A Study of Trends in Occupational Risks Associated with Coal Mining

by C. Amoudru

The coal industry is well known as a major source of specific types of risk and harmful effects including, for instance, harm to the environment, pollution from various surface installations and *hazards associated with the actual task of mining.* We shall confine our attention to the third group and discuss only the occupational risks facing miners and ex-miners.

Unlike the nuclear and oil industries, coal-mines employ very large work-forces, and the risks associated with mining therefore have a considerable impact. Mining is also a highly integrated industry: a mine's own work-force carries out all the underground engineering work (preparatory excavations, installation work, etc.) as well as maintenance.

In this narrow field, a distinction should immediately be drawn between two main areas:

- industrial accidents; and
- occupational diseases, which include silicosis or, more precisely, coal-miner's pneumoconiosis.

1. INDUSTRIAL ACCIDENTS

Mining disasters, such as those caused by firedamp and coal-dust explosions, the inrush of water, fire and sudden outbursts (of CO_2 or CH_4) are collective hazards which have been associated with the industry from its very beginnings. They have always caught the imagination, as is shown by the wealth of fiction writing on the subject, particularly from the 19th century. These large-scale accidents very soon led to the systematic introduction of preventive measures on a collective and regulatory basis at a time when other branches of industry were not receiving the same attention.

The first technical safety document to be published in France was the Order of 14 January 1744 which laid down a few rules governing underground working, with particular reference to the use of pit props. However, it was the law of 21 April 1810

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which introduced the concept of mine inspections and personnel protection. A decree was promulgated on 18 November 1810, setting up the "Corps des Ingénieurs des Mines" (Mining Engineer Corps) which covered the whole of the French Empire. This was the first body specifically entrusted with responsibility for occupational safety and health not only in France but also in the former departments of the Napoleonic Empire, such as Belgium.

Worker participation in safety inspections began in 1890 with the introduction of "safety representatives". This was an extremely novel institution at the time since the law granted these representatives complete moral and technical independence by seconding them to the "Corps des Mines" after they had been elected by their fellow workers. An accident prevention campaign was carried out on a small scale but did not succeed in overcoming the new risks which appeared as coal-mines became deeper and more extensive.

Subsequently, safety in the mines gave rise to a considerable amount of scientific and technical research in the course of the last century, which in turn led in the 20th century to the establishment of specialized research institutes such as the "Bergbau-Berufsgenossenschaft" in Bochum, the "CERCHAR" in France, "MAKNII" in the USSR, etc. International co-operation in matters of safety and hygiene has gradually developed since the early days when German rescuers helped to save the victims of the Courrières disaster, and it is now organized on a European scale, particularly via the Mines Safety and Health Commission, with financial assistance from the European Coal and Steel Community (ECSC)[1].

These bodies have created an international community of research workers, which sets an example to other employment sectors, and they have standardized the compilation of statistics on industrial accidents in European mines.

Without going into the details of the numerical data from France and other countries, it can be seen in Table 1 that, although the risks are still there, disasters have become less frequent as knowledge and technology have progressed and the regulations have been up-dated. For instance, checks for firedamp used to be made by a worker carrying a naked flame and later a safety lamp. Nowadays, electronic devices are used and their readings relayed to monitors on the surface which keep a continuous log of the firedamp level at each face. A watch is also maintained on the CO level which gives an early warning of any temperature rise which might develop into a fire.

However, as early as 1838, John Buddle noted that in British mines individual accidents were the main cause of death and especially of non-fatal injuries. Efforts have also been made to prevent these individual accidents, and appreciable results have been achieved, as shown by the Community statistics compiled by the Mines Safety and Health Commission.

For instance, the fatal accident rate per million tonnes mined in Europe dropped from 3.05 in 1958 to 0.69 in 1977 (Fig.1). The number of persons killed underground per day per million tonnes dropped from 3.21 in 1958 to 0.50 in 1979 (Table 1).

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[1] Since the establishment of the ECSC, 30 million European Units of Account have been allocated to research on safety and health in the mines.

Table 1. Number of Persons Killed Underground and Surface (per million tonnes) (1958–79)

	Underground			Underground and surface		
Years	Output (in kt)	Number killed (mine-workers)	Killed (per 10^6 t)	Output (in kt)	Number killed (mine-workers)	Killed (per 10^6 t)
1958	58 405	169	2.89	53 897	189	3.21
1959	58 513	148	2.53	58 723	158	2.69
1960	56 830	92	1.62	57 025	111	1.95
1961	53 314	91	1.71	53 521	111	2.07
1962	53 473	86	1.61	53 721	97	1.81
1963	48 809	68	1.39	49 243	79	1.60
1964	53 864	81	1.50	54 593	96	1.76
1965	52 295	96	1.84	52 988	108	2.04
1966	51 345	88	1.71	51 895	99	1.91
1967	48 796	62	1.27	49 298	89	1.40
1968	43 058	65	1.51	43 536	68	1.56
1969	41 599	60	1.44	42 189	63	1.49
1970	38 092	61	1.60	38 871	66	1.70
1971	33 656	51	1.52	34 590	55	1.59
1972	30 400	21	0.69	31 252	28	0.90
1973	26 346	31	1.18	27 136	39	1.44
1974	23 594	66	2.80	24 500	73	2.98
1975	22 898	13	0.57	23 959	20	0.83
1976	22 037	41	1.86	23 435	45	1.92
1977	21 012	12	0.57	22 566	15	0.66
1978	19 916	12	0.60	21 255	13	0.61
1979	18 807	8	0.43	20 136	10	0.50

In particular, the typical risk of roof falls and cave-ins has been virtually eliminated since the introduction of powered face supports which are now used for 77 per cent of longwall mining production. The risks which remain are not specific to mining, e.g. handling operations, movement of traffic, moving machinery. The main effort to improve upon the results already achieved is directed towards further training of the work-force and routine accident prevention techniques.

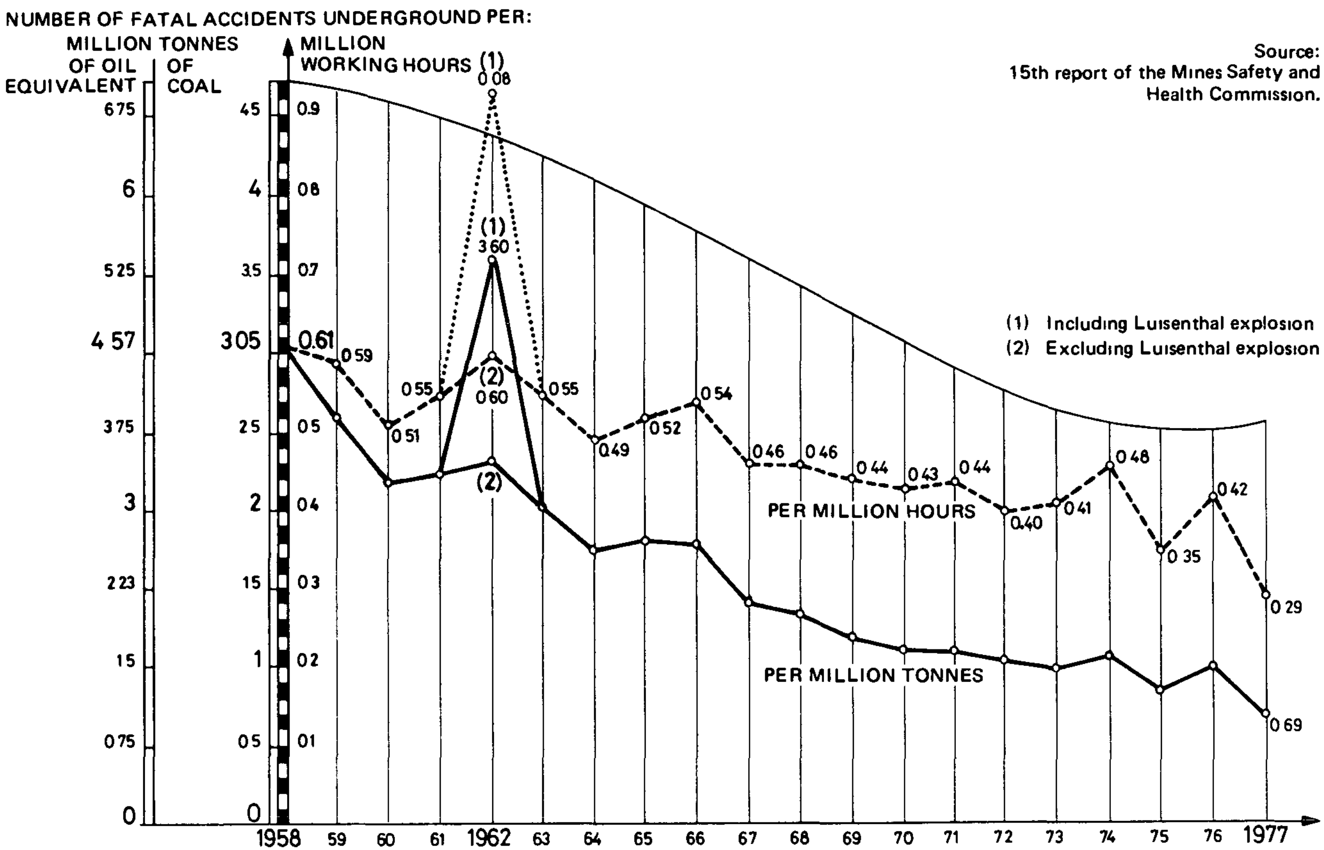

Figure 1. Underground accidents in the six community countries since 1958.

Here again, there has been no lack of scientific work. Ergonomic studies of industrial mining accidents, particularly by the team led by Professor Faverge of Brussels, were among the first (1959–1964) to distinguish clearly between the immediate causes and the remote causes on which the real effort to ensure safety by both technical and organizational means should be concentrated. It was also in mines that the first studies of the "fault-tree" type were performed.

Although the results which have been achieved so far are still not entirely satisfactory, an impressive safety campaign has been carried out which has had a useful spin-off for other industries.

Without dwelling on these aspects which merit further discussion, we would simply point out that the main advances in collective safety have been due to scientific research and a greater mastery of the related technology.

In the early days, the introduction of a new mining technique led to an immediate, and often very sharp, increase in accidents. Nowadays, the idea of built-in accident prevention has caught on and has led to some novel approaches and quite remarkable results. For instance, underground electrification, which could have been a fresh source of hazards, has been introduced without causing any additional accidents. On the contrary, there was a reduction in the number of accidents associated with the previous technologies.

Let us quote a few statistics in order to illustrate this favourable trend.

(a) – Since **fatal accidents** are rather exceptional, it is preferable to study the medium-term trends over as broad a population spectrum as possible, and we have therefore chosen the original six Common Market countries. The number of fatalities per million tonnes has dropped by a factor of four since 1958, and France has one of the best records in this respect.

(b) – **With regard to industrial accidents in general,** the frequency rate is not very meaningful, and the severity rate is subject to a number of social factors. It seems more interesting to calculate the number of pension units generated per year and per employee. This is a cumbersome and complex exercise in data collection, and so we consider only the Northern and Pas-de-Calais coalfields which employed the largest work-force. The number of units per year per employee dropped from 0.36 in 1967 to 0.25 in 1975, i.e. a decrease of 30 per cent in nine years:

	1967	1968	1969	1970	1971	1972	1973	1974	1975
Number of permanent partial disability units per employee	0 35766	0.29852	0.32301	0.28257	0 32699	0.27916	0 27176	0.28407	0.25418

In general, it may be concluded that mining safety was originally focused on the individual factor: in the early days the word "victim" was often another way of saying the "guilty party".

Subsequently, an intense technological effort gradually shifted the emphasis towards the material causes of accidents, and greater attention was paid to factors relating to working conditions. However, as the mining industry grew more sophisticated and more complex, safety came to be analysed in terms of a system in which the reliability of the human operator was again considered, but this time from a scientific and ergonomic viewpoint, as in all advanced industries.

2. OCCUPATIONAL DISEASES

The main occupational diseases affecting miners are of the cumulative type; arthrosis, deafness, pneumoconiosis, etc. Cases of arthrosis tend to be few in number and moderate in intensity. Pneumoconiosis is a particularly serious problem throughout the world's mining industries, and we shall therefore study in detail the present position regarding this disease. However, a clear distinction must be made between (i) the past record; (ii) the present situation; and (iii) the future effects of the preventive measures currently employed.

The past

We do not intend to compare the present situation with the situation as it was during the first decades of the century when silicosis wrought havoc in the mines owing to the widespread, unguarded use of dry drilling. On the contrary, the deaths occurring now and the prevalence of the disease should be considered as the result of what has happened in the past.

Miner's pneumoconiosis does not appear until after a very long exposure to the risk and is generally very slow to develop. The deaths occurring now are, therefore, the result of dust inhalation dating back in most cases as far as the 1930's when there was a complete lack of understanding of this risk. On average, some 900 deaths from miner's pneumoconiosis occur each year.

However, the most important point is that the average age at death was approximately 50 in 1946 but had risen in 1978 to 65.8 for all coalfields, 69.5 for Lorraine and <70 for the Federal Republic of Germany. These quite spectacular figures are, perhaps, the most striking illustration of the profound changes which have occurred in this area of pathology.

Classical silicosis which used to result in rapid death has virtually disappeared (<5% of new cases reported in the coalfields). Mixed-dust pneumoconiosis or cod-miner's pneumoconiosis (M.P.) still occurs, where silica plays only a relative part. M.P. is characterized by much more discrete lesions which are very slow to develop. It occurs very late in working life, the average age being 51.9 in 1978. However, a lung infected by pneumoconiosis is very delicate and susceptible to other diseases, primarily tuberculosis, which until recently were the main cause of early death.

Thirty years ago, about 60 percent of pneumoconiosis patients at some stage developed tubercular complications which in those days were virtually incurable and rapidly fatal, such was the severity of the combined effects of pneumoconiosis and tuberculosis. This type of complication has gradually become less prevalent (0.5 per cent incidence of tuberculosis in pneumoconiosis sufferers), and chemicotherapy can be used to keep it in check in 94 per cent of cases. The annual number of deaths (from all causes) compared with the total number of pneumoconiosis cases is also gradually declining (from 3.32 per cent in 1955 to 1.51 per cent in 1978).

The prevalence of disease

The prevalence of the disease (the number of cases at a given date in a given population) is also directly related to the past. On 31 December 1978, 49 000 pneumoconiosis cases (including both employed and retired persons) had been officially registered for medical and legal purposes, with very considerable variations in the severity rate:

– less than 20% disability:	42.4%
– 20–39% disability:	24.8%
– 40–65% disability:	17.8%
– disability exceeding 66%:	15.0%

There is also a considerable geographical disparity. Eighty per cent of the cases come from the Northern and Pas-de-Calais coalfield, although at its height this field accounted for only slightly more than one half of the total mining work-force. The average age of the pensioners is 58. Eighty-eight per cent of pneumoconiosis cases are pensioners and the prevalence among the work-force in 1978 was 9.3 per cent.

The present

According to our model, the present situation consists of the new cases which are reported. Although changes in detection criteria have been increasingly to the patient's advantage, the incidence, or number of new cases reported each year, has dropped slowly from 2.4 per cent in 1954 to 0.77 per cent in 1977, i.e. a decrease of 66 per cent. This is, indeed, a general trend in Europe since the available statistics show that the incidence in the United Kingdom dropped by 50 per cent between 1960 and 1976, in Germany by more than 30 per cent, etc., although it should be noted that the initial extent of the disease was not the same in all countries.

Experience has shown that new cases are now occurring late in life (51.9 years). They are detected at an early stage in the form of a simple radiological trace with no sign of any real clinical disorder. The patient is regularly X-rayed before the disease takes a hold in order to eliminate the risk and to provide the basis for the official epidemiological statistics[1] which will serve as a guide for the necessary preventive measures.

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[1] See Fig.2 taken from the epidemiological data supplied each year to the "Service des Mines".

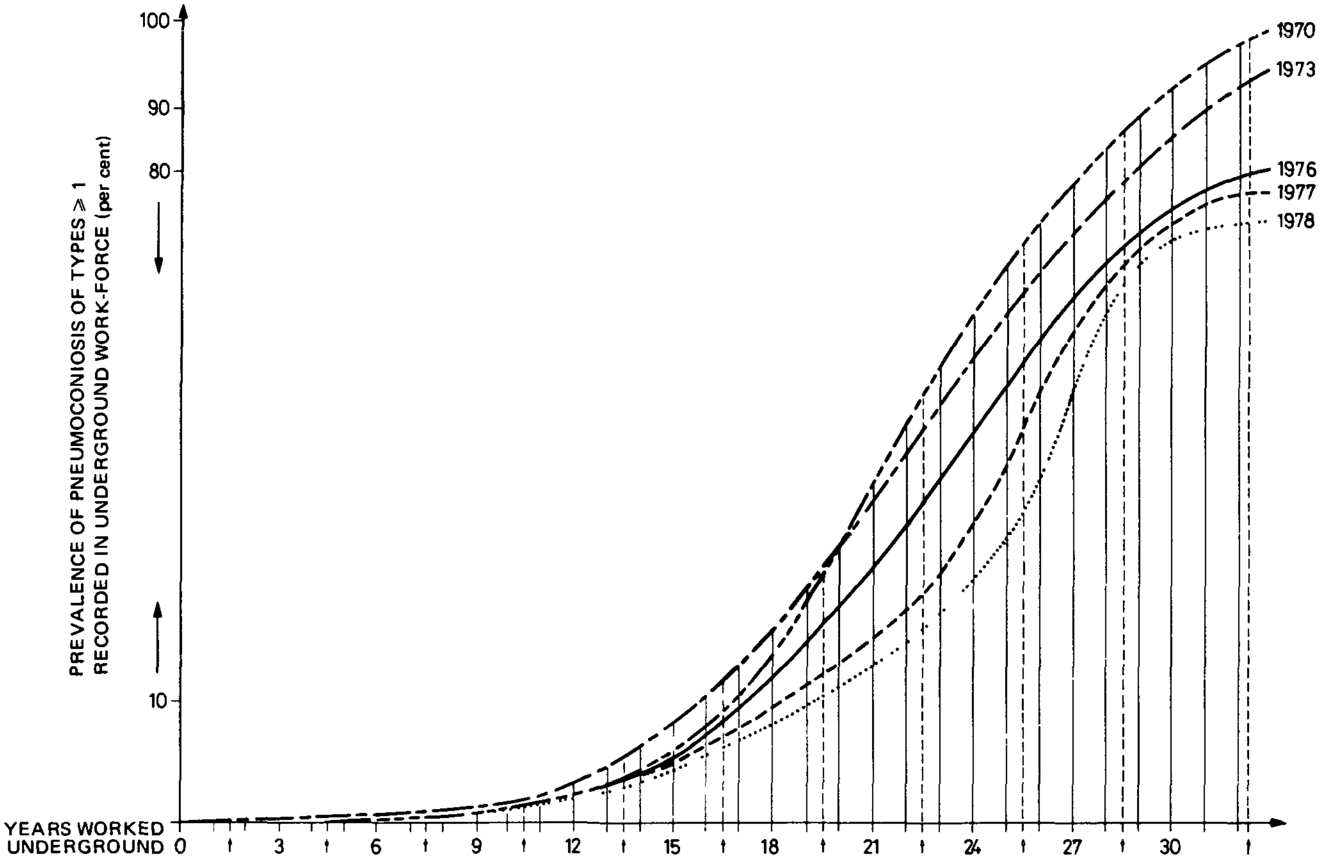

Figure 2. Prevalence of Pneumoconiosis of types ≥ 1 (Northern and Pas-de-Calais coalfields: 1970, 1973, 1976, 1977 and 1978).

Unlike other hazards such as lead poisoning, there is still no treatment against pneumoconiosis lesions which would remove the contaminating agent and "put the clock back to zero"[1]. Nevertheless, rehabilitation at an early stage can slow down or even prevent the further deterioration of the patient's condition.

Since the prevalence of the disease remains high even though the incidence has been shown to be falling, this is a mathematical proof that the course of the disease (or the life expectancy of the patient) is becoming longer.

In conclusion, the results may be broken down into two main groups:

(a) the tubercular complications which were the main cause of early death can now be successfully treated as a matter of routine;

(b) preventive measures have reduced the incidence and severity of the disease and have increased the average age of onset.

However, the reduction in risk over the past 25 years has gradually revealed various other problems which had hitherto remained concealed. For a long time, silicosis alone was enough to cause illness and death. Then, tuberculosis was soon recognized as an exceptionally serious co-factor. Once these two factors had been brought more or less under control, the harmful, delayed-action effects of coal-dust, which could not be known during the period of acute silicosis, came to light.

As progress has been made in the fight against coal-dust (for instance, in the Northern and Pas-de-Calais coalfields, which used to be the most hazardous area, the number of particles per cm^3 has dropped from 25 000 to 1450 in 1979), the individual predisposing factors (e.g. region having an immunizing effect) which hitherto played a negligible part are taking on some importance in the residual stages of the disease. As the patients live longer, they become subject to various additional chronic conditions such as chronic bronchitis. Lastly, at this stage in the development of the risk, the social and economic situation can affect the data, as with all syndromes involving chronic respiratory insufficiency.

From the assumption that SiO_2 causes the rapid development of silicosis, we have moved into the realm of multicausality and chronicity which is of general significance from the point of view of occupational pathology. In particular, multicausality has led to a different approach to prevention and to the determination of permissible concentrations. It is rather easy to set a maximum permissible concentration (mpc) value for a pure toxic agent acting in isolation.

However, airborne dust in mines is a very complex mixture of coal and nearly 25 types of mineral including silica, clays, mica etc., which vary in combination from one coalfield to another. Some of these minerals have a synergic effect on pulmonary fibrogenesis, whereas others have an antagonistic effect (even though they may themselves be harmful). There are too many factors involved to predict the harmfulness of the mixture from that of each

[1] Etio-pathogenic therapy tests are under way; even though the first results are encouraging, it is highly improbable that one day a chemoprophylactic treatment will be found for pneumoconiosis

Table 2. Incidence of Pneumoconiosis Cases Giving Rise to Compensation in 1978

Coalfield in France		Incidence among the Work-Force (%)	
Northern and Pas-de-Calais		1.14	
Lorraine		0.36	
Central and Southern		0.62	
Central-Southern	Aquitaine		0.22
	Auvergne		0.05
	Blanzy		0.66
	Cévennes		0.65
	Dauphiné		0.87
	Loire		1.31
	Provence		0.00
Total French coal industry		0.77	

of its constituent parts (assuming that each is known). The complexity of the airborne dust mixtures in mines explains why the harmful effects caused by dust vary from one coalfield to another, as is illustrated by comparing the data on incidence in the various French coalfields (Table 2).

The same variations occur in the Federal Republic of Germany, the United Kingdom and the United States, and they cannot be explained by differences in the weight of the dust or its silica content. Other constituents or factors must therefore come into play. All the major institutes are running extensive programmes of research into these variations, but until they have been identified and quantified, a reliable determination cannot be made of an mpc value which is expressed solely in terms of weight and silica content and which is applicable to all coal-mines. Our epidemiological statistics show that the permissible concentration varies from coalfield to coalfield, possibly as a function of several types of factor (dust concentration, specific harmful effects of the dust, working conditions and length of exposure, ecosystem, individual factors).

However, in order to limit research and speed up preventive action, we have had to assume that the co-factors associated with the ecosystem are a parameter over which we have no immediate influence. The weight of dust inhaled per m^3 of air is regarded as a "black box" whose overall harmfulness is measured independently of its constituent parts. By means of appropriate mathematical calculations and by following the corresponding variations[1] in dust content and endemic disease patterns in the same coal-mine or coalfield, the permissible values P_0[2] for each mine or field can be determined. This was the method adopted in the regulations ("DM/H") issued in 1975 concerning the medical prevention of cod-miner's pneumoconiosis, and it seems to be an original approach to the hazards caused by mixed combination of factors.

The future

The incidence rates are remarkably low, if not zero, in the coalfields offering the best prospects for the future: 0.36 per cent in Lorraine and zero in Provence. Although these rates are low, they reflect the working conditions of the past. We must now seek to predict the fate of a miner working underground in a mine where present-day safety standards apply. Such predictions, which are linked by definition with the calculation of mpc values, have been made in the Federal Republic of Germany, the United Kingdom, Belgium and France on the basis of epidemiological surveys. The results are given in various ECSC publications by Reisner, Jacobsen, Degueldre, Ganier, etc. It can be said that, if the exposure values are observed, the probability of occurrence of an ILO (International Labour Organization) type 2 pneumoconiosis (i.e. a non-disabling pneumoconiosis) at the end of a miner's working life will be less than 5 per cent (e.g. in the United Kingdom the risk is less than 3.4 per cent for a working life of 35 years).

Furthermore, over the next 30–35 years, further progress is very likely to be made in the field of preventive techniques and even medicine. However, it is equally true to say that any relaxation of preventive measures would very soon have the opposite effect.

Once again, it should be stressed that these advances are not only due to joint action by the engineering and medical professions but are also the result of an immense research effort which originated with the work done in South Africa around 1910 and which was followed up by substantial contributions from the United Kingdom and then from the other major coal-producing countries. The ECSC co-ordinated this research effort and has been a major source of funds for research workers both from the universities and from the coal industry itself and its associated institutes; 14.4 million European Units of Account have been allocated to research into "chronic respiratory conditions" since 1955.

Some of this high-level research, particularly with regard to pulmonary physiopathology, has applications in other branches of occupational pneumology. The epidemiological models have been used in other fields of cumulative pathology. It should not be forgotten that pneumoconiosis is not exclusive to the mining industry and that many other industries have benefited directly from the studies and research carried out by the coal-producers in this field.

In conclusion, as was clearly stressed by Bertin in a recent paper published in the "Concours Médical", the present medical and legal position regarding mining pathology, e.g. the number of pensions paid to pneumoconiosis patients, is essentially a reflection of the past.

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[1] See Figure 2.

[2] Expressed in mg/m^3 for a free silica content of more than 7 per cent

RESPECTIVE RISKS OF DIFFERENT ENERGY SOURCES

In order to make an objective comparison with the health hazards from other sources of energy, the probable risks facing workers in a modern mine should be compared with those currently confronting workers in other industries. Although the overall relationship between the risks from the various sources of energy may not necessarily change, the margin between the risks will be appreciably narrowed.

In this article we have discussed only the risks associated with underground mining. However, coal deposits can also be worked from the surface, and this method of extraction has developed considerably: in the United States 60 per cent of coal produced in 1979 was extracted from open-cast mines. The risk of pneumoconiosis is virtually nil in these mines, and the small work-forces lessen the risk of industrial accidents. Moreover, we shall not go into the more remote hypotheses regarding underground gasification. As was done by Belhoste, a clear distinction should be drawn between the risks associated with underground mines and those associated with other types of mine when devising systems for comparing the implications of the various energy cycles.