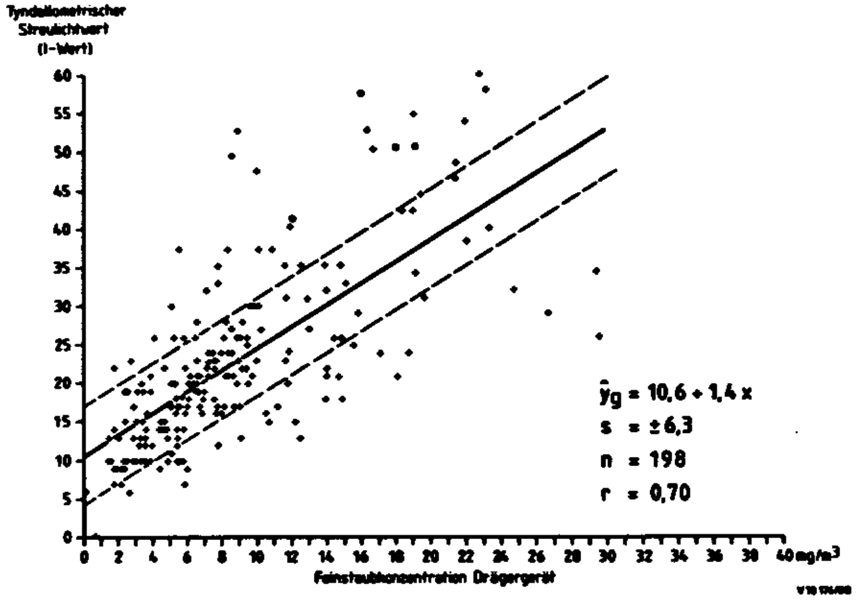

Figure 1. Comparison between tyndalloscopic and gravimetric measuring values.

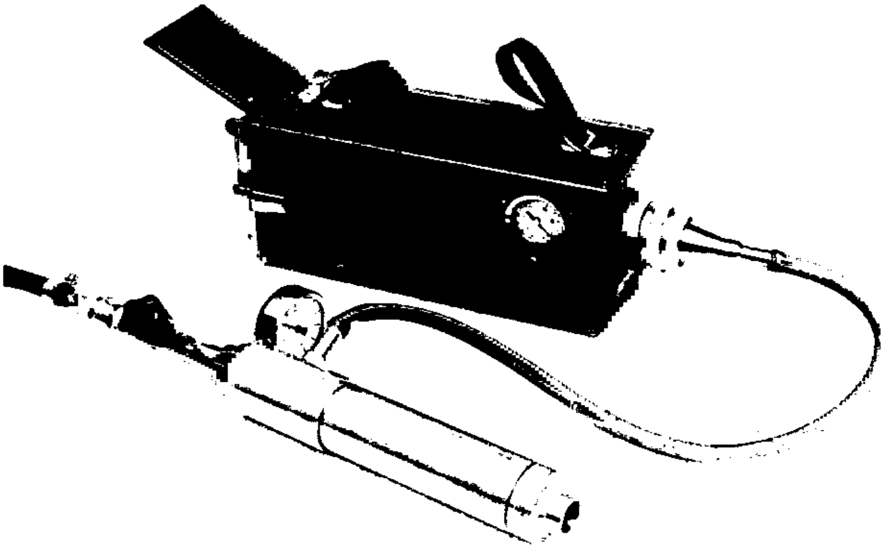

Figure 2. MPG II.

pendency of the conversion factor level on mined coal type as well as on mining method (Figure 10).

Outgoing from gas-flame coal, a low rank coal, and ending with high rank coal, the conversion factor increases, especially for plough mining. This tendency is less distinct when mining is performed with shearer-loaders. For this type of mining, uncorrected results of almost equal concentrations for MPG II and CIP 10 instruments can be based in general. The different reaction of both types during dust measurements in various mines applying different mining methods and the mining of coal with varying ranks is the result of different coarse dust pre-extraction in connection with varying particle size distributions of suspended dust. In one case for example, a change of mining methods from stripping to cutting resulted in the reduction of average particle size diameters by about 26 per cent. Likewise decreased the conversion factor from 1,4 to 1,1.

The outcome of these comparative measurements indicates the difficulty to use instruments with a deviating fractionation when referring threshold limits to a specific fine dust definition. Usually, general conversion factors cannot be applied; allocation has to be face-specific.

Due to the conversion to gravimetric methods, it is nearly impossible to recognize individual emitters and to proportionate them according to mining methods. Therefore, a new handy instrument, measuring on tyndallometric basis, was

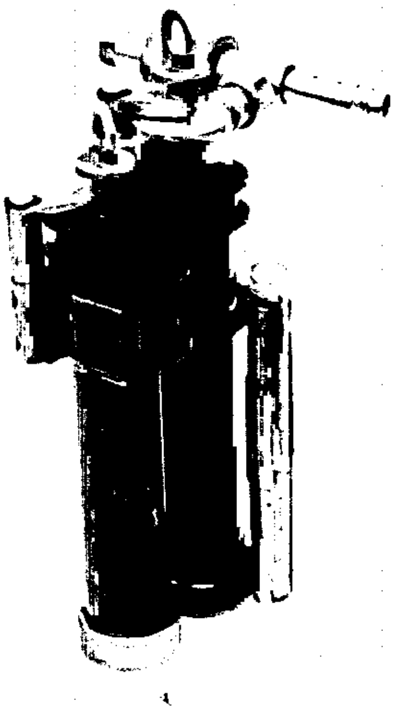

Figure 3. TBF 50

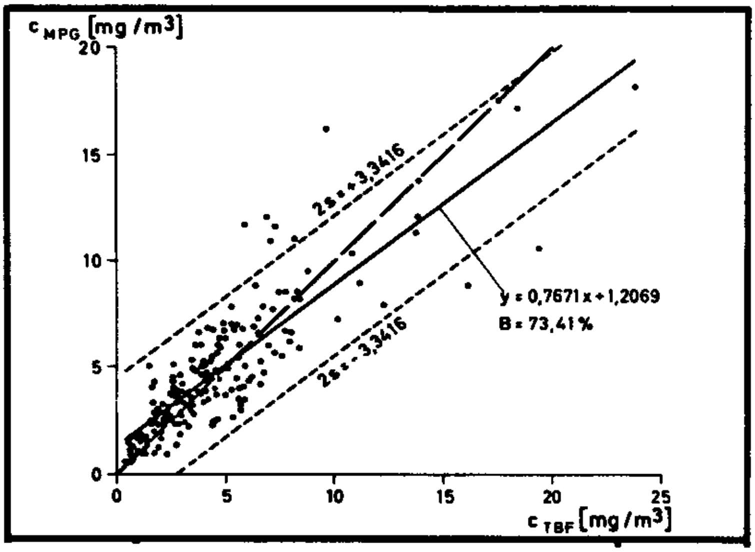

Figure 4. Concentration comparison between C_{TBF} and C_{MPG}.

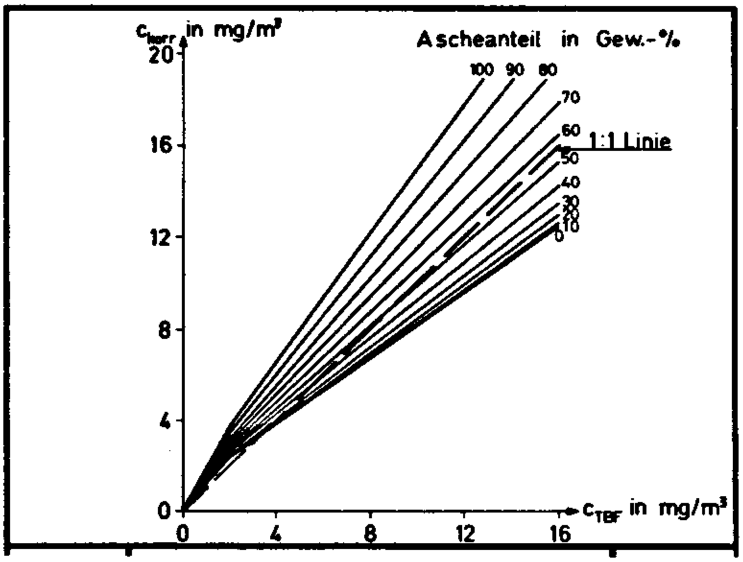

Figure 5. Conversion C_{TBF} into C_{corr}.

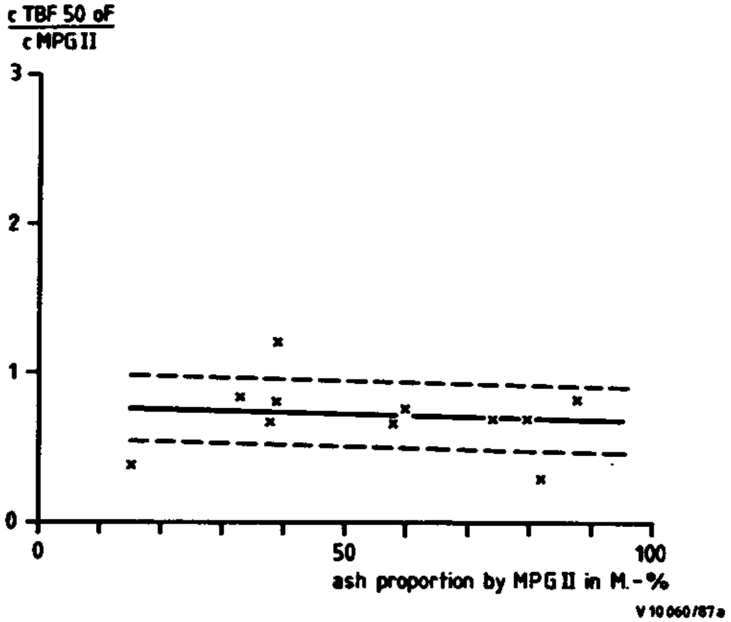

Figure 6. Ash proportion obtained by MPG II in mass %.

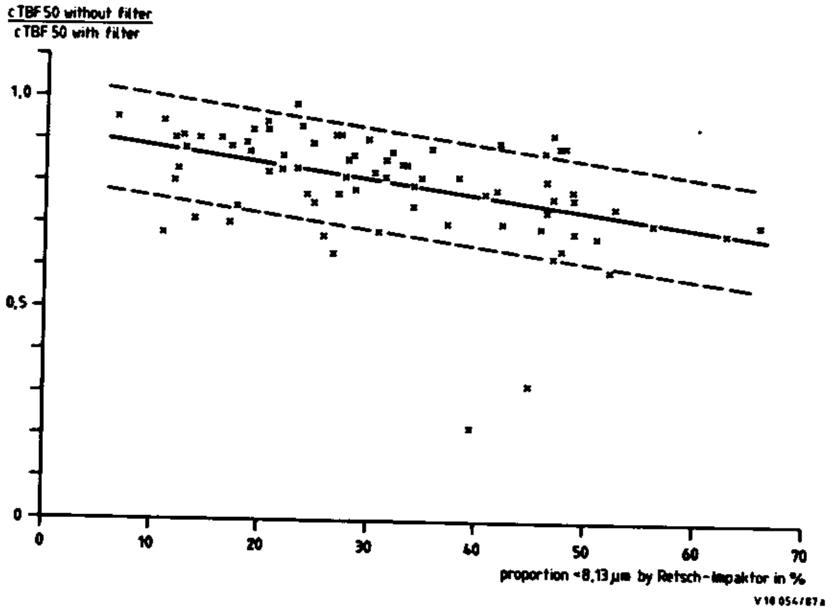

Figure 7. Conversion factors for TBF 50 with and without filter.

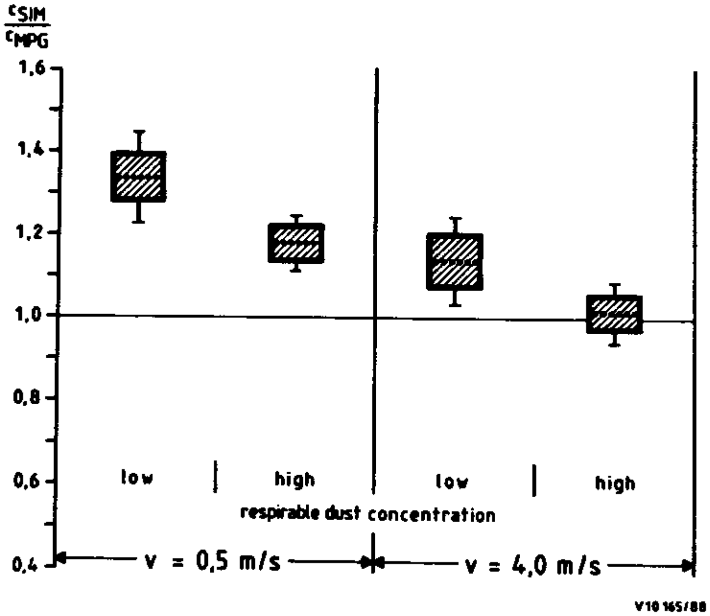

Figure 8. Conversion factors for Simpeds and MPG II.

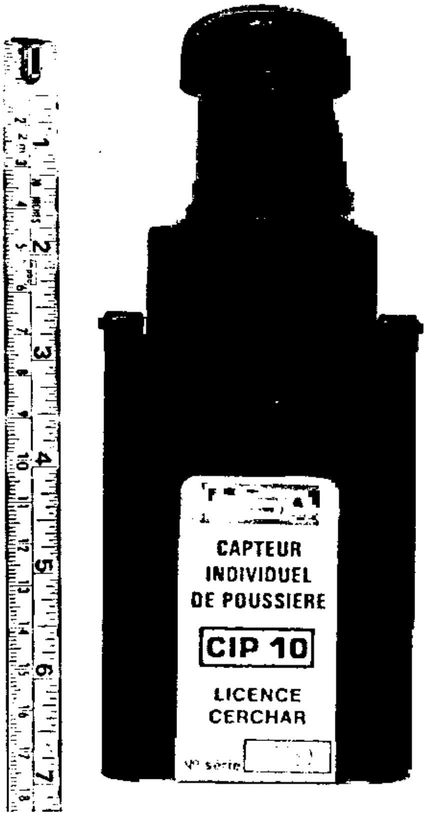

Figure 9. CIP 10.

developed: the TM digital µP which indicates single and average values for random measuring periods (Figure 11). Measuring sensibility due to particle size was diminished in this equipment. The advantages were mainly attained by measuring scattered light at an angle of 70° compared to 30° for the former tyndalloscope, and using monochromatic primary light of a wave length of 0,94 µm instead of visible light. Although the primary objective for using the TM digital µP was dust measurement for technical purposes it was also designed as supplementary or auxiliary device for occupational medical surveillance under specific operational conditions. At first, comparative measurements with the MPG II did not yield encouraging perspectives (Figure 12). The wide distribution of comparative values seemed to exclude an acceptable allocation of scattering light values to gravimetric concentrations. Classifying values according to specific characteristics of mining did not result in a substantial improvement, either. However, face-referred evaluations and limitation to areas of low exposures obtained good correlations between MPG II and tyndallometer (Figure 13). It is true that conversion factors vary widely from face to face; a linear relationship to comparative values is obtained, however, if a specific face is referred to.

At first, this assessment had the only objective to find out which tyndallometric measuring values have to be determined for the "worst case" in an area of low dust make and thus a low health risk in order to abstain from time-consuming gravimetric measurements. The linear correlations shown in figure 13, however. To prove this, comparative measurements during about 100 subsequent shifts were performed

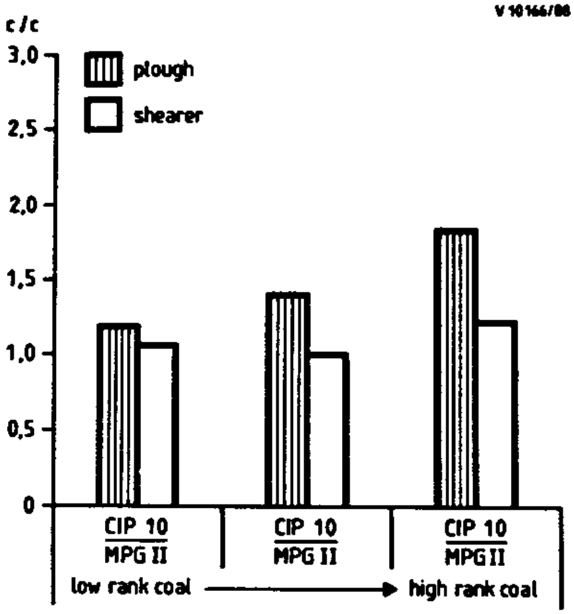

Figure 10. Conversion factors CIP : MPG II.

Figure 11. TM dig. µP.

in various mines with the TM digital µP, the MPG II, the TBF 50 and with a fine dust measuring device developed for permanent measurements with remote transmission of values on the basis of the tyndallometer digital µP. These devices were placed in a frame to maintain the same arrangement of instruments even when positions in mines changed (Figure 14).

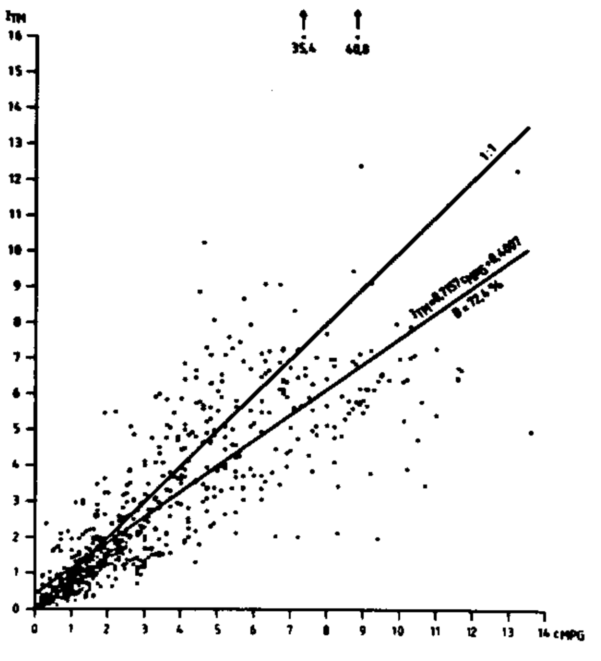

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Figure 12. Relation between gravimetric and tyndallometric intensity values of respirable dust concentrations.

To avoid dust deposits in the measuring chamber of the tyndallometric dust measuring device, clean air flows through a small fan at the inside of the measuring chamber. Speed

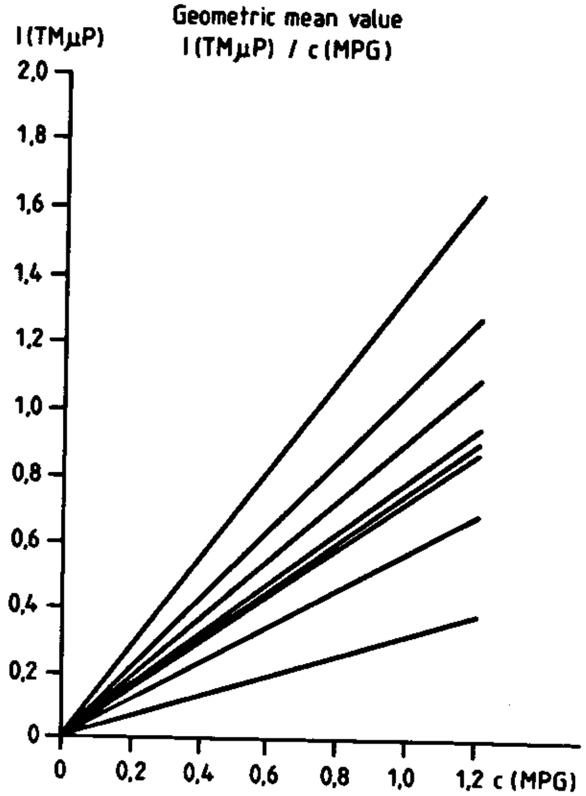

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Figure 13. Conversion relation for different faces (low concentrations).

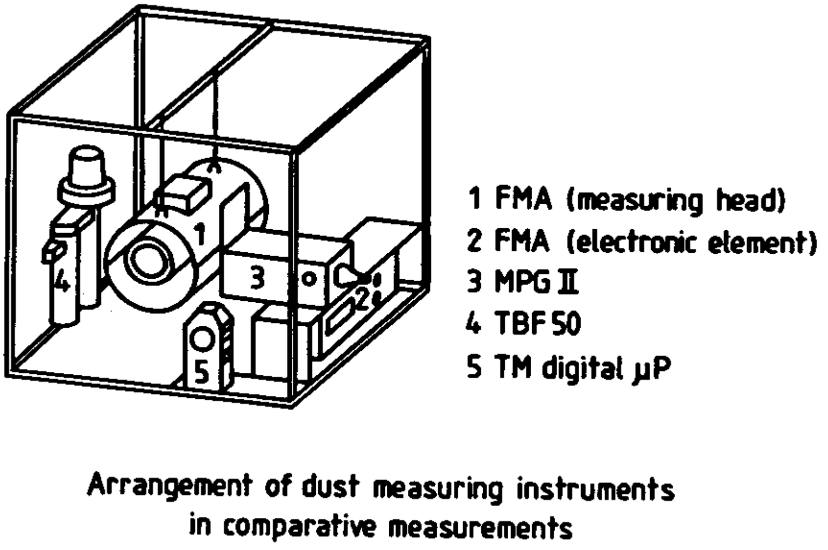

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Figure 14. Arrangement of dust measuring instruments in comparative measurements.

can be adapted to environmental velocity. In order to illustrate the comparison of results achieved by the tyndallometric fine dust measuring instruments with those of other instruments a field test typical for instrument reaction is described. The comparison with the MPG II showed a linear correlation over the whole sphere of concentrations (Figure 15). This also includes the other field tests which show in some cases a varying increase of the balancing straight line. However, the positions of balancing straight lines are typical for each face. Their rise remains nearly unchanged during varying operational processes in the same face. Thus, a face-specific allocation to the MPG II is feasible but also necessary. In this case, the conversion factor is not only valid for short-term but also for long term periods.

Regarding the TBF 50, correlations are less distinct (Figure 16). The distribution is higher. In another case, an allocation was even impossible (Figure 17). Since measuring values of the tyndallometer can be face-specifically allocated to gravimetric measuring values of the MPG II as the basic instrument, the following consequences can be drawn:

1. It is suitable to give a review on dust conditions between two gravimetric measurements.
2. It can help to decide for which shifts of operational procedures gravimetric measurements are required and for which shifts separate measurements should be carried out.
3. It is apt to indicate whether normal dust conditions were prevailing in the time of gravimetric measurements in order to exclude positive or negative extreme situations which may influence long-term classifications of the face.
4. In particular cases, the interval between two gravimetric measurements could be extended under the condition that the frequency of tyndallometric measurements increases in the meantime or a permanent tyndallometric surveillance is provided.
5. Basically, tyndallometric measuring instruments offer the possibility to allocate short-term concentration changes to specific operational procedures, to introduce dust suppression measures and to check the efficiency of them.

However, the tyndallometric measurement will not be able to replace the gravimetric measurement. As far as test methods for the direct determination of specific fibrogeneity of a dust collective are not at disposal substance quantities obtained by gravimetric samplers will have to be classified more extensively than hitherto to acquire a better knowledge on changing proportions of individual components, their particle size distributions and information about their potential interactions in dust mixtures with regard to fibrogenic tissue reactions. Primarily, single particle analyses on homogeneous and heterogeneous compositions including element analyses by electron microscopy and Lamma spectrometry are required.

As in many other countries, the evaluation of quartz-including fine dust mixtures in the FRG is carried out according to total fine dust concentration considering the quartz proportion of this dust mixture. Quartz as individual mineral serves as reference value (Figure 18, middle-line). Thus, the approved fine dust concentration in case of quartz quantities <100% is an operand only. In the FRG, however, this method is not consequently applied in cases of low quartz

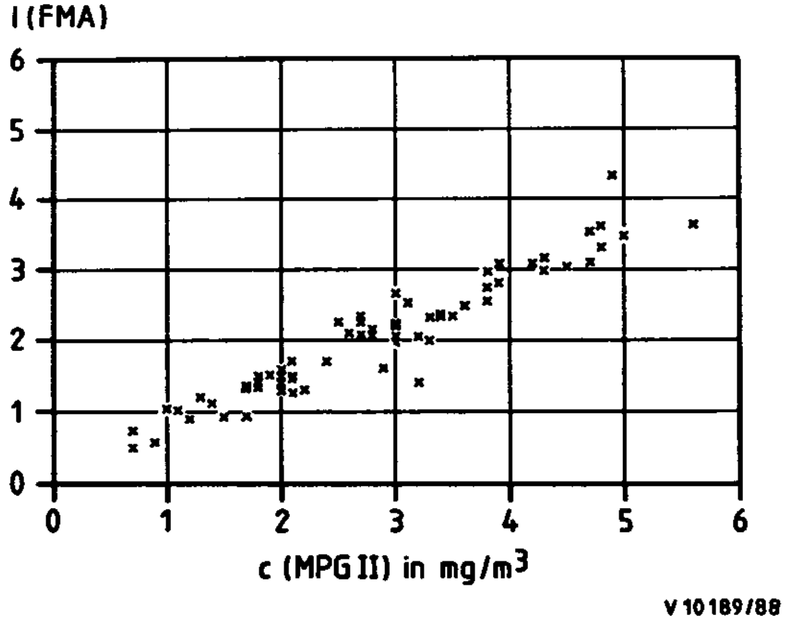


Figure 15. Comparison tyndallometer (FMA) and MPG II.

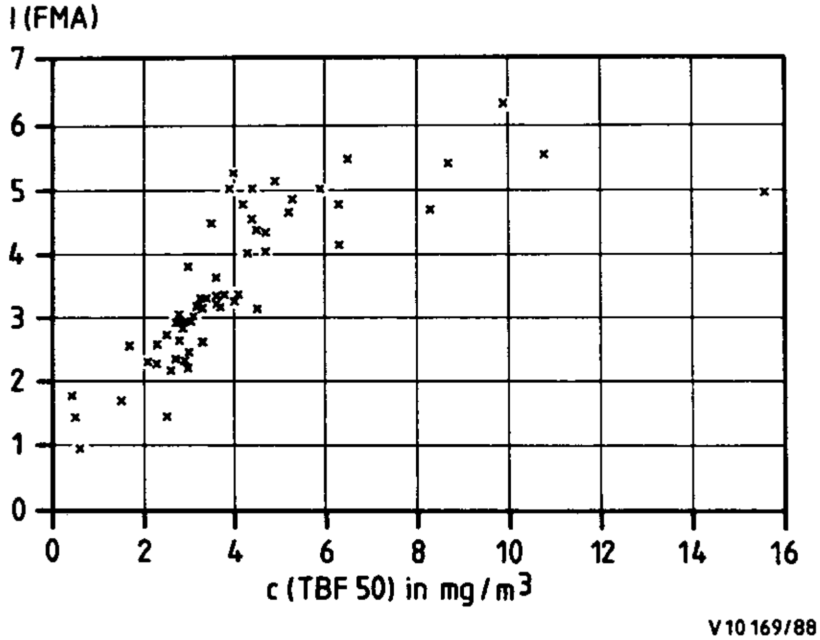


Figure 16. Comparison tyndallometer (FMA) and TBF 50.

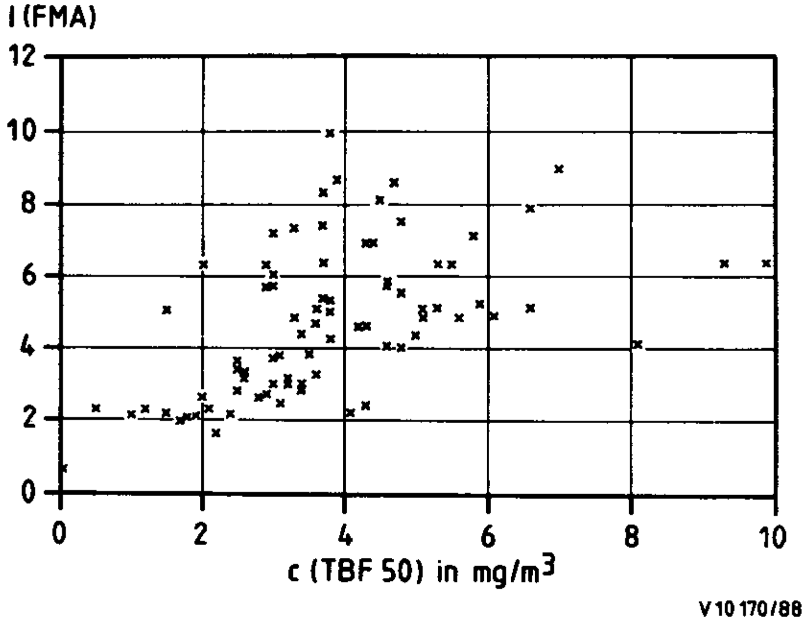


Figure 17. Comparison tyndallometer (FMA) and TBF 50.

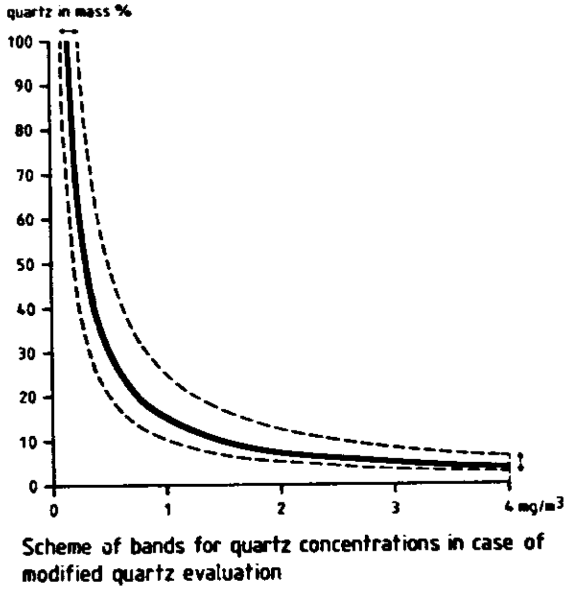


Figure 18. Scheme of bands for quartz concentrations in case of modified quartz evaluation.

proportions. In the presence of low quartz proportions, a defined fine dust threshold value was established which is not to be exceeded during a long-term assessment period. In case of small proportions, quartz is believed not to be the decisive biological parameter. At least in the hard coal mining industry it is doubted that quartz has the same fibrogenic power under any petrographic condition. Due to different developments, quartz as single component might show varying activities, or, referring to its harmfulness, it could be modified on account of interaction with other mineral components during or after deposit formation. For example, in spite of high quartz dust concentrations in a mine of a sedimentary hydroxide iron ore over a long-term exposure period did not provoke lung damages in exposed miners. At that time, this outcome was attributed to insoluble quartz surface masking.

In other hard coal mines, too, the risk to disease obviously cannot be directly and generally related to quartz fine dust concentrations. For example: the quartz proportion of dust originating from high rank coal is essentially lower than that of younger strata (Figure 19). The number of diseases is contrasting, however. These hints and findings raise two questions

1. Can occupational medical evaluation be based on a standardized quartz definition?

   When referring to pure quartz wouldn't it be preferable to make modifications considering the different fibrogeneity and to fix specific limit values?

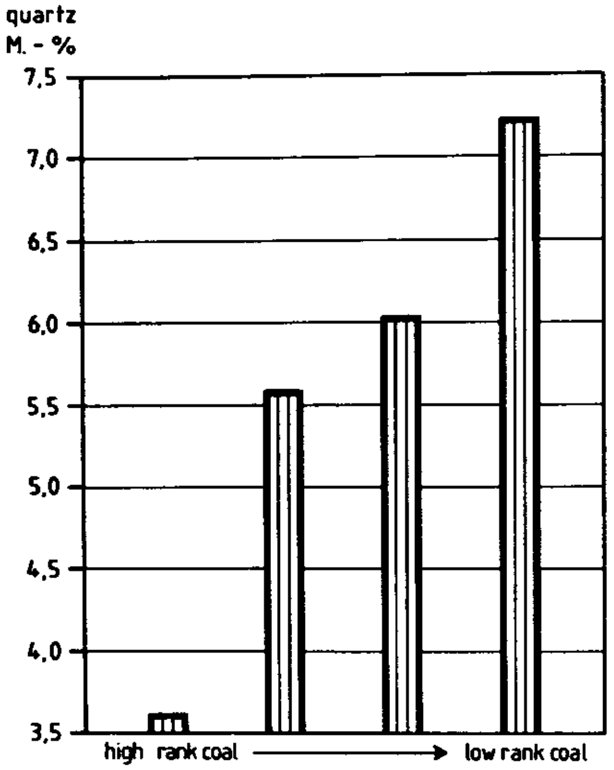


Figure 19. Quartz contents in respirable dust (measurement results obtained between 1980 and 1988).

2. Is it justified to restrict approved total fine dust concentration mathematically only by taking into account the respective quartz proportion without considering the components in the dust mixture interacting with quartz?

Several countries might have based their limit values on reference values for quartz of different origin which have different effects, therefore. This could explain the partly widely varying approved mass concentrations. A well-known fact is that free crystalline silica has not only structural differences but also varying biological effects. The results of animal experiments after using quartz of different genesis but also with cristobalite, tridymite, coesite, stishovite as well as amorphous silica confirm these findings. This means that the conditions of quartz formation and of the growth of quartz crystals in the plutonic development from early release out of liquid magma up to the telethermal phase in the hydrothermal sphere can vary widely. Therefore, deviant effective potentials of the mineral which is generally regarded as quartz should be taken into account. The SiO_4 tetrahedron arrangement determining SiO_2 modifications does not seem to be decisive, but rather the undisturbed or disturbed formation of individual tetrahedrons, for example substitution of Si ions by aluminium or phosphor.

Under the condition that a specific limit concentration of for example 4 mg/m³ for respirable dust including quartz must not be exceeded the curve progression of the approved fine dust concentration considering the proportion of the modified quartz component would change (Figure 20). However, the potentially inhibitory effect of substances in the dust mixtures would not be taken into account when applying this purely mathematical procedure. A more reliable assessment might be possible if chemical, physical and mineralogical characteristics could be determined for the specific nocuousness of a total respirable dust collective. This assessment cannot be realized yet for the hard-coal mining industry. Subject of present discussions is a model to better adapt the occupational medical assessment of dust uptake in workplace atmospheres in case of exposure to dust originating from various stratigraphic horizons by means of correction factors. In case of an uncorrected reference to the quartz proportion, this mineral component in the dust of seams with low rank coal was the decisive parameter of the approved total fine dust concentration since the limit of 5 mass per cent was essentially exceeded in general. However, disease frequency in the presence of seams with high rank coal and substantially lower quartz components was much higher.

These different findings are intended to be harmonized by correction factors for exposure evaluation. This means that the quartz proportion in mass percent of seam strata with low rank coal has to be converted into an "effective quartz proportion" referring to the conditions in layers with a higher rank coal. Irrespective of this parameter, the fine dust concentration of 4 mg/m^3 represents the maximum limit concentration in an assessed period (Figure 21). In the practice, the consequences would be as follows: Applying factor 1, valid for seam strata with high rank coal, quartz evaluation would continue to begin for a quartz proportion of 5 mass percent in the German hard-coal mining industry. The further progression of approved respirable dust concentrations will ensue from the orientation to the pure respirable quartz dust concentration of 0.2 mg/m^3. Using factor 0.5, quartz evaluation would start for a quartz proportion of 10 mass percent only, i.e., that the calculated respirable quartz fine dust concentration of 0.4 mg/m^3 analytically determined via the quartz proportion in mass per cent would be converted into an effective concentration of 0.2 mg/m^3. It is certainly not yet justified to provide as many categories for seam strata as shown in figure 21. A relatively rough differentiation into 2 or 3 groups of factors would be preferrable. In our opinion, the observed risk variations could be better taken into account by such a procedure, even when evaluating dust uptake in various stratigraphic horizons. Such a convention demands that the adaptation to an evaluation is restricted to modified factors of the quartz component until general systems to evaluate the specific nocuousness of the whole dust collective will be developed.

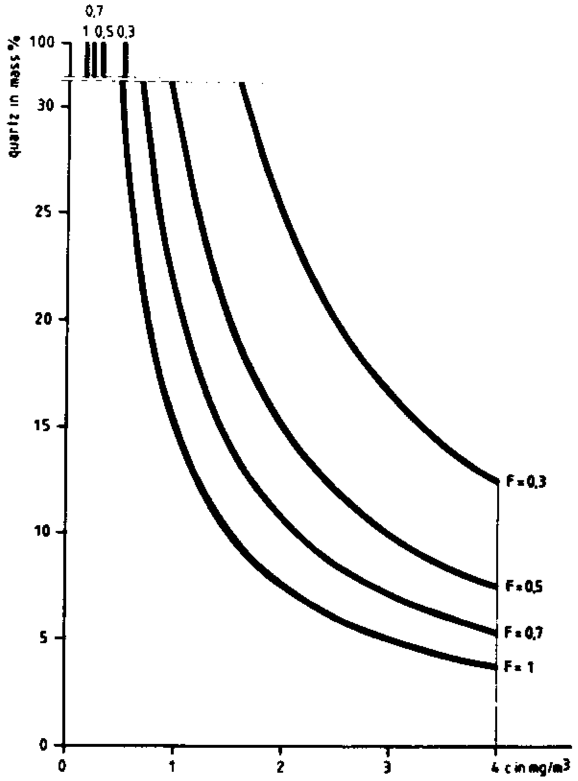
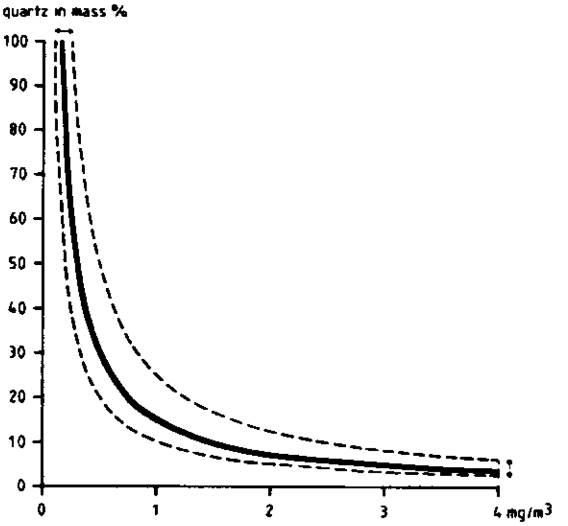


Figure 21. Approved respirable dust concentration in dependence on quartz proportion and the application of correction factors.



Scheme of bands for quartz concentrations in case of modified quartz evaluation

Figure 20. Scheme of bands for quartz concentrations in case of modified quartz evaluation.

MEETING DUST ASSESSMENT NEEDS OF AN AUTOMATED MINING INDUSTRY

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INTRODUCTION

The Bureau of Mines is vigorously conducting research to automate mining processes in an effort to keep U.S. coal mining competitive in the world market. However, just as the industrial revolution and its aggressive push for productivity exposed increased numbers of workers to serious injury, will "high-tech" mining also mean high-risk mining? The answer is "no," or at least "not necessarily." In fact, one potential benefit of automation is to remove humans from the most hazardous underground tasks. This concept is certainly not new. Tethered or radio-operated remote control miners signaled the very beginnings of automation. Miner operators could now work under well-supported roof, away from potential methane ignitions and high dust levels in the face area.

The Bureau is now conducting the next logical step in automation research. A continuous miner has already been outfitted with a suite of sensors and a computer to interpret sensor data and control movement of the machine. With the push of a button, the mining machine can execute a complete sump-shear-load cycle with the machine head position controlled to within 1 cm. Navigation research is well underway, so eventually the miner will be able to mine coal within the seam with very little human intervention. Several schemes to detect the interface between the coal and surrounding strata are being researched. Sophisticated laser, acoustic, inertial, and magnetic guidance systems will soon become feasible. The ultimate goal, of course, is completely automated operation that requires no human involvement.

Does this mean that our worries about pneumoconiosis, silicosis, and related dust-induced diseases are over? Not for many years. While the objectives of automation and robotics are admirable, humans will still be going underground well into the next century. Individual exposure to dust may be reduced in many cases, but certainly not eliminated. For the foreseeable future, robotic miners will require human supervision; and like today's technologically advanced automobiles, tomorrow's mining systems will still require maintenance. Maintenance will be a service that highly trained humans will continue to provide, and those humans will be exposed to dust. Machines designed to mine more coal will likely liberate more dust, unless dust control research keeps pace. In addition to health concerns, increased dust levels may pose problems for optical or laser guidance systems and other types of sensors, as well as increase the requirement for rock dusting to prevent dust explosions.

A critical element of any control system is monitoring. Information about the contaminant must be gathered so control efforts can be assessed and adjusted as required. This paper provides a brief overview of a Bureau project that addresses improved monitoring and analysis of hazardous coal mine dusts. Since the project is a recent initiative, the intent of the paper is not to provide extensive technical detail, but only to introduce the reader to the work being conducted.

REAL-TIME DUST LEVEL ASSESSMENT

Since the respirable coal mine dust exposure standard in the United States is expressed as a mass concentration (2 mg/m^3), gravimetric dust sampling techniques are appropriate and acceptable for compliance monitoring if conducted properly. The Bureau recognized several years ago, however, that a real-time method for assessing dust levels was needed to locate dust sources and evaluate dust control systems efficiently. The long sampling time required to collect filter samples and the delay involved in weighing the filter make gravimetric techniques too time-consuming and labor-intensive for such purposes. This realization brought about the development of several light-scattering dust monitors, including the widely used RAM-I[1] and the more recent MINIRAM. Other private sector instruments were developed without Bureau sponsorship. The advantages of these devices are almost instantaneous indication of dust levels, portability made possible by small size and battery-powered operation, and relative mechanical simplicity.

Many researchers have evaluated the performance of these and other light-scattering dust monitors. The conclusion common to almost all of these works is that the response of photometers is *not* directly related to the mass concentration of the dust. Particle characteristics such as size, index of refraction, and shape all affect the response. A special concern when sampling near water sprays used for dust abatement is that water droplets entering the instrument sensing chamber can scatter light and cause falsely high readings. The water droplet problem is minimized with instruments like the RAM-1 that use a cyclone preseparator. In that case, the cyclone captures most droplets larger than a few micrometers. In passive, open-chamber instruments like the MINIRAM, however, the problem can be severe unless a cyclone adaptor is used. Such uncertainty in light-scattering measurements makes them unsuitable for compliance measurements, but is generally acceptable for relative "before-and-after" measurements associated with evaluation of control systems. Even here, however, results can be very misleading if the size distribution of the dust cloud is dramatically altered by the dust control system.

The Bureau is conducting basic research to develop a light-scattering dust monitor that accurately measures the mass concentration of dust, even in the presence of water droplets. The Mie theory of scattering of electromagnetic radiation is often applicable to the scattering of light by respirable dust particles. The detailed mathematics are quite complex, but in general, the intensity of light scattered by a particle is a function of detection angle, intensity and wavelength of the source light, and particle size, index of refraction, shape, and surface properties. The Bureau is using computer models of Mie scattering to study the implications of varying instrument configurations and particle characteristics. The theory and computer models deal with ideal spherical particles. Although particle irregularity will introduce unknown changes into the model predictions, the model can still provide general guidance regarding the selection of important instrument parameters.

As an example, Figure 1 shows a two-dimensional diagram of the intensity of light scattered by a spherical particle as a function of angle for a given set of conditions. The value α, called the particle size parameter, is the ratio of the particle diameter to the source light wavelength. Figure 2 shows an intensity diagram for a somewhat larger particle, all other parameters remaining the same. This analysis indicates that each particle will have a scattering signature that may be unique to its physical characteristics. A novel experimental apparatus, called DAWN-A, has been obtained by the Bureau's Pittsburgh Research Center that will allow direct three-dimensional measurement of the intensity of light scattered by a particle as a function of angle. As shown in Figure 3, the device consists of a sphere upon which are mounted several photodetectors. As a particle passes through the sphere, laser light is scattered to the detectors in a pattern associated with that particle. Intensity information is processed by a computer. Research during the remainder of the project will examine the scattering signatures for a wide variety of particles likely to be found in coal mines. Once these signatures are known, a photometer may be designed that uses only those parts of the scattering signature needed to discriminate between liquid and solid particles, and to compensate for particle size, shape, and index of refraction effects. The eventual design might need to include more than one source and detector in order to gather enough information to complete the analysis. Long-term research might even lead to limited dust component analysis using the scattered-light signature.

The anticipated result of the research will be a dust monitor that can continuously and accurately measure the real-time mass concentration of dust particles in a coal mine. A monitor with such capabilities will find applications in dust control research, and perhaps even in compliance monitoring. The real value of such a device, however, lies in automated dust control systems. Dust control research has identified many viable methods to control respirable dust, but operating parameters must often be adjusted to fit the situation at hand. Water spray pressure or ventilation rate may need to be changed, for example. To automate the adjustment of dust control parameters requires that information about dust levels be fed back to a control unit that can decide what change to make in the operating parameters. The improved photometer could serve as that critical feedback mechanism.

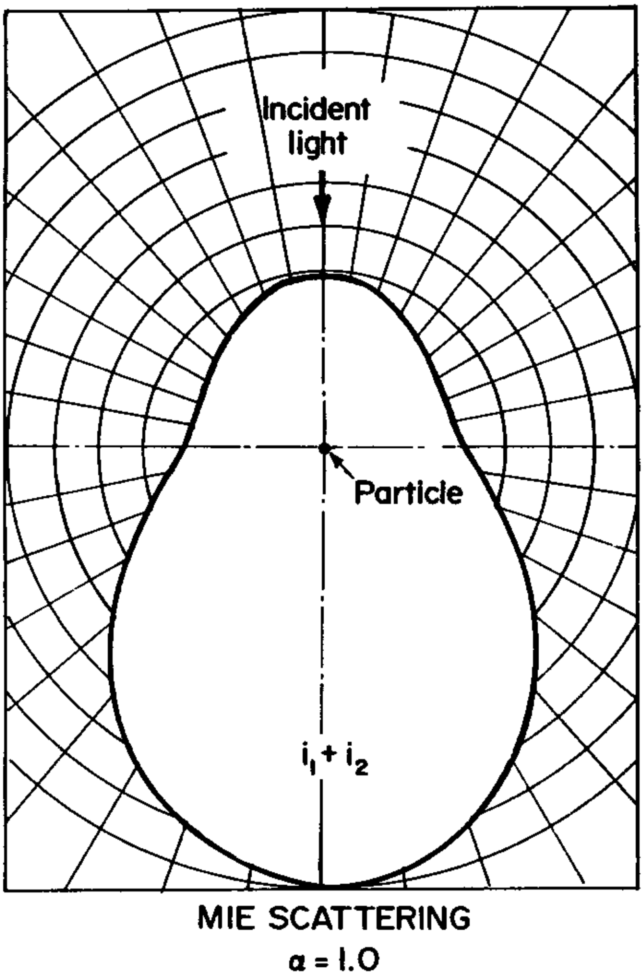

Figure 1. Scattered light intensity as a function of angle α = 1.

Requiring worker presence to adjust dust control system operating parameters manually would largely defeat one purpose of automated mining, that is, to remove personnel from hazardous areas. Automated dust controls would greatly reduce the need for human presence.

In addition, they would address the other main reason for automated mining, competitiveness. Controlling dust is not free. Power for fans, scrubbers, and water pumps is an expense that must ultimately be reflected in the cost of coal. Along with reducing labor costs to monitor and adjust dust

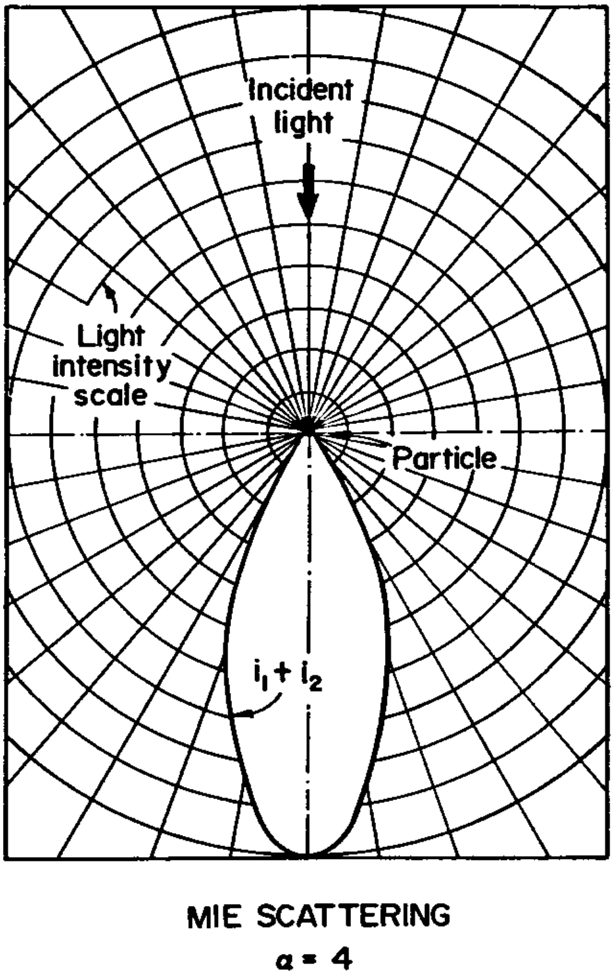

Figure 2. Scattered light intensity as a function of angle α = 4.

control operating parameters, automated systems could prevent unnecessary costs incurred by using overly restrictive dust control methods.

DUST COMPONENT ANALYSIS

While real-time knowledge of airborne mass concentrations of respirable coal mine dust is important for control purposes, health specialists know that lung diseases, especially silicosis, are not correlated simply to levels of coal mine dust. The individual components of the dust have an important bearing on the likelihood of contracting disease. This realization is reflected in the practice of reducing exposure standards in coal mines when quartz levels exceed 5 pct. Some European data suggest that silicosis is not directly related to the percentage of quartz alone. Other minerals such as kaolin and mica have some fibrogenic capacity of their own. On the other hand, minerals such as feldspar, calcite, calcium sulphate, siderite, hematite, pyrites, etc., exist in high quantities in coal mine dust samples and may reduce the toxicity of the quartz present. All of this research points to the importance of being able to determine the amount of quartz and other components in respirable coal mine dust samples accurately.

Real-time, in situ component analysis of airborne coal mine dust remains a researcher's dream, but significant progress has been made in spectroscopic analysis techniques. The Bureau has purchased a Fourier transform infrared (FTIR) spectrometer to assess its capabilities. Already, the instrument has demonstrated an order of magnitude greater sensitivity to quartz than dispersive infrared techniques. These results were obtained by the manufacturer during courtesy analyses of Bureau-prepared filter samples.

Dispersive infrared spectroscopy has served as a mainstay analysis technique for quartz for many years. It has a working measurement range of 25 to 250 µg of quartz with a precision of 13 to 22 pct. Figure 4 is a diagram depicting the operation of a typical dispersive infrared spectrometer. By a system of mirrors and lenses, the source beam is split and follows two separate paths to the detector. Synchronized beam choppers (C_1 and C_2) allow the beams to alternately pass through a sample and a reference cell to the detector. The reference cell measurement allows compensation for such things as variation in source light intensity, temperature, pressure, etc. Infrared light from the source is viewed in discrete wavelength intervals throughout the range of interest, and the transmitted intensity is measured at the detector at each wavelength interval. These wavelength intervals can be referred to as "resolution elements." According to Skoog and West,[1] "The quality of the spectrum—that is, the amount of spectral detail—increases as the number of resolution elements become larger or as the frequency intervals between measurements become smaller." For dispersive infrared spectroscopy, then, increased spectral quality involves two costs. The first is the increased time required to measure transmittance at a greater number of resolution elements. The second is diminished sensitivity. This results because as the resolution interval gets smaller, the signal available to the detector is smaller.

Figure 5 is a diagram of a typical FTIR spectrometer. Here as well, the beam is split, but there are no choppers to alternate beam paths. Half the beam is reflected from a fixed mirror, through the sample to the detector. The other half of the beam is reflected from a mirror that moves at a well-defined rate, changing the path length of half the beam. The recombination of the two beams results in an optical interference that strengthens or diminishes the signal at the detector. In fact, the rate of change of signal strength is directly proportional to the movement of the oscillating mirror. By applying a mathematical Fourier transform to the function that describes the detected signal intensity as a function of mirror position in time, a function describing the intensity as a function of wavelength, that is, the absorption spectrum, can be obtained. The advantage of the FTIR is that all resolution elements for a spectrum are measured simultaneously. Separate measurements need not be taken for each wavelength as is the case in the dispersive infrared system.

Since quartz is recognized as a major health hazard and receives special emphasis under the respirable coal mine dust

Figure 3. DAWN-A

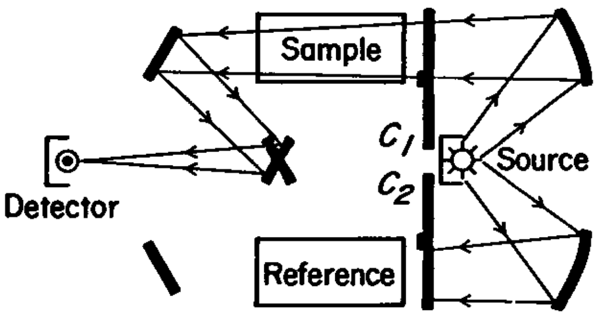

Figure 4. Typical dispersive infrared spectrometer.

exposure standard, the project is directing substantial effort to improving the analysis methods for quartz. The Mine Safety and Health Administration (MSHA) is already considering the use of an FTIR in its Method P7 for routine coal mine dust sample analysis. Although users will enjoy the benefits of improved sensitivity, they must conduct the somewhat laborious sample preparation required by Method P7. Preparations include low-temperature ashing and sample redeposition. One objective of the Bureau project is to develop a valid, convenient method for direct on-filter FTIR analysis for quartz.

As discussed above, other minerals appear to either enhance or diminish the toxicity of quartz, or even cause damage

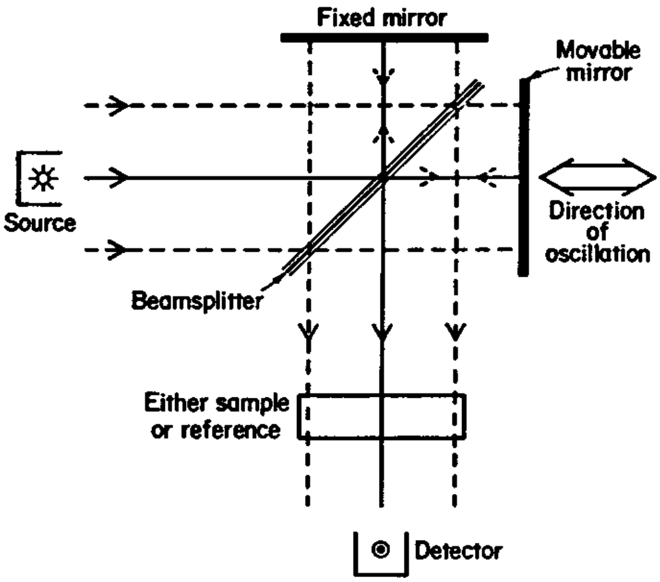

Figure 5. Typical FTIR spectrometer.

on their own. Thus, to understand completely occupationally related lung diseases, the capability of measuring the other components in the dust sample will be essential. Multicomponent analysis of dust samples is, therefore, another of the many long-range objectives of the project.

SUMMARY

The project reviewed in this report has two primary goals. The first is to provide accurate real-time measurement of the mass concentration of airborne respirable coal mine dust. Such capability is needed to provide feedback regarding dust levels to future automated dust control systems. The DAWN-A, a unique experimental apparatus for studying light scattered by dust particles, will be used to design an improved photometer. The second goal is to provide improved capabilities for respirable dust sample component analysis. Such information will be needed to understand occupational lung disease and to better assess the hazards of workplaces. Fourier transform infrared spectroscopy has been selected as a promising technique to accomplish that goal. Just as the Bureau of Mines is applying high technology solutions to problems of production and competitiveness in the international mineral industry market, it is also applying state-of-the-art technology to the measurement and analysis of respirable dust. The project tasks are in their early stages, but initial work points to an exciting and fruitful future.

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[1] Use of trade names is for identification only and does not imply endorsement by the Bureau of Mines.

ASSESSMENT OF PERSONAL DUST EXPOSURE WITH THE CIP10 FOR A BETTER MEDICAL MANAGEMENT OF THE PNEUMOCONIOSIS RISK IN COAL WORKERS

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ABSTRACT

According to French regulations, level of coal dust exposure in each underground working must be measured by static sampling. In collieries of Lorraine a single sampling site, in the return air, is selected for each working. Each miner is assigned to one working in accordance with his fitness for work as determined by the occupational physician.

A new individual dust sampler (CIP 10) developed by the *CERCHAR* has been used in a national survey in which more than 5000 measurements in 194 jobs were carried out. That sampler is now at the occupational physician's disposal for a better prevention of pneumoconiosis.

So far it has been possible to:

- look after the placement of pneumoconiotic miners still occupied underground. A survey (207 measurements) showed that those workers were in average exposed to 0,64 mg/m^3 respirable dust TWA;
- check dust exposure of miners with a profusion of 0/1 level (263 measurements, mean = 0,89 mg/m^3);
- document the exposures associated to some job suspected by the physician to be specially at risk.

Some over exposure situations have been already detected. They offer a possible explanation for recent cases of particular pneumoconiosis.

A strategy for the use of CIP 10 is proposed, based on 5 successive days of measurements, eventually repeated following the results dispersion and their extreme values.

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CORRELATION OF TESTS FOR MATERIAL DUSTINESS WITH WORKER EXPOSURE FROM THE BAGGING OF POWDERS

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INTRODUCTION

Laboratory dustiness tests have been devised[1] to provide a quick and convenient means of estimating a material's relative dustiness. These tests are empirical in that they do not measure a fundamental property or response of the material being tested. In using these dustiness tests, one assumes that the dust generation in the test simulates the dust generation in an actual powder handling operation. In order to be useful, the results of these tests must be correlated with personal dust exposures. Because this correlation has not been evaluated, NIOSH researchers conducted a study to evaluate the correlation between worker dust exposure and the results of two dustiness tests. The two dustiness test devices are the Heubach Dust Measurement Appliance and the Midwest Research Institute (MRI) tester.[1,2]

This study was conducted in the packaging room for a powdered acrylic resin production line. The plant produced a variety of resins which differ in bulk density, particle size, moisture content, and observed dustiness. The resin powders were auger fed into tuck-in valve bags. The bags were filled with 50 pounds of powder, they were sealed and dropped onto a conveyor belt which transported the bags to a palletizing operation. The operator tended a number of bag packing machines. Several workers rotated between the bagging equipment and the palletizing equipment in an adjacent storage area.

EXPERIMENTAL PROCEDURES

For six different resins, the workers' dust exposures were measured and dustiness tests were conducted on bulk samples of the material to determine if the dust exposures and the dustiness test results were correlated. For each material packaged, exposures to total dust were measured using NIOSH Method 0500.[3] Air samples were collected using personal pumps operated at 3.7 liters per minute. Separate sets of measurements were taken for different workers who rotated through the bagging machine operations. Usually, 4–6 measurements were taken for each powder.

The Heubach unit, depicted in Figure 1, consists of a horizontal rotating drum with internal baffles that produces a repeated dust fall through a regulated airstream. Airborne dust from the drum enters a settling chamber and is then collected on a preweighed glass fiber filter (50 mm, Schleicher and Schull GmbH). The test parameters (mass of material, airflow rate, and total flow) for the Heubach dustiness tester are not unique; they are set for each type of powder tested so that a desirable quantity of dust is collected on the filter. A sample of about 20 grams, a flow rate of 4 liters/minute and a sampling time of 5 minutes were selected as appropriate test conditions for this study site.

In the MRI tester shown in Figure 2, powder is poured out of a metal beaker in an enclosed space and the resulting air-

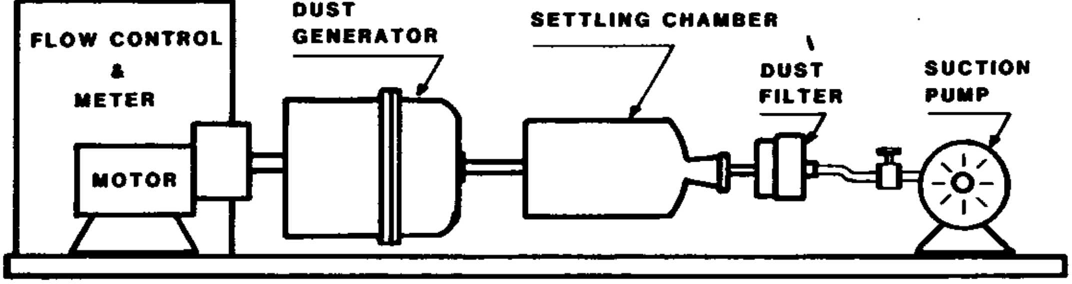

Figure 1. Heubach dustiness tester.

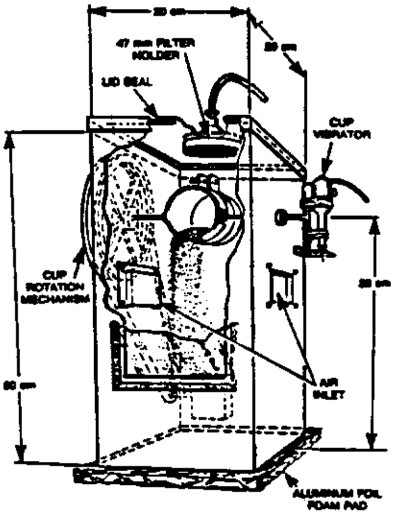

Figure 2. MRI dustiness tester.

borne dust is collected on a preweighed filter (47 mm glass fiber Gelman type AE) at a rate of 10.8 liters per minute. The cup was rotated at a constant speed to dump the powder. A vibrator mounted to the cup shaft helps to dislodge the dust. The sample pump was run for 10 minutes after the rotation of the cup was initiated. The MRI dustiness index was computed from the following formula: Dustiness Index = Dust collected (mg)/((Sample Weight [Kg])(Flow rate [1 pm])).

RESULTS

The personal dust exposure data and the dustiness test indices were fit to a regression model of the following form: in (X) = a + b (Y). In this model, the terms "a" and "b" are the regression coefficients, the term "X" is the individual dust exposure, and the term "Y" is the average dustiness index for a material. For both the MRI and Heubach dustiness test indices, a significant correlation was found between MRI and Heubach dustiness test results and worker dust exposures. Statistical results for the analyses are listed in Table I. In Figures 3 and 4, the exposure data, the predicted worker dust exposure, and the 95% prediction intervals for individual dust exposures are plotted as a function of dustiness test results. The prediction intervals include 95% of the exposures which would be predicted from the regression model.[4] The prediction interval width is proportional to the standard error of estimate (S_e), which is essentially the standard deviation about the regression line. It is the result of two sources of error: (1) the lack of fit of the model to the data; and (2) the sampling error in measuring the dust exposure. The significance of the lst source of error was evaluated using the method described by Mendenhall.[4] This method tests whether the error caused by the lack of fit is larger than the sampling error. The significance of this difference is stated as "the-significance level for lack of fit" in Table I. This indicates that the correlation between the MRI dustiness test and the worker dust exposure involves a significant lack of fit. Apparently, this source of error causes the wider prediction intervals for the MRI dustiness tester. For the Heubach dustiness test, the lack of fit was not significant. This means that the width of the prediction interval is caused by the variability in the workers' exposure data. Thus, the prediction intervals in Figure 3 cannot become much smaller.

DISCUSSION AND CONCLUSION

The preceding regression analysis shows that dustiness test results were correlated with worker dust exposure and can be used to predict worker dust exposure to within an order of magnitude. The width of the prediction interval about the regression lines was largely caused by the variability in the worker dust exposures and the width of this prediction cannot become much smaller. The correlations between worker dust exposure and dustiness test results are totally empirical and the results of the regression analysis must be used care-

Table I

Evaluation of Exposure Models

Statistical terms	Heubach	MRI
intercept (a)	-0.5	-0.1
slope (b)	10	0.09
Probability of a larger F	<0.0001	<0.0001
R^2	0.59	0.45
s_e	0.75	0.86
significance level for lack of fit test (Probability of a larger F)	0.28	0.013

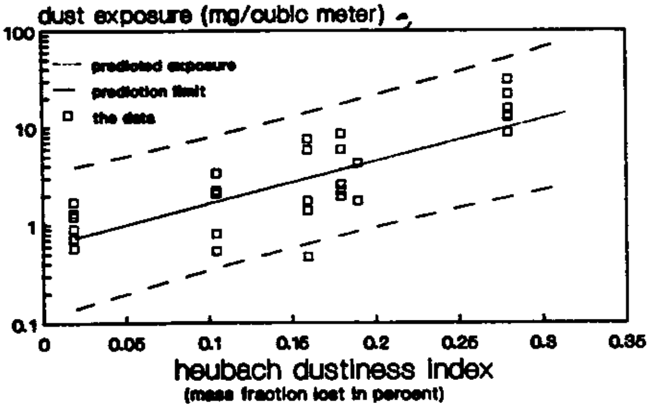

Figure 3. Predicted dust exposure, and prediction intervals plotted as a function of weight % lost, Heubach test.

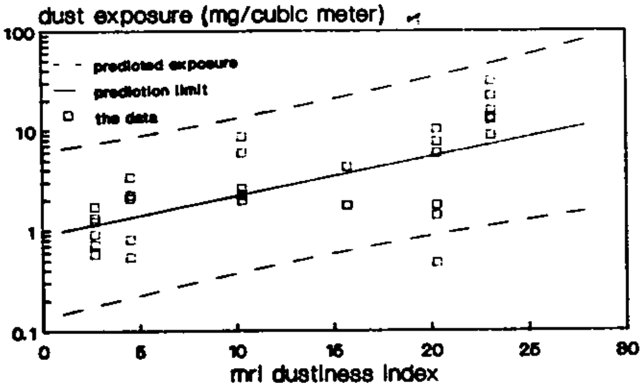

Figure 4. Predicted dust exposure, and prediction intervals as a function of MRI Dustiness Index.

fully. The regression equations present in this paper are useful only to the extent that conditions at this plant at the time of this study are duplicated. If conditions at the plant change, the correlation will change.

The fact that a significant correlation between dust exposures and dustiness test results was observed in an actual plant shows that addressing material dustiness is important in predicting and controlling worker dust exposure. It also suggests that significant correlations may be present at other plants and other processes. As a result of this, dustiness testers can presently be used to do predictive industrial hygiene (the estimation of exposures before they occur). For example, suppose a new product is being considered for production in a process or an operation where two or more different materials are being used. For this process or operation, one can develop a correlation between dustiness tester results and dust exposure. The correlation and dustiness test results from a small sample of this new material could be used to predict the dust exposures to within an order of magnitude. This could allow one to make dust control recommendations before the new product is produced or used on an industrial scale.

Presently, dustiness testers are empirical tests which are used to simulate the formation of airborne dust during powder handling operations. Unfortunately, the mechanism of aerosol generation during operations such as bag dumping is not well understood in terms of the identity and magnitude of the forces which affect dust generation. An improved fundamental understanding of airborne dust generation by powder handling operations would allow one to select and devise dustiness tests which closely simulate the actual process which generates the airborne dust.

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Note: A more complete version of this paper has been submitted to *Applied Industrial Hygiene*.