Comparative Measurements of Air Pollutants in the Iron and Steel Industry of Five Member-Countries of the European Coal and Steel Community*

Metingen in internationaal verband van luchtverontreinigingen in hoogovens en staalbedrijven*

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Samenvatting

Door een zestal instituten worden in vijf landen metingen van luchtverontreinigingsniveaus in hoogoven- en staalbedrijven uitgevoerd. Ingegaan wordt op de bijzondere moeilijkheden die het vergelijken van stofconcentraties oplevert, indien deze door verschillende instituten met niet-gestandaardiseerde apparaten worden uitgevoerd.

Summary

Six institutes in five countries perform measurements on the air pollution level in the iron and steel industry.
The authors present difficulties which occur when one wants to compare dust concentrations measured by different institutes with non-standardized equipment.

1. Introduction

The structure of the "rich" countries is based on agriculture as developed about six thousand years ago in the Near East and on the production methods developed during the eighteenth century in Western Europe and, since the end of the nineteenth century, also in the USA.
These developments were initiated by inventions which revolutionized the coal and steel industry. The extent to which that branch of industry affects the economical mechanism of a nation is demonstrated by the input-output matrices which Leontief developed for the American economy (1); they are now also used by many other countries including the Netherlands. To the negative side of these developments belong the mental and physical stress at many working places in the coal and steel industry. It is therefore gratifying to note that, ever since its creation in 1952, the European Coal and Steel Community has been particularly interested in the health problems inherent in this branch of industry.
The investigations described in this article, enabled by a subsidy granted by the Community, relate to the specific aspects of those problems; their major objective is the determination of the dust concentrations in relation to the risk of silicosis, with regard to various working places in the iron and steel industry.

The methods used are standardized by a working party of the Community. The investigations are carried out in Belgium, Western Germany, Italy, Luxemburg and the Netherlands. The magnitude of the problem may be illustrated by the fact that the number of workers in the iron and steel industry of all the six countries forming the European Community amounts to 600,000.

2. Problems connected with the investigation

Both the type and the quantity (dose) of the polluting agent taken up by persons determine the damage to the human organism. In our case — exposition to mineral dust of low solubility — the relationship between the quantity taken up and the measured dust concentration can be approximated by the formula:

$$D = \int V\,(C_i - C_e)\,dt$$

D = dust taken up
V = volume of inhaled and exhaled air per unit of time
C_i = concentration of dust in inhaled air
C_e = concentration of dust in exhaled air
t = time

Occupational hygienists generally express the dust concentration in air in mg/m^3 or in number of particles per cm^3. It is clear that for the concentra-

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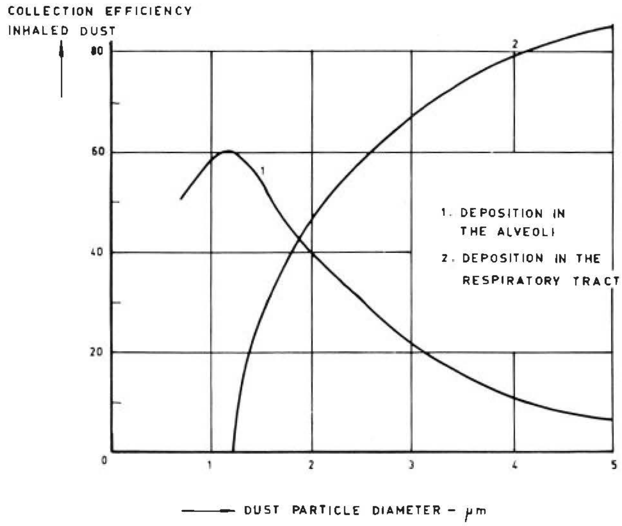
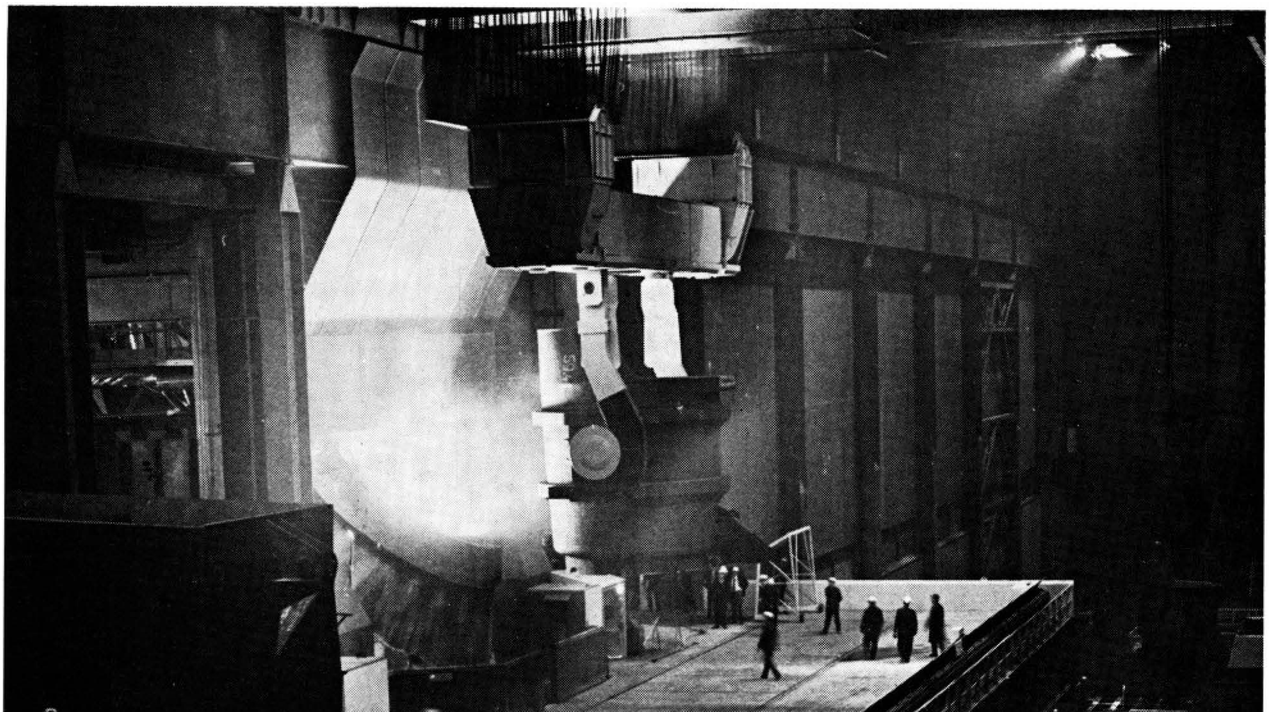
tion either of these two expressions can be used in the above formula, provided the units of the other variables are chosen consistently.
In investigations under consideration the normal procedure is to determine only the concentration, C_i, to which the people are exposed. Both V and C_e, however, vary from person to person. These factors again depend on the local situation. Because nose, pharynx and bronchia jointly operate as a filter, the pulmonary vesicles (alveoli) can only be reached by dust particles of a diameter less than 5 μm. Figure 1 shows this filtering action; more refined models are given in the literature (2). This action is the reason why the fine fraction of quartz dust is generally held responsible for initiating silicosis.
Broadly speaking, neither the mechanism nor the quantitative purely phenomenological relationship between the quartz concentration and the occurrence of silicosis are really known (3).
Though some of the toxicological and physiological problems have been briefly indicated, the determination of concentration C_i is likewise attended with difficulties; they become particularly evident when several institutes perform measurements with the intention to compare the results. These difficulties are due to the sampling system, usually carried out by sucking a known quantity of air through a sample collection device. In this process

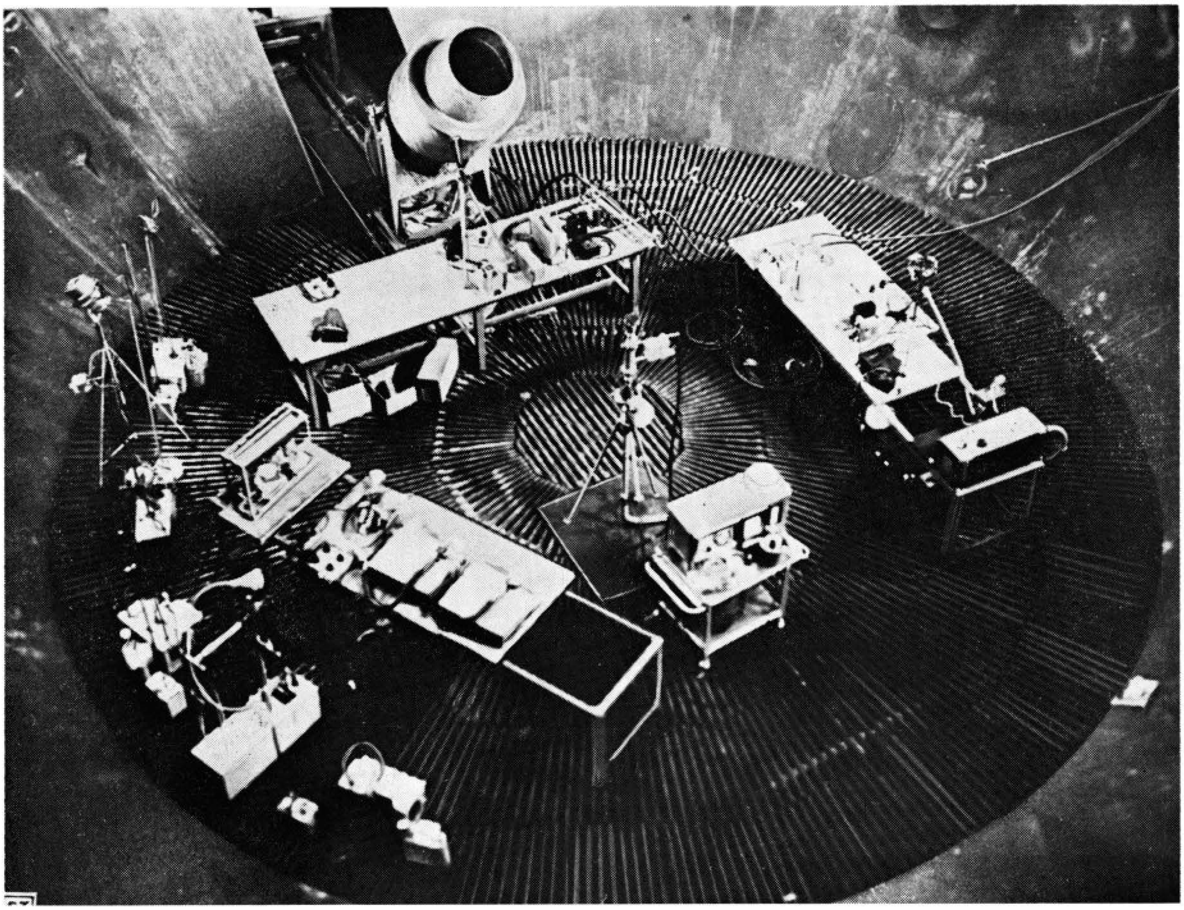


1. Dust deposition in the alveoli and the respiratory tract.

the dust is separated from the air. As the inert and heavy mass of the dust particles flowing into this device can generally not be neglected, the quantity of the dust separated will depend on the speed pattern of the air around the device. This speed pattern, in turn, depends on the characteristics and the geometry of the sampling device. As each self-respecting research institute develops its own measuring equipment with its own characteristics, the results of the measurements of different insti-

A. Steel-production.





2. Arrangement of the dust measuring instruments in the sphere at Le Bouchet (France).

tutes can not be compared without first establishing correlation factors.

3. Investigations

In view of the problems mentioned above, 1961 and 1963 were devoted to investigations aiming at establishing correlation factors between the measuring results of instruments exposed to identical dust concentrations (4).

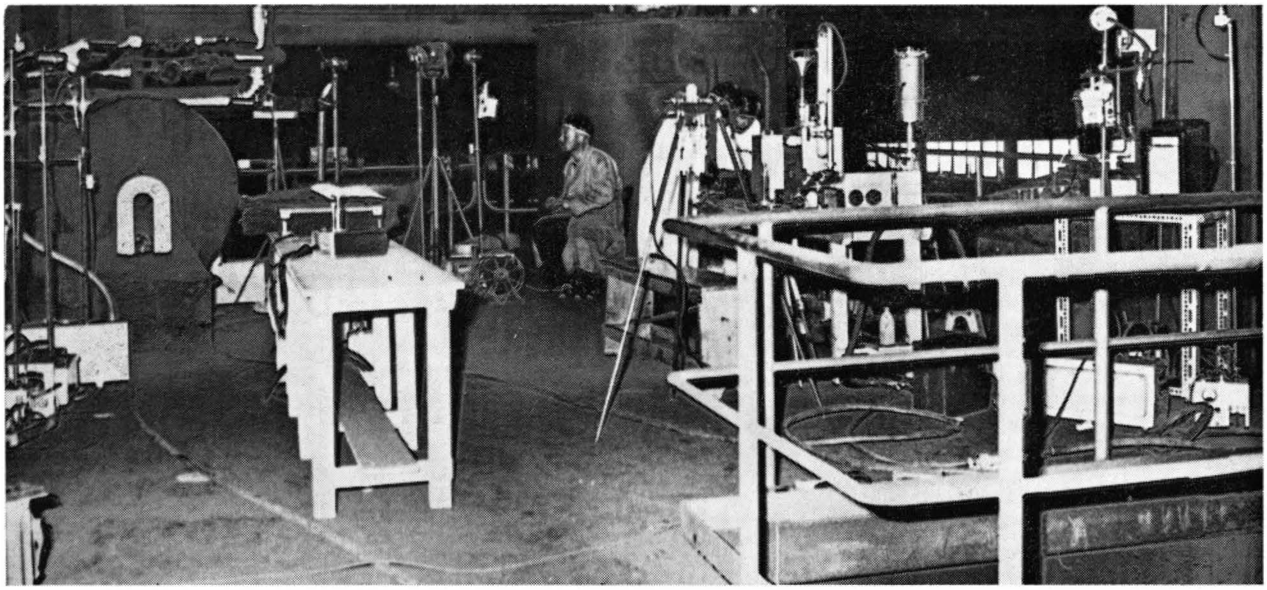
These experiments were carried out in a sphere with a diameter of approximately 15 meters, located at the Institut National de Recherche Chimique (IRCHA), at Le Bouchet near Paris. The dust sampling instruments were installed in this sphere (Fig. 2) and exposed to a homogeneous dust concentration. The comparative investigations were continued under more realistic conditions at Koninklijke Nederlandse Hoogovens en Staalfabrieken N.V. at IJmuiden (Fig. 3a and 3b) and at the Niederrheinische Hütte at Duisburg. Table 1 shows some results of measurements; considerable variations under identical conditions can be noticed.

The instruments compared belong to two categories: those for the determination of the number of particles per cm^3 of air (Table 1 A) and those for the determination of the gravimetrical concentration in mg per m^3 of air (Table 1 B). These two units are not straight forwardly relatable; knowledge of the particle size distribution of the dust is required. Actually, the gravimetrical concentration is mainly determined by the relatively small number of large particles; the numerical concentration, on the other hand, is mainly determined by the many, very light particles. Accordingly, the two units should be considered as mutually independent. However, even with the knowledge of these two data, the dust concentration is not defined satisfactorily. For the occurrence of silicosis, knowledge of the concentration of the particles that reach the alveoli is important.

The determination of the concentration of these particles is desired in order to get an impression of the hazards involved in working at certain locations.

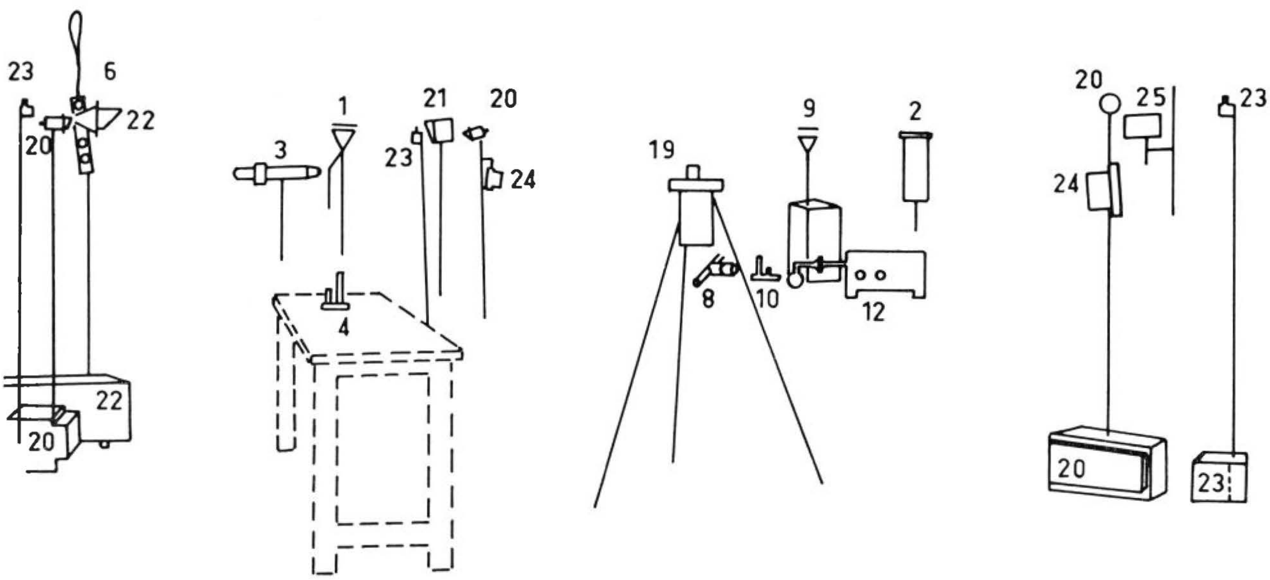
This aspect finds expression in the concept of the maximal acceptable concentration, abbreviation m.a.c.*, for quartz-containing types of dust (5) (In

* M.a.c. values refer to time-weighted concentrations for a 7 or 8 hour working day and 40 hour working week. It is assumed that grown-ups will normally suffer no adverse effects of air pollutants at their working place if the concentrations are kept below the recommended levels. For further details see references (5) and (6).



3a. Comparative investigation of dust instruments under industrial conditions.

1. *Filter device (horizontal type), Staubforschungsinstitut des Hauptverbandes der gewerblichen Berufsgenossenschaften e.v., Bonn.*
2. *Filter device (vertical type), Staubforschungsinstitut, Bonn.*
3. *Hexhlet (dust measuring instrument with elutriator), Staubforschungsinstitut, Bonn.*
4. *Zeiss-Konimeter, Staubforschungsinstitut, Bonn.*
6. *Classifier (dust measuring device separating the dust in classes according to particle size).*
8. *A.R.M. dust measuring instrument, Institut National de Recherche Chimique Appliquée, Paris.*
9. *Filter device, Verein Deutscher Eisenhüttenleute, Düsseldorf.*
10. *Sartorius Konimeter, V.D.Eh., Düsseldorf.*
12. *Dust measuring instrument with pre-impinger, Silikose-Forschungsinstitut der Bergbau-Berufsgenossenschaft, Bochum.*
19. *Thermal precipitator, Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V., IJmuiden.*
20. *Filter device, Instituut voor Gezondheidstechniek TNO (Research Institute for Public Health Engineering TNO), Delft.*
21. *High Volume Air Sampler (Hivas), IG-TNO, Delft.*
22. *Gromoz (filter device of large capacity), IG-TNO, Delft.*
23. *Thermal precipitator, IG-TNO, Delft.*
24. *Long running thermal precipitator, IG-TNO, Delft.*
25. *Optical dust measuring instrument, IG-TNO, Delft.*

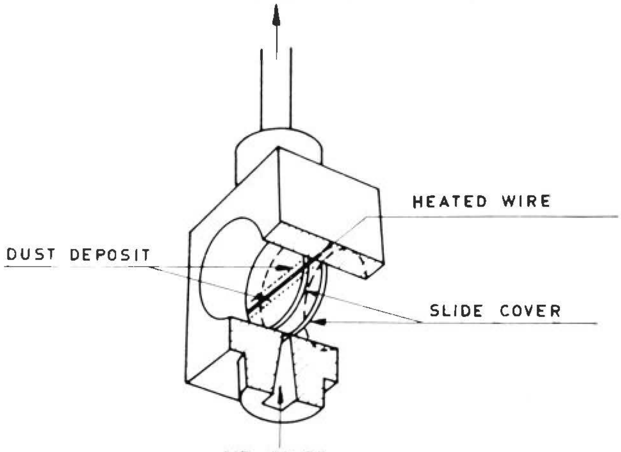


3b. Survey of the instruments at test-site.

the Anglo-Saxon literature often called "threshold limit value - t.l.v." (6).

In various countries, both gravimetrical and numerical m.a.c. values are used, though a shift from numerical to gravimetrical standards can be observed. An important reason for this shift is that the gravimetrical determination is less laborious than the numerical one. This will be explained now.

The gravimetrical dust concentration is determined by sucking air through a filter; the dust present in the air then remains behind in the filter. This dust is isolated and weighed; the quotient of the weight and the volume of air yields the concentration in mg/m^3. Isolation of the "respirable fraction", i.e. the particles smaller than 5 μm, is performed by dispersing the dust in a liquid and separating the smaller particles by Andreasen's pipette method (7). Here the dependence of the sedimentation speed on the particle size is utilized. Another possibility is to separate the respirable fraction already during sampling by a cyclone or an elutriator (11). In the dust fraction < 5 μm, the quartz content is determined by X-ray diffraction analysis or infrared spectroscopy. The numerical concentration is determined by precipitating the dust particles on a medium allowing microscopic investigation. An example of this method is filtration through a membrane filter, which is subsequently made transparent. An instrument frequently used is the thermal precipitator (Fig. 4).



4. Diagram of the sample head of the thermal precipitator.

In this instrument the dust of appr. < 5 μm deposits quantitatively from the air stream onto the glass slides, due to a temperature gradient maintained between a heated wire and the slides.

The dust particles deposited in this way are subsequently counted microscopically.

Table 1 A

Comparison between instruments for the determination of numerical dust concentrations, exposed to identical dust concentrations.

Instrument	Suction speed cm/sec	Magnification	Medium of immersion: Type	Medium of immersion: Refractive index	Number of particles per ml (light field)
Sartorius-Konimeter (Bonn)[1]		370	vaseline	1.44	666
Mercury pump with membrane filter (Milan)[2]	6	250	methyl-cellulose	1.40	525
		400		1.40	914
		600		1.40	953
A.R.M.-apparatus (Paris)[3]	33	300	water	1.33	1040
Thermal precipitator (Delft)[4]	0.1	560	air	1.00	1700

Table 1 B

Comparison between instruments for the determination of gravimetrical dust concentrations, exposed to identical dust concentrations.

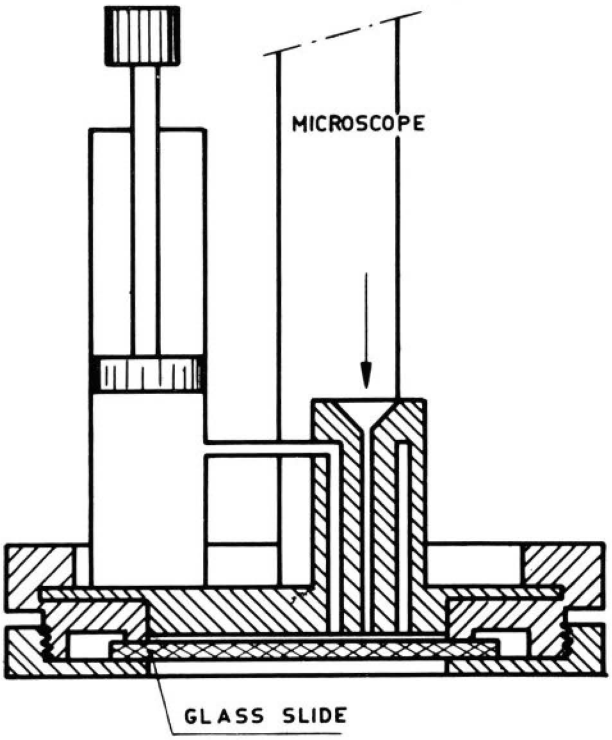
Instrument	Suction speed m/sec	mg dust per m^3 of air
Classifier (Milan)[2]	26.7	4.0
A.R.M.-apparatus (Paris)[3]	0.33	2.0
Gromoz (Delft)[4]	1.24-0.97	1.8

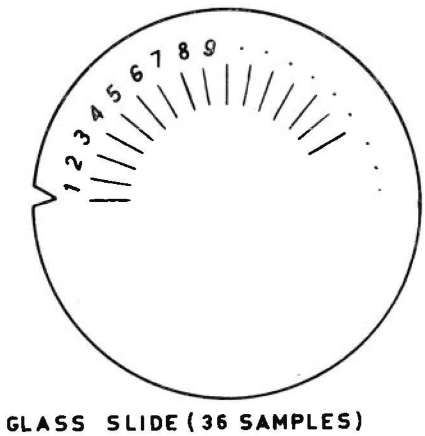
[1]) Staubforschungsinstitut des Hauptverbandes der gewerblichen Berufsgenossenschaften e.v., Bonn.

[2]) Clinica del Lavoro „Luigi Devoto", Milan.

[3]) Institut National de Recherche Chimique Appliquée, Paris.

[4]) Research Institute for Public Health Engineering TNO, Delft.





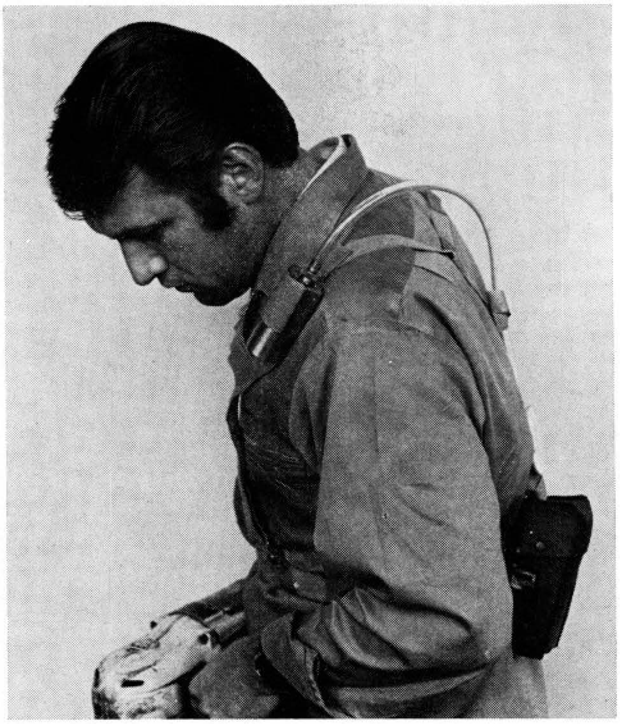
5. Konimeter.

The konimeter (Fig. 5) is an instrument which is often used in Germany. By releasing a spring a small quantity of air is sucked through a nozzle at high speed. Facing the nozzle, a glass slide covered with vaseline collects the dust particles. A simple microscope attached to the instrument is used to count the particles. A disadvantage of these two methods is that the microscopic evaluations is laborious.

Besides the above mentioned stationary instruments, we use personal air samplers (8) in our investigations. These samplers contain a membrane pump, a battery and a filter device, all attached to a system of straps (Fig. 6).

The total weight is less than 1 kg and, generally, the outfit can be worn throughout a working day without causing great inconvenience. The filter device contains a membrane filter support and a cyclone (Fig. 7).

The cyclone simulates the filter characteristics of the human upper respiratory tract (see Figure 1); this means that the filter only collects the respirable dust i.e. the particles with a diameter less than approximately 5 μm. These instruments have already proved their use, especially when they were worn by workers who do not perform their duties at a fixed location or perform dust generating activities, e.g. grinding, polishing and so on. With regard to the latter type of activities we found that the concentration to which the worker was exposed can be between two and five times as high as those measured with a stationary instrument, placed in his immediate environment.



6. Personal air sampler, worn during work.

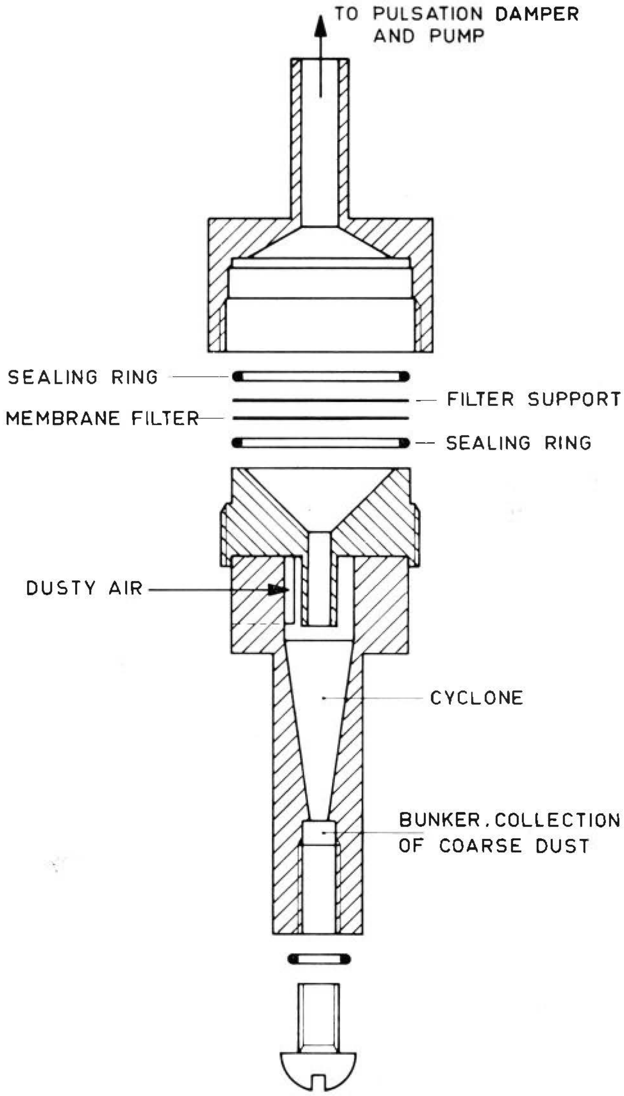
Another development is the use of monitoring instruments. During the fifties instruments were developed that record the light scattered by dust particles.

The parameters influencing the output are, besides the particle size distribution, the refractive index, the colour and the shape of the particles. These

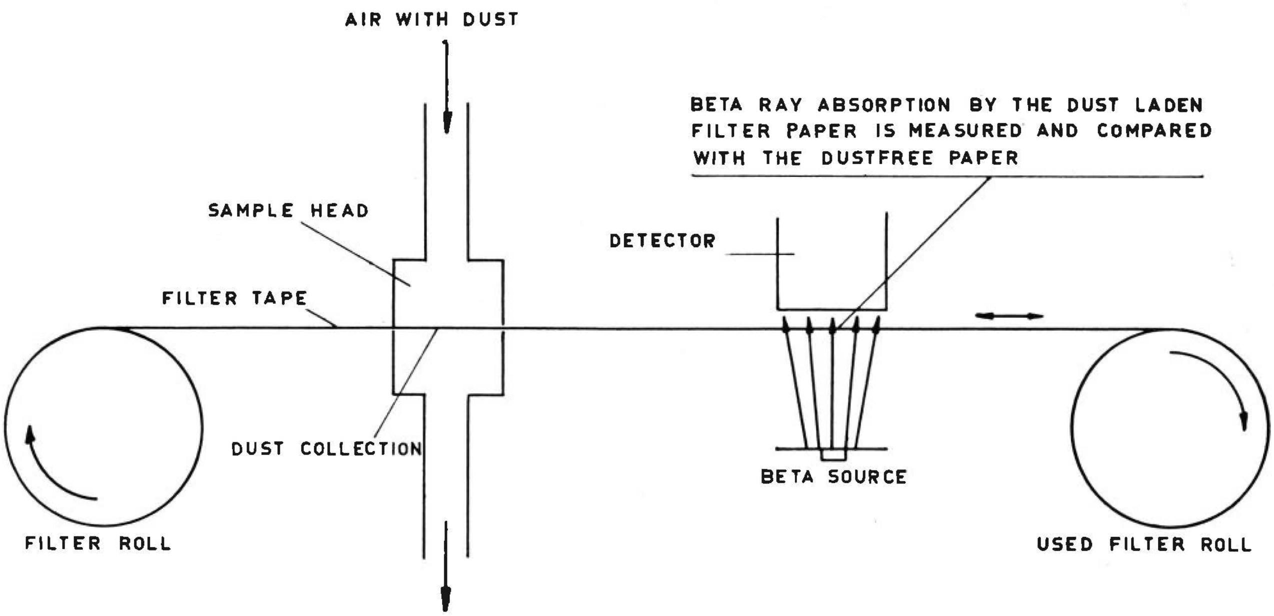
parameters vary during the production process, which complicates the interpretation of the measurement results.
A newer type of instrument is based on the attenuation of beta rays by a dust laden filter (9). The output of such an instrument depends only on the mass of the precipitated dust and is therefore directly related to the gravimetrical concentration. The diagram of a beta dust monitor is shown in Fig. 8.
It registers the fluctuations of the dust concentration. Knowledge of the fluctuations is important when acutely toxic dust occurs. In our project the monitor will in particular be used for the location of dust sources.
The following five institutes participate in the current investigation:

Belgium,	Cebedeau, Liège;
Germany,	Staubforschungsinstitut des Hauptverbandes der gewerblichen Berufsgenossenschaften, Bonn and Bayerisches Landesinstitut für Arbeitsschutz, Munich;
Italy,	Clinica del Lavoro "Luigi Devoto", Milan University;
Netherlands,	Research Institute for Public Health Engineering TNO, Delft.

Teams of these institutes take samples in the iron and steel industry in the respective countries; ten precisely described working places are indicated for this purpose. At each place, the measurements have to be carried out at least four times, twice during the morning shift and twice during the evening shift. The sampling periods should be spread over the seasons. The earlier measurements have shown that the air speed at the filter device



7. *Personal air sampler.*



8. *Principle of the beta dust monitor.*

is an important parameter for the comparability of the gravimetrical concentrations measured. It was, therefore, agreed to standardize the suction speed at 1.25 m/sec ± 20%. The isolation of the fraction < 5 μm is carried out according to a standardized specification with the aid of Andreasen's sedimentation pipette.

The thermal precipitator is used for the determination of the numerical dust concentration. Since the investigations at the Research Institute for Public Health Engineering TNO (10), the long running thermal precipitator may be used too. The precipitated dust is counted microscopically. Comparative investigations have shown that the numerical aperture of the microscope used, the type of field illumination used, the medium of immersion and the magnification have to be standardized. Under standardized conditions counting deviations between institutes can be limited to appr. 20%.

Dust sampled at some working places has to be analyzed on iron, manganese, chromium and fluoride content. In some factory halls, gaseous pollutants, e.g. CO, NO and NO_2, O_3, are measured too. Under prevailing conditions, these determinations yield relatively few difficulties and therefore are not treated further.

The results of the measurements in the various countries will be compared and analyzed. The aim of this analysis is to account for the differences and thus suggest recommendations for improvements. In the second place the workers' health condition will be correlated with the generated pollution levels.

The programme sketched above is scheduled for completion by 1974. As a result of the measurements, some of the iron and steel works have already introduced process changes to reduce the exposition to dust of the operating personnel.

Obviously, a detailed account of the complications inherent to internationally arranged research cannot be given within the scope of this article. Nevertheless, it can be stated that, although investigations of international projects are difficult to co-ordinate and progress is relatively slow, the ultimate effect is — due to the scaling-up effect — so much more important that international collaboration will doubtless be intensified in the future.

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