

JOURNAL OF THE MINE VENTILATION SOCIETY OF SOUTH AFRICA

Published monthly by the Mine Ventilation Society of South Africa.

Secretaries — ASSOCIATED SCIENTIFIC AND TECHNICAL SOCIETIES OF SOUTH AFRICA, KELVIN HOUSE,
2 HOLLARD STREET, JOHANNESBURG. TELEPHONE 834-1271 P.O. BOX 61019 MARSHALLTOWN, TVL

<i>President</i>	— M. J. MARTINSON
<i>Hon. Editor</i>	— M. J. HOWES
<i>Hon. Assistant Editors</i>	— A. D. UNSTED and W. HOLDING
<i>Hon. Treasurer</i>	— C. W. CAREW

Contributions are welcome from members and non-members.

*The attention of authors is drawn to the Guide to Authors, conventional signs and abbreviations
which appear in the Journal from time to time.*

The opinions expressed by contributors do not necessarily represent the official views of the Society.

VOLUME 29 No. 2

FEBRUARY, 1976

PRICE R1,25

PRESIDENTIAL ADDRESS OCCUPATIONAL HEALTH AND SAFETY IN UNDERGROUND MINES (conclusion)

2.5 Alpha Radiation in US Uranium Mines

From 1898 to the end of the 'forties the Colorado Plateau (a mountainous region embracing parts of Colorado, Utah, Arizona and New Mexico) was the principal source in the United States of carnotite (i.e. uranium-vanadium) ores used mainly in the glass, ceramics and pigments industries, for steelmaking, and for the extraction of radium. Most of the mines were very small, and in 1962 Archer *et al* (73) estimated that the total number of men employed in the industry in 1945 was 350 miners and 600 millworkers. The figures for 1950 were 550 and 800 respectively.

Meanwhile the US Atomic Energy Commission (USAEC) had been established in terms of the Atomic Energy Act of 1946, and in 1948 the Commission offered to buy uranium oxide at attractive prices for military and civilian nuclear projects. As a result mining operations on the Colorado Plateau expanded rapidly and deposits in South Dakota, Wyoming and Washington also began to be exploited. Archer *et al* record that 2 157 miners worked in the industry in 1955 and 5 760 in 1960, but in 1961 the USAEC experienced an over-supply of uranium oxide and began to 'stretch' supply contracts, with the result that employment declined as can be seen from the figures published by the Federal Radiation Council (FRC) in 1967

The large number of mines in relation to the number of miners was partly due to the high proportion of very small mines (in 1963 about 60% of the mines employed 15 men or less, 27% employed 16 to 50 men, and 13% employed more than 50 men (74)), and partly because operations tended to be spasmodic and mines were apparently included in the count if ore was produced at any stage during the calendar year in question; a mine might moreover change from open pit in one year to underground in the next — and *vice versa* — depending on the circumstances. In 1966 a total of 621 mines produced ore but the average number in operation at any one time probably did not exceed 400; roughly one-third of the total production was derived from open pit workings. These conditions undoubtedly contributed to the unusually high labour turnover in the industry, and made the task of measuring radiation exposure far more difficult than might otherwise have been the case.

**NUMBERS OF US URANIUM PRODUCERS AND MINERS AT WORK:
1954-66**

Year	UNDERGROUND		OPEN PIT	
	Mines	Miners (a)	Mines	Miners
1954	450	916	50	53
1955	600	1 376	75	293
1956	700	1 770	100	584
1957	850	2 430	125	574
1958	850	2 796	200	1 175
1959	801	3 996	165	1 259
1960	703	4 908	166	1 499
1961	497	4 182	122	1 047
1962	545	4 174	139	1 074
1963	573	3 510	162	886
1964	471	3 249	106	726
1965	562	2 900	74	700
1966	533	2 545	88	359

Note:

- (a) Excludes employees who might go underground occasionally.
 (b) Data are estimates given in tables 1 and 2 of reference (74).

In 1965 New Mexico, Wyoming, Colorado and Utah produced a total of about 4 million tons of uranium ore (about 90% of the total US production) containing approximately 0,23% U_3O_8 and valued at about \$150 million. In the same year the four States produced 43 million tons of copper, lead and zinc ore with a recoverable value of about \$295 million.

In situ uranium ores contain, in addition to uranium, a full suite of disintegration products derived from each of the parent uranium isotopes. In the present context the decay series from uranium 238 to stable lead 206 is of paramount interest, and within this series the short-lived alpha energy emitters descended from radon (i.e. the so-called radon daughters*) represented the principal radiation hazard in mines. Radon, an inert gas, diffuses into the mine atmosphere from the shell of rock surrounding excavations and from broken material, and after its escape continues to decay in the mine atmosphere. All the daughter products are particulates but rapidly become attached to larger aerosols normally present in the mine atmosphere by diffusion and turbulent mixing.

Radon inhaled with mine air may decay before being exhaled but the radiation dose received in this way is likely to be less than 5% of the alpha energy theoretically available. When air containing aerosols with attached daughter products is inhaled, however, a relatively high proportion of the aerosols present are deposited either in the bronchial tree or in the alveolar region of the lungs. When the radon daughters undergo further decay adjoining tissue is irradiated by the alpha particles emitted during the decay process.

* Part of uranium 238 – lead 206 decay series adapted from reference (74)

Isotope	Historical Name	Half-Life	Radiation	Alpha energy MeV
Radon 222	Radon	3,82 days	α	5,49
Polonium 218	Radium A	3,05 min	α	6,00
Lead 214	Radium B	26,8 min	$\beta\gamma$	
Bismuth 214	Radium C	19,7 min	$\beta\gamma$	
Polonium 214	Radium C	1,64.10 ⁻⁴ s	α	7,69
Lead 210	Radium D	22,0 years	$\beta\gamma$	

The health hazard associated with the inhalation of airborne radionuclides received fairly widespread attention in the first half of the twentieth century, but the plight of miners working high-grade uranium deposits on the Colorado Plateau seems to have escaped notice right until the end of the period. Even in 1944 Lorenz (75) of the US National Cancer Institute, in his well-known review of the relationship between occupational exposure to radioactivity and lung cancer in Schneeberg (Saxony) and Joachimsthal (Bohemia) uranium miners, makes no reference to the possibility of a similar hazard in American mines, although measurements in US uranium mines a few years later were to show that radioactivity levels were comparable with levels recorded in Schneeberg and Joachimsthal mines. Moreover, as far as can be ascertained the American authorities among the 57 references quoted by Lorenz do not refer to radioactivity in US mines.

The lung cancer hazard in American mines seems to have been officially recognized for the first time in 1949, when the US Public Health Service (USPHS) embarked upon a study of the hazard. It is not clear how the inquiry was originally initiated — whether by the USPHS in its role as guardian of the nations' health, State public health authorities, representative bodies in the mining industry, or the USAEC in its role (from 1948) as the principal buyer of uranium oxide — but in any event the inquiry was destined to develop into one of the classic epidemiological studies in the history of occupational diseases. Throughout the study (it is still being updated at the present time) the USPHS has very commendably followed a policy of full publication of results, so that there is today an extensive literature on the mine air sampling programme, the pathological studies, and the biostatistical aspects of the investigation. In 1971 the USPHS published a comprehensive monograph by Lundin *et al* (76) containing an excellent summary of the epidemiological studies, and in November 1974 published a review by Holaday (77) on the evaluation and control of radon daughters in uranium mines.

In 1950 few, if any, of the uranium mines on the Colorado Plateau were systematically ventilated and consequently many miners were exposed to high radon daughter concentrations underground; a survey of 157 mines in 1952, for instance, showed that 44.9% of the miners sampled were working in radon daughter concentrations of 10 working levels* (WL) or above. In the period 1950-67 gradual improvements were effected as a result of pressure exerted by the USPHS, the US Bureau of Mines and State authorities, but even by mid-1967 about 1.5% of the miners sampled in 119 mines were still exposed to full-shift concentrations equivalent to 10 WL or above (77). The adjoining table shows how radiation exposure increased the incidence of respiratory cancer among White uranium miners in the period October 1960-September 1968 —

**RESPIRATORY CANCER DEATHS AMONG US URANIUM MINERS (a):
OCTOBER, 1960 — SEPTEMBER 1968**

Estimated cumulative WLM (b)	Person-years at risk of dying	Respiratory cancer deaths		
		Expected — no adjustment for nonmetropolitan residency (c)	Expected with adjustment for nonmetropolitan residency (c)	Observed
Less than 120	3 466	1.78	1.54	4
120-359	3 788	1.84	1.60	11 (d)
360-839	4 134	2.24	1.94	11 (e)
840-1 799	3 106	1.83	1.57	12 (d)
1 800-3 719	1 858	1.04	0.91	17 (d)
3 720 and over	528	0.31	0.27	8 (d)
Total	16 878	9.04	7.83	63 (d)

* Paragraph (a) of 41 CFR 50-204.36 defines a 'working level' (WL) as —
Any concentration of radon daughters in 1 liter of air which will result in the ultimate emission of 1.3×10^3 million electron volts (MeV) of potential alpha energy. The numerical value of the 'working level' is derived from the alpha energy released by the total decay of short-lived radon daughter products in equilibrium with 100 pico-curies of radon 222 per liter of air. A working level month (WLM) is defined as the exposure received by a worker breathing air at one working level concentration of $4 \frac{1}{3}$ weeks of 40 hours each.

Note:

- (a) Relates to White underground miners aged 35 years and older in study group of 3 366 White miners with one or more months of underground uranium employment prior to 1 January, 1964.
- (b) WLM estimated to month at risk of dying; no non-uranium hard rock mining exposure included in estimated cumulative WLM.
- (c) At four-state (Arizona, Colorado, New Mexico, Utah) male rate; over 90% of the person-years at risk were experienced in the four-state area.
- (d) Significantly different at 1% level from adjoining figure.
- (e) Significantly different at 5% level from adjoining figure.
- (f) Adapted from table 13 in reference (76).

In the period 1950-66 attempts were made to introduce standards to limit occupational exposure to radon daughters in mines, but these were either unsuccessful or ineffectual. However on 4 May 1967 the FRC eventually met to consider proposed radiation standards for US uranium mines, but could not agree on the standard to be recommended to the President. One standard would have limited exposure to not more than 6 WLM in any consecutive 3-month period and not more than 12 WLM in any consecutive 12-month period, and called for mine air sampling and the maintenance of occupational records in respect of each mineworker to enable the standard to be implemented. The alternative (and more onerous) proposal called for a 0,3 WL standard. The day after the FRC impasse the Secretary of Labor published details of a proposed 0,3 WL standard which would, in terms of the Public Contracts (Walsh-Healey) Act of 1936, apply to all mines fulfilling Federal (notably USAEC) contracts; only four days later, however, the radiation subcommittee of the joint (House and Senate) committee on atomic energy began its long — and occasionally acrimonious — hearings on radiation exposure of US uranium miners. After sitting for eleven days the hearings finally terminated on 10 August 1967; the foreword to the published record of the hearings (78) justifiably asserts that the record 'constitutes the most comprehensive collection of information ever amassed concerning the exposure of human beings to radiation incident to the mining of uranium'.

While the hearings were still in progress the Secretary of Labor on 9 June signed revised regulations* regarding radiation standards for uranium mining. The revised regulation incorporated the 0,3 WL standard in the form of a 3,6 WLM (in 12 months) standard, but with provision for a 12 WLM standard for an 18-month transitional period (see pp 587-92 of reference (78)). In July, still during the hearings, the FRC met again and on this occasion agreed to recommend to the President (in a memorandum dated 21 July) that the more lenient standard noted earlier should be promulgated with an injunction that lower levels be maintained as far as practicable, and incorporating a proviso that the standard would be reviewed in a year's time. In this form the standard was approved by President Johnson on 27 July and published in the Federal Register on 1 August 1967 (see pp 595-7 in reference (78)).

A year later the Secretary of Labor announced (in the Federal Register of 20 September 1968) that labor department hearings would be held with a view to amending the existing regulation to provide for a 4 WLM (in 12 months) standard. The new standard was duly promulgated by the secretary on 24 December 1968 to take effect on 1 January 1969, but the amended standard provided for variation of the standard with the consent of the Director of the Bureau of Labor Standards in Mines where exposures were below 12 WLM and *bona fide* efforts were being made to reduce exposures to 4 WLM by 1 January 1971 (see pp 175-6 in reference (79)). Meanwhile in a memorandum to the President dated 27 December 1968 the FRC recommended that the 12 WLM (in 12 months) standard be maintained for another year, but 'as a policy of prudence' a standard of 4 WLM (in 12 months) should be introduced with effect from 1 January 1971. This recommendation was approved by President Nixon on 11 January 1969 (see pp 176-8 of reference (79)), but on 15 December 1970 the President approved a FRC recommendation to the effect that the introduction of the new standard should be deferred from 1 January 1971 to 1 July 1971 (80).

In March 1969 the radiation subcommittee of the joint committee on atomic energy held further hearings on radiation standards for uranium mining (79), during which the standards enacted by the FRC

* 41 CFR 50-204.321

and the Secretary of Labor since the last hearings, and the evidence upon which they were based, were again subjected to detailed, but ultimately inconclusive, inquiry. The fundamental problem facing the subcommittee and the host of expert witnesses called to testify before it was that the information available on the dose-response relationship at low working levels was simply inadequate to formulate rational standards. However, as the special committee of the National Academy of Sciences appointed at the request of the FRC had earlier said in its conclusions (see pp 187-221 reference (79)) —

7.8 Recognizing the unreliability of present data on uranium miners, but accepting them at face value with a realization that decisions must be taken before completely adequate scientific evidence is available, the committee draws the following conclusions:

- (a) There appears to be a causal association between lung cancer and exposures of approximately 1 000 CWLM and higher.
- (b) There is a statistically significant increase in the lung cancer risk for miners with approximately 100 to 400 CWLM exposure that cannot be explained by any known artifact of the data.
- (c) The hypothesis is favoured, pending more definitive data, that radiation exposure at least contributed to the excess lung cancer observed in the miners in the 100 to 400 CWLM category.

The alpha radiation hazard in US uranium mines has passed through three distinct phases since mining of uranium-rich ores first began in 1898. There was, firstly, the period of almost exactly half a century during which no thought was apparently given to the hazard even though it had been experienced and recognized in another mining field. Secondly, there was a period of awakening of about 17 years during which a small group of dedicated workers gradually accumulated, in the face of considerable physical and financial difficulties, sufficient evidence to formulate a meaningful dose-response relationship, and during which improvements were slowly effected by continued exhortation. Finally there is the post-1966 era in which the hazard has been subjected to searching public inquiry at Congressional hearings and by a variety of national institutions; during this latter era the hazard has also been the subject of an unprecedented spate of regulatory standards. The depth and intensity of the inquiries, and the speed with which remedial regulations were promulgated once the hazard received political recognition, are probably uniquely American.

Although American miners are now protected by radiation standards which hopefully ensure that they will not be exposed to any appreciable risk of work-related respiratory cancer during a typical working lifetime in underground mining, it remains to be noted that some mineworkers who contracted respiratory cancer — or their dependants — found that they were simultaneously ineligible for statutory workmen's compensation benefits and barred from pursuing the common law remedy in tort.

Statutory workmen's compensation has until very recently been essentially a State (as opposed to Federal) function in the USA, the only exceptions prior to 1970 being Federal government employees and a limited number of inter-State workers. Historically there have been major differences between the constitution, operation and benefits payable by the 58 State and Federal workmen's compensation schemes in the United States — a national commission recently recommended greater uniformity, increased coverage, and improved benefits (81) — but in the 'fifties and 'sixties probably a majority of uranium miners with respiratory cancer were ineligible for benefits either because the State scheme in question did not recognize work-related cancer as an 'accident', or because claimants could not prove to the satisfaction of the local scheme that the disease was work-related. Other claims were denied on technical grounds such as the statute of limitations (i.e. prescription), the exclusion from State schemes of concerns employing limited numbers of workers, multi-State uranium mining service, and the ephemeral character of many of the smaller mining companies. In 1968 bills were introduced in the Congress to authorize the Secretary of Labor to provide supplemental compensation for permanent total disability or death from lung cancer resulting from exposure to ionizing radiation in uranium mines, and to provide grants to States for research and planning with respect to ionizing radiation in uranium mines. The bills were the subject of sympathetic hearings before the labor subcommittee of the House Committee on Education and Labor (82), but were effectively resisted by some States as constituting further infringement of their autonomy and by vested interests in the insurance business. A year later similar objections to Federal black lung compensation in terms of the Federal Coal Mine Health and

Safety Act of 1969 were swept aside by the political forces arraigned on the side of the US coal miner, but the generosity of the treatment accorded to the disabled coal miner and his dependants emphasises the unfortunate lot of the disabled uranium miner and his dependents.

3. DESIGN CRITERIA FOR MINE VENTILATION

3.1 Mine Ventilation

The field embraced by the rubric 'mine ventilation' is more flexible, and the penumbral areas wider, than is generally the case with engineering topics, but in general terms mine ventilation can be described as 'the branch of mining engineering concerned with the controlled coursing of air through ramified mine workings to maintain acceptable atmospheric environments wherever men work or travel underground, with the assistance if necessary of some form of air conditioning'. Air ventilating mines may also be used for other essential purposes — as a heat sink, for example, in relation to mechanical and electrical equipment — but however important these ancillary functions may be locally they are not considered here.

Three discrete elements or functions may be identified in the definition quoted above. *Firstly* one can identify an engineering element which includes monitoring the atmospheric environment, the flow of air through airways and working places (including the controlled distribution of air throughout the workings based on quality considerations), and the conditioning of air wherever requisite atmospheric standards cannot physically or economically be attained by air circulation alone. *Secondly* the definition incorporates a biological element in that the rational assessment of atmospheric environments presupposes an understanding of the total biological response (physiological, pathological and psychological) of men exposed to the full range of atmospheric conditions experienced in mines. *Thirdly* the concept of an acceptable atmospheric environment introduces a philosophical element in the sense that value judgements must be applied to determine what risk of injury, or degree of discomfort, can be construed as being socially acceptable.

Paradoxically, for over a century the principal exponents of mine ventilation have concentrated their efforts almost exclusively on the engineering element, but whether this has been due to the intrinsic appeal of engineering, ignorance or distrust of biology and philosophy, or failure to recognize that the three elements are inseparable, is not clear. When Atkinson (5) in 1854 published his seminal paper on 'the theory of the ventilation of mines' he could perhaps be excused for concentrating exclusively upon airflow phenomena, but even in 1854 there is something vaguely disturbing about an extremely capable engineer calculating friction factors, flows and splits to four or five significant figures without attempting to relate flowrates to the risk of firedamp explosions which the forced circulation of air was intended to abate*. The situation is perhaps analogous to Telford or Brunel designing a bridge without considering traffic loads.

Many competent engineers have written on mine ventilation since Atkinson, but even if in recent years biological factors have received some attention — notably as regards occupational heat stress and strain in mines — the question of risk as a design criterion has to all intents and purposes been ignored. This is anomalous, because without correlating risk and air flowrate the selection of flowrates for design purposes must be based on intuitive or arbitrary criteria. Intuition plays an important role in engineering design, but if it is merely used as a soft option for rational analysis it degenerates into arbitrariness.

Mining is generally acknowledged to be an inherently hazardous occupation (83) (84) (85), and under the circumstances it is surprising that risk in the context of personal injury has received so little attention in mining literature. Ventilation apart, risk analysis is fundamental to the rational control of occupational accidents and diseases in mines, and should of course form the basis for statutory standards and factors of safety.

* Boydell (16) reports the following fatal injuries from firedamp explosions alone in British coal mines in the period 1851-80 —

1851-60: 1 271 deaths

1861-70: 1 444 deaths

1871-80: 2 014 deaths.

3.2 Current mine ventilation design practice

Flowrate specification is of paramount importance in mine ventilation design since the sizes of fans, the economic sizes of airways, and the mechanics of distribution and conditioning are all dependent upon flowrate. However anyone who has participated in ventilation design knows how difficult it is to specify rational flowrates, and may have experienced the frustration of seeking guidance in the ventilation literature.

The older textbooks (e.g. Beard, Briggs, Moss, Motram, Penman and Penman, Weeks, etc.) to all intents and purposes ignore flowrate specification altogether, and even the more recent books do not deal with the subject adequately. Thus Hartman (86) (USA) in an introduction stresses the need for control of the total atmospheric environment in mines, but in dealing with individual atmospheric hazards does not suggest how this control should be related to flowrate. In Roberts' textbook on mine ventilation (Britain) Pursall (87), in a chapter on estimating air quantity in ventilation planning, notes that the air quantity should be 'estimated as accurately as possible'; he analyses methane emission rates in British coal mines and suggests an empirical formula for determining air flowrate as a function of methane emission rate and output, but the source of the formula is not given, nor is there anything to suggest that it is based on risk analysis. In a chapter on the thermal environment Williams (88) observes that 'The British miner will not accept very hot and humid atmospheres, and it seems that ventilation engineers will have to aim at wetbulb temperatures of 80°F (26, 7°C) or less, and consider 83°F (28, 3°C) as the maximum'. This evidently represents a situation in which comfort rather than risk is the ultimate criterion.

In South Africa the MVSSA textbook on Witwatersrand ventilation practice contains a chapter by Grave (89) reviewing main and auxiliary ventilation in which the author provides a graph showing air flowrate as a function of virgin rock temperature; the graph is essentially based on a review of past practice and should be viewed against the picture of steadily deteriorating thermal environments in Witwatersrand mines in the period 1957-68 provided by Wyndham (71) in the same book. In his chapter on heat stress Wyndham includes a graph showing the statistical probability of heatstroke as a function of wetbulb temperature, but this is the only quantitative reference to risk in the book.

Among papers published in the last decade on ventilation design, Hargraves (90) (Australia), devotes considerable space to the occurrence and migration of gases in coal seams, but concludes his summary with a statement which is probably a fair reflection on the present state-of-the-art of mine ventilation design —

In the planning of gassy mines it is possible to make an assessment of gas contained in the seams and to estimate what proportion will be released into the mine air, but emission of gas is never steady and at present there is no better planning criterion than experience at the mine next door !

Experience at the mine next door should certainly be studied as thoroughly as circumstances permit, and patently any useful information emerging from such a study should be incorporated in the design of a proposed ventilation system. Unfortunately if ventilation practice in the mine next door is accepted without critical inquiry unsatisfactory features may be perpetuated indefinitely, and may only emerge as a result of disaster-type occurrences. The report of the commission of inquiry into the Wankie Colliery disaster (91) in Rhodesia highlights the dangers of accepting practice in the mine next door at face value.

The quandary which faces a conscientious ventilation engineer in the design situation is aptly expressed by Tabor (92) (Britain) in a thoughtful paper on justifying capital expenditure for the installation of a new fan at an established colliery —

Mining engineers in all parts of the world are without doubt agreed on the need for 'good ventilation' at working faces. Where men of experience differ is on what constitutes good ventilation. Universal agreement on the basis for evaluating need would materially help to ensure that all high productivity faces have sound ventilation standards, i.e. standards which virtually guarantee that business objectives will not be restricted, and which are almost certain to prevent injury or loss of life from environmental causes.

Unfortunately to say that 'standards . . . which are almost certain to prevent injury or loss of life' begs the question and the vital issue of what constitutes good (or sound) ventilation remains unanswered. The other important question touched upon in the quotation but not answered in the paper is how much can or should one pay to obtain good ventilation.

McPherson (93) (Britain) has discussed the changing techniques of ventilation planning — with particular reference to the use of digital computers — and has suggested a 'systems' approach for integrating ventilation and production planning; however as the title indicates the paper is concerned with planning techniques rather than design philosophy.

The only reference known to the author which attempts to base mine ventilation design on risk is the admirable pocket handbook on controlling employee exposure to alpha radiation in underground uranium mines prepared by the US Bureau of Mines. Volume 1 (94) contains a general discussion on the alpha radiation hazard — including the dose-response relationship published by the FRC (74) — and its control by ventilation, filtration, personal protection (respirators) and limitation of employee exposure. Volume 2 (95) contains a succinct account of basic ventilation principles with useful appendices on alpha radiation sampling and recording of exposure. A similar handbook embracing all atmospheric mine hazards would be a very useful innovation.

It seems reasonable to conclude this section by suggesting that the pragmatic approach of basing ventilation design on the trials and errors of (perhaps) less-informed practitioners is unacceptable on scientific grounds, and seems particularly inappropriate in a multi-billion Rand industry which employs highly sophisticated risk analysis for financial decision making and uses exceedingly complex modelling systems based on the analysis of vast quantities of operating data for formulating and controlling mining programmes. Many such systems are described in the literature, of which the paper by Williams and Ellis (96) is a recent example; similar systems could — and should — be developed to allow decision making in the field of personal injury protection to be based on rational criteria.

3.3 Ventilation design in terms of statutory regulations

On various occasions it has been suggested to the author by miners and others that the designer of a mine ventilation system need do no more than ensure that his design complies in every respect with the minimum statutory requirements applicable to the mine in question. This solution would certainly relieve the ventilation engineer of the need to make invidious value judgements, and might simplify flow specification considerably, but perhaps the implications of this procedure should be examined more closely. For convenience the provisions applicable to South African mines in terms of the Regulations promulgated under section 12 of the Mines and Works Act 27/1956 will mainly be considered here, but the provisions are not significantly different from similar provisions in other jurisdictions.

Three regulations relate directly to the quality of the atmospheric environment in South African mines

- 10.6.2 The workings of every part of a mine where persons are required to travel or work shall be properly ventilated to maintain safe and healthy environmental conditions for the workmen and the ventilating air shall be such that it will dilute and render harmless any inflammable or noxious gases and dust in the ambient air.
- 10.6.6 In the general body of the air at any place where persons are required to work or travel, under normal working conditions —
 - (a) the amount of carbon dioxide shall not exceed 5 000 parts per 1 000 000 of air by volume,
 - (b) the amount of carbon monoxide shall not exceed 100 parts per 1 000 000 of air by volume,
 - (c) the amount of oxides of nitrogen shall not exceed 5 parts per 1 000 000 of air by volume,

- (d) the amount of hydrogen sulphide shall not exceed 20 parts per 1 000 000 of air by volume,
- (e) the amount of inflammable gas shall be insufficient to show a distinct cap on the reduced flame of a safety lamp, and
- (f) the concentration of dust shall not exceed such standard as may from time to time be specified by the Government Mining Engineer.

10.12.1 Except as is provided for in regulation 10.12.2 no person shall cause or permit any non-scheduled person to work in a part of any mine where the environmental conditions are conducive to heat stroke unless he has been acclimatised to such conditions. This prohibition shall not apply to non-scheduled persons in the process of being acclimatised according to a procedure prescribed by the manager.

Regulation 10.6.2 seems to have been modelled on rule 1 of the 'general rules' enacted in the British 1855 Act (except that rule 1 made no reference to dust), and read together the three regulations bear a strong resemblance to section 55 of the present British Mines and Quarries Act of 1954. Section 55 additionally requires 'a sufficiency of oxygen' (defined as not less than 19% by volume) and makes no reference to carbon monoxide, oxides of nitrogen and hydrogen sulphide; inflammable gases are covered by Part II of the Coal and Other Mine (Ventilation) Regulations 1956. Heat and respirable dust are dealt with in a curiously convoluted subsection of the 1954 Act which seems only to obfuscate the manager's duties —

55(3) In the discharge of the duty imposed on him by subsection (1) of this section, the manager of a mine shall have regard to the desirability of securing (consistently with the discharge of that duty) the maintenance in the mine of working conditions that are reasonable so far as regards the temperature and humidity of the atmosphere and the amount of dust therein.

The directive in the British and South African regulations that toxic and inflammable gases are to be diluted and rendered harmless seems explicit enough at first sight, but how should it be interpreted for design purposes? If, for example, pure methane flows into an airstream in a mine airway from a fissure the resulting air-methane mixture is only explosive in the range 15% — 5% methane, but during the dilution process there must inevitably exist an explosive envelope within the airstream. In general, for constant methane flowrate and fixed airway geometry, the bigger the airstream the smaller the explosive envelope, and the smaller the envelope the lower the probability of an explosion and the less the damage if an explosion should occur. However power costs are proportional to the air flowrate cubed, so that the designer must strike what he considers to be a reasonable compromise between risk and cost in complying with this type of regulation. Other regulations may also affect flowrate specifications, but at present no attempt is made to quantify the cost-effectiveness of risk reduction in design situations of this sort.

Regulation 10.6.2 is equally explicit about respirable dust, even though the GME has seemingly not specified dust standards in terms of regulation 10.6.6 (f) except possibly in the case of asbestos. Nevertheless it is quite clear that mineworkers inhaling a variety of mineral dusts in South African mines are contracting pneumoconiosis, and indeed virtually the entire purpose and fabric of the Occupational Diseases in Mines and Works Act 78/1973 and its predecessors, including the concept of 'risk work' in mines, is based on a tacit recognition of the fact that regulation 10.6.2 is ineffectual. The concept of diluting noxious dusts in the ambient air to such a degree that they are rendered harmless may represent an ideal, but it seems unlikely that any mine in South Africa has been designed to comply with this requirement of regulation 10.6.2, nor is there any record of the literal meaning of the regulation ever having been enforced.

The standards for gaseous contaminants prescribed in South African regulation 10.6.6 obviously represent some form of threshold values; although some of the individual values are perhaps debatable* the concept of maximum allowable concentrations is widely used in occupational health and safety

* See for example the criteria for a recommended standard for carbon monoxide published by the US National Institute for Occupational Safety and Health in 1972 (97).

regulations. In mine ventilation, however, a design engineer may have to contend with three problems not experienced to the same degree in other industrial situations, i.e. the vast extent of many mine workings; the difficulty of predicting inflows of contaminant gases; and the difficulty of measuring the concentration of contaminant gases with portable instruments to an accuracy consistent with the specified standards (98). It may be observed, moreover, that regulation 10.6.6 only deals with a few of the simpler contaminants found in mine atmospheres. Among the more notable omissions are radon and its daughter products (76) and the aromatic hydrocarbons found in diesel engine exhaust products, each of which may be significant as a carcinogen or synergistic agent.

Even if the South African regulation 10.12.1 on exposure to heat and acclimatization is less circumlocutious than section 55(3) of the British 1954 Act, it is not of much assistance to the designer because it simply provides that Black mineworkers must be acclimatized before being exposed to working conditions 'conducive to heat stroke'. As Wyndham (66) has shown 'conditions conducive to heat stroke' may cover a wide range of thermal environments.

A further series of South African regulations determines minimum quantities of air which must independently of quality be supplied to working places. The regulations distinguish between controlled metalliferous and diamond mines on the one hand, and coal mines on the other; only the former will be examined here —

10.7 In every controlled metalliferous or controlled diamond mine unless exempted in writing by the Inspector of Mines —

10.7.1 the velocity of the air current along the working face of any stope shall average not less than 0.25 metre per second over the working height: and

10.7.2 the quantity of air supplied at the working face of every development end such as a tunnel, drive, crosscut, raise or winze which is being advanced and at the bottom of any shaft in the course of being sunk shall not be less than 150 cubic decimetres per second for each square metre of the average cross-sectional area of the excavation.

Some years ago these regulations replaced a regulation which required 30 ft³/min of air to downcast into the mine for each person employed underground. Presumably the earlier regulation originally related to oxygen requirements, but it is not clear how the present regulations relate to any of the atmospheric hazards. The regulations certainly determine local flowrates, but as re-use of air is not prohibited the regulations no longer fix downcast quantities.

Broadly there are two schools of thought on the role of statutory regulations in occupational health and safety in mines. In Britain, on the one hand, there has been a longstanding reluctance to control mine injuries by enacting and enforcing specific statutory regulations and standards; this attitude can be traced back to the 1835 Parliamentary select committee — which considered it impracticable to lay down rules of universal application since conditions between mines varies so greatly* — right down to the Robens Committee on Safety and Health at Work which reported in 1972 (100). The British attitude is epitomised by the following statement taken from the report of the 1938 Royal Commission on Safety in Coal Mines (20) —

But statutory regulations after all can go no further than, and seldom as far as, what is already accepted as good practice, and their principal purpose is to require those who do not voluntarily adopt the best practice to approach as closely to it as informed opinion considers reasonably practicable.

This attitude is echoed in the report of the Reid Committee on coal mining technology (101) published in 1944 — 'In general, we feel that while statutory restrictions and legal standards (appertaining to ventilation) have their place, legislation is concerned only with minimum standards and good practice should be well in advance of it'. In much the same vein Rogers (102), a senior member of the British mines inspectorate, said in a presidential address in 1956 —

* Bryan (99) points out that a mines inspectorate was established in France in 1810, where the first code of regulations was promulgated in 1813.

Observance of the statutory requirements relating to Safety and Health, requirements which must necessarily lag behind the best practice, is not enough. Strict observance of these requirements, in the spirit as well as the letter; can go a long way towards averting accidents but a great deal more is required.

The difficulty with the British approach — and this applies in equal measure to most of the jurisdictions, South Africa included, which have been influenced by the British philosophy — is that the design of every system affecting health and safety must still be based on purely subjective interpretations by each individual designer as to what constitutes 'good (or best) practice', 'a great deal more' than just strict compliance with regulations, and similar exhortations to abstract degrees of excellence. In the harsh reality of a competitive economy how must management reconcile the call for occupational nirvana with the first function of management — to put economic performance first ?

Very broadly the British system is based on persuasion and self-regulation rather than compulsion. What might by contrast be termed the American approach appeared virtually overnight five years ago with the enactment of the Federal Coal Mine Health and Safety Act of 1969. The 1969 Act is discussed in greater detail in a later section, and here it will suffice to say that the new legislation established a series of tough mandatory standards, provided for more frequent and more thorough inspections of all US coal mines by Federal inspectors, and created a system of sanctions to help enforce the health and safety standards. Other provisions in the 1969 Act are not relevant to the present discussion.

3.4 Ventilation Design based on Risk

In the definition quoted in 3.1 the purpose of mine ventilation is seen as 'the maintenance of acceptable atmospheric environments wherever men work or travel underground', and acceptability is related to the risk of harmful biological responses associated with exposure to atmospheric environments in mines.

Broadly, atmospheric hazards may be distinguished as being acute in the sense that the undesired reaction occurs after relatively short exposure to the causative agent, or chronic in the sense that the undesired reaction only manifests itself after prolonged exposure. The distinction may be a matter of degree, and the two categories are not necessarily mutually exclusive. Hazards associated with the total atmospheric environment experienced in mines include —

Acute hazards

Contaminant gases
 explosive
 asphyxiant
 toxic
High heat stress
Explosive dusts
Airborne spores
Abnormal noise levels
Inadequate lighting
Claustrophobia

Chronic hazards

Respirable pathogens
 mineral dusts
 radon & radon daughters
 micro flora
 other aerosols
High heat stress
Gaseous pollutants
 sulphur dioxide
 oxides of nitrogen
Airborne spores
High noise levels
Inadequate lighting
Psychoneuroses
Psychosomatic disorders.

Atmospheric hazards may further be classified as hazards which can in the first instance be abated by the forced circulation of air and those which are not significantly affected by air movement; noise and lighting obviously fall into the latter category, and for present purposes it will be assumed that psychological effects are also too remote to be affected by air movement. Of the remaining 'ventilation' hazards explosive gases and dusts are different from the others because the hazardous substance is not necessarily biologically harmful in the acute sense, but if the gas and/or dust is somehow ignited then the flames, shockwaves and gaseous by-products of the explosion may be highly injurious to persons in the

vicinity of the explosion. Furthermore the explosion may so damage the ventilation system that mineworkers outside the explosion area may be exposed to one or more of the other acute hazards.

For risk analysis the main difference between acute and chronic hazards is the degree of difficulty associated with the determination of reliable dose-response relationships. Brief notes follow on three discrete hazards and these may help to illustrate the difficulties —

Carbon monoxide

Methane

Respirable pathogens.

Carbon monoxide. To estimate the risk of asphyxiation by inhaling carbon monoxide the designer needs to know —

- (a) the dose-response relationship for carbon monoxide based on laboratory tests and accident investigations;
- (b) the distribution of carbon monoxide throughout the system as a function of ventilation flowrate under normal conditions (i.e. normal flowrates and gas emission rates) based on accurate periodical sampling at key points in the system;
- (c) the probability of abnormal concentrations occurring in the system based on a statistical analysis of the mine's own sampling records, adjusted if necessary by data from gas sampling and injury statistics in comparable mines.

For carbon monoxide the dose-response relationship is reasonably straightforward. Most ventilation personnel are familiar with the curves compiled by Spencer (103), and have possibly seen the similar curves in the criteria document published by the US National Institute for Occupational Safety and Health (97). Probably few mines record data of the requisite quality and quantity for the analysis envisaged in (b) and similarly the data mentioned in (c) may not be readily available. Nevertheless there is no insuperable difficulty involved in assembling all the data required for risk analysis.

Methane. Methane in a mine ventilation system constitutes a hazard both as an asphyxiant and as a fuel for fires and explosions. So far as the risk of asphyxiation is concerned the *modus operandi* for determining the risk quantitatively would be the same as for carbon monoxide above.

Determining the ignition and explosion risk would likewise require a detailed record of methane distribution and variability under normal conditions, together with estimates of the probability of abnormal occurrences of dangerous concentration (5%-15% methane) and the probability of ignition or detonation. The probability of ignition and detonation would have to be synthesised from laboratory tests and investigations into *in situ* incidents; although there is an immense and invaluable literature on the theory and phenomenology of gas ignitions and explosions in mines, the probability of ignitions occurring in working places (i.e. as a function of gas emission rate, ventilation flowrate, geometry and means of ignition) has not received much attention in the past.

Respirable pathogens. Laboratory experiments on animals and epidemiological studies have established that a wide range of airborne particulates and some gases are pathogenic when inhaled in large enough quantities over long enough periods. Typically the diseases attack the respiratory system, but other parts of the body may also be involved.

Broadly the philosophy of basing risk on dose-response relationships is the same as it is for acute atmospheric hazards, but the establishment of the relationship for chronic hazards is more difficult. Because the diseases in question are generally irreversible direct laboratory experiments on humans to determine biological reactions are not permissible, and the relationship can only be obtained from epidemiological studies involving large numbers of subjects and employing extensive statistical analysis.

Exposure is a function of both concentration and time, and appropriate strategies can be devised to measure both parameters. Problems may arise where two or more potential pathogens occur simultaneously — e.g. silica dust, diesel exhaust products, and radon and its daughter products — or where

synergistic agents such as oxides of nitrogen are present. Patently in such situations each causal agent has to be identified and measured separately if the subsequent analysis is to differentiate between the various agents.

Similar difficulties may be experienced in measuring biological response. In its early stages the clinical manifestations of the disease may not be readily identifiable or distinguishable, and may be confused with similar diseases of non-occupational origin. Again, the population at risk may have a high turnover, or be drawn predominantly from a particular social class or ethnic group, and certainly there will be wide differences in susceptibility as between individuals due to genetic factors and differences in life-style and personal habits. Nevertheless these and similar difficulties can be overcome as Beadle (54) has shown in South Africa for radiological silicosis in White miners, Walton (104) in Britain for coalworkers' pneumoconiosis, and Lundin *et al* (76) in the USA for lung cancer of uranium miners.

The difficulties of preparing meaningful risk estimates for each of the atmospheric hazards experienced in mines is not underestimated. Nevertheless some of the data required for such estimates are already measured routinely, although perhaps not accurately enough or systematically enough for risk analysis. Automated monitoring of the mine environment, now used in a few mines to measure a limited number of atmospheric parameters, could be extended to monitoring all the hazardous characteristics of the mine atmospheric environment. Furthermore there is no reason why the output of such monitoring systems should not be fed directly into a risk assessment programme operating in conjunction with an automated ventilation control system.

As a result of compulsory periodical medical inspections for all mineworkers, and post-mortem examination of mineworkers' cardio-respiratory organs, South Africa possesses a store of information on the biological responses of mineworkers to the mine environment unequalled elsewhere in the world. Unfortunately too little use is made of this latent research material, but if it were to be analysed properly in conjunction with injury statistics submitted to the GME and the Workmen's Compensation Commissioner a very powerful tool would be created for formulating policy on occupational health and safety in mines and for measuring the effect of control measures.

4. THE SUPPORT OF MINE WORKINGS

The rockburst problem in Witwatersrand gold mines is discussed in some detail in 3.4.3, where brief reference is also made to falls of hanging. The two problems are of course merely specific manifestations of a general support problem in mines — a problem which is responsible for a significant proportion of the injuries experienced in a wide variety of mines.

Most mine excavations can be characterised by the broad requirement that they remain safely open long enough for the purpose for which they were excavated to be accomplished; thus at one end of the scale a main shaft system can be regarded as a permanent excavation, whereas a production face (surface subsidence apart) need normally remain just long enough for all the accessible mineral to be extracted. A fully mechanised longwall face in a coal mine represents an extreme example of the latter situation, where the travellingway along the face may be kept open for minutes rather than hours before the powered supports move forward again and the space is abandoned. In most mining fields the risk of injury from the collapse of shaft walls is very low, whereas the risk in production areas is relatively high. The present discussion is therefore limited to production areas.

An unintended collapse of a working place may injure miners and is likely to interfere with the production process, while mineworkers and production in other areas may be affected indirectly. Protection of workings against collapse, whether by the installation of support or control or the layout, or both, normally constitutes a significant production cost, and the cheapest system which just prevents collapse until the working place is vacated for the last time represents an ideal (albeit highly unrealistic) design. Once the working place has been vacated for the last time, and it is not required for any other purpose, it can if needs be collapse forthwith.

The design of a support system for underground workings which periodically or continuously change shape due to mining operations poses problems not dissimilar to those experienced in ventilation design. Very broadly the greater the expenditure on support — whether expressed in terms of engineering

design costs, the value of labour and materials, the cost of interruptions in the breaking and cleaning cycles, etc. — the better the protection and hence the smaller the risk of injury experienced by mineworkers. As with ventilation design, risk of injury is seen as the most important measure of the efficacy of a support system, but loss of production also provides a valuable alternative index.

In the discussion on rockbursts in Witwatersrand mines in 2.4.3 mention is made of the voluminous literature on rock mechanics generated in the last quarter-century, a substantial proportion of which has been devoted to aspects of support in underground mines. However a cursory review of this literature suggests that few authors consider injury or loss of production in quantitative terms; at the symposium on rock mechanics and strata control in mines (105) held in 1965 under the aegis of the S A Institute of Mining and Metallurgy, for instance, not one of the seventeen published papers analysed either criterion. The paper by Ortlepp and Steele (64) is one of few references known to the author in which injuries and loss of production are considered in relation to support design.

The science of rock mechanics has made impressive progress in the last two decades, but as in mine ventilation there has been a strong tendency for practitioners to become so immersed in the intellectual intricacies of the subject that sight is lost of the fundamental rationale for rock mechanics in underground mining. Greater emphasis on the risk of injury and loss of production might help to focus attention on the more urgent problems and the same time provide a yardstick for measuring the success of control measures.

5. MINE INRUSHES

The term inrush is sometimes used to mean the unintentional release of water or liquified material impounded in a recognized storage space within the mine, but here it is used to mean the rapid and unexpected influx of water or liquified material from natural or artificial reservoirs adjoining the mine workings. The former occurrence is akin to what has been described earlier as an industrial-type hazard, whereas the latter is seen as one of the three fundamental hazards faced by mineworkers. Brief details of a few disastrous incidents in the latter category in this century are given in the table —

SOME SELECTED MINE INRUSH DISASTERS: 1900 — PRESENT

Year	Name of mine	Country	Killed	Reference
1901	Donibristle Colliery	Scotland	8	(21)
1911	Wharton Mine	New Jersey, USA	12	(106)
1914	Balkan Mine	Michigan, USA	7	(106)
1918	Amasa-Porter Mine	Michigan, USA	17	(106)
1918	Stanrigg & Arbuckle Coll	Scotland	7	(21)
1923	Redding Colliery	Scotland	40	(20)
1924	Milford Mine	Minnesota, USA	34	(106)
1925	Montagu Colliery	England	38	(20)
1926	Barnes-Hecker Mine	Michigan, USA	51	(106)
1936	Loveston Colliery	Wales	7	(20)
1950	Knockshinnoch Colliery	Scotland	16	(21)
1956	Welkom Mine	South Africa	11	(107)
1956	Merriespruit Mine	South Africa	10	(107)
1970	Mufulira Mine	Zambia	89	(108)
1973	Lofthouse Colliery	England	7	(109)
1974	Bafokeng Mine	South Africa	9	(110)

Liquids can travel far and fast under high hydrostatic heads and favourable flow conditions, so that areas remote from the point of origin may rapidly be inundated with little or no warning*. The available evidence suggests that few inrushes are totally unpredictable in the sense that the presence of neighbouring mine workings, large quantities of groundwater, extensive tracts of surface water, or the existence of waste dumps or dams is unknown or unsuspected; generally it is the mechanism of the inrush and its devastating force and effect which are overlooked, mainly because engineering appreciations of the risk have not been prepared.

Due to their relatively rare and diverse occurrence the phenomenology of inrushes has not received nearly as much attention as the atmospheric and rockfall hazards in mines, and because inrushes do not have a natural niche in mining technology they tend to be overlooked. The Aberfan disaster in 1966 (111), though not an underground incident, demonstrated this point very clearly, and despite the warning provided by Aberfan a comparable situation arose at Mufulira in 1973. As the latter commission of inquiry said in its final report (108) —

90 . . . The accident was caused by faulty operational procedure; a stoping method, a tailings disposal practice and a drainage scheme, all sound enough in their isolation, became a dangerous combination. Whatever the actual mechanics of the disaster, and whatever is eventually accepted as the most likely explanation, this conclusion cannot be affected.

In view of the limited data available on inrush injuries it might be difficult to calculate or estimate precise risks in respect of inrushes — in any event the numerical value of the risk would undoubtedly be very small — but nevertheless it is suggested that if a rational system of risk determination and control were to be adopted the mere process of risk analysis might well reveal the sort of imminent dangers which have in the past deteriorated into disaster.

6. THE ACCEPTABILITY OF RISK

Looking at occupational injuries realistically it is abundantly clear that for the foreseeable future it will not be possible to mine minerals by conventional mining methods without exposing mineworkers to some risk of injury. It is also clear, however, that historically injury rates in mines have been unconscionably high in most parts of the world, and on all important fields strenuous efforts are currently being made to reduce these risks. At the same time it is not altogether clear that the efforts being made to reduce injuries are based on rational criteria.

Assuming that the risk of injury associated with each occupational hazard can be assessed quantitatively, for engineering design and risk control purposes the maximum risk to which mineworkers should routinely be subjected in the course of their ordinary work underground must be determined. Ideally the limit should be specified for each individual hazard and for the aggregate risk, but the principles applicable to maximum risk specification need not be discussed in relation to any particular hazard.

In discussing risk acceptability some general points should be noted at the outset. *Firstly*, although in determining limits of acceptability one may try to quantify as many of the relevant factors as possible, in the ultimate analysis the proposed limit is essentially a value-judgement, i.e. the figure is based on moral concepts of what is right in the circumstances. In other words the limit should represent some form of social consensus rather than merely the opinion of a single designer or official, and obviously there can be no unique level of acceptability. *Secondly*, due to vast differences in social and economic circumstances between different jurisdictions one would expect to find major differences in levels of acceptability as between a highly-developed industrial state and an under-developed, newly-emergent nation. *Thirdly*, in most jurisdictions one would expect to find that levels of acceptability would change with time in tune with evolutionary changes in the social, economic and technological development of the country.

Since World War 2 increasing use has been made of cost-benefit analysis as an aid to decision-making in areas of social concern analogous to occupational injuries in mines — such analyses are no substitute

* The Mihailovici Commission (108) estimated that the Peterson section of Mufulira mine was flooded with about 450 000 m³ of flotation tailings in 10-15 minutes.

for value-judgements, but the preparation of a detailed balance sheet incorporating estimates of all quantifiable costs and benefits often helps to narrow-down considerably the field of alternatives. In the United States, Fine (112) has described how the technique has been used to facilitate expeditious control of hazards for accident prevention purposes in the Naval Ordnance Laboratory, Maryland; Langlois (113) has applied cost-benefit analysis to the cost and prevention of coal workers' pneumoconiosis in Appalachia; and the Federal health department (114) has used the cost-benefit analysis for allocating funds between various programmes aimed at combating cancer, arthritis and similar diseases. In Britain, Sinclair (115) prepared a very useful review of the cost-effectiveness approach to industrial safety for the Robens Committee, and on both sides of the Atlantic the technique has been used in the debate on nuclear power.

Rather limited use has been made of cost-benefit analysis in South Africa up to now, but last year Simpson *et al* (9) published an interesting paper on the use of the risk concept and cost-benefit analysis in the safety assessment of nuclear installations in this country. In discussing the acceptability of additional risks of injury created by the establishment of nuclear facilities the authors examine the risk experienced voluntarily by the national populations from a range of 'conventional' accidents, and using this exposure as a base suggest what they consider to be acceptable risks from nuclear sources. Recommendations for maximum acceptable risks in respect of occupational hazards in mines could be formulated along similar lines.

7. THE EMPLOYER'S DUTY OF CARE

Earlier in this address it is mentioned that occupational injuries and diseases are distinguishable on social rather than biological or medical grounds in that a worker may be obliged for economic reasons to accept employment in a particular occupation, and because he may often be required to perform the task allotted to him in a workplace provided and controlled by the employer. This combination of circumstances may act to the detriment of an employee *vis-a-vis* his employer in the event of the employee being injured while at work, and both Anglo-American and Roman-Dutch common law require employers to exercise a duty of care in respect of an employee engaged upon his employer's business. Munkman (116) summarizes the position in English law as follows —

It is the duty of an employer, acting personally or through his servants or agents, to take reasonable care for the safety of his workmen and other employees in the course of their employment. This duty extends in particular to the safety of the place of work, the plant and machinery, and the method and conduct of the work; but it is not restricted to these matters.

A similar rule applies in South African law (117).

It has been argued that the common law duty is in several respects an inadequate safeguard for employees (118), but for the vast majority of workers in North America and South Africa the matter is largely academic because in both areas the common law right of recourse against employers is in most cases barred by workmen's compensation legislation. In South Africa the bar appears in section 7 of the Workmen's Compensation Act 30/1941, but it may be noted that in terms of section 43 an employee or his dependants may apply for increased compensation where it can be shown that an injury was due to the negligence of his employer (or certain fellow employees), or due to certain specified defects. In practice little use is made of section 43, possibly because reports of official inquiries into accidents are not normally published in South Africa and a workman (or his dependants) may face insuperable difficulties in trying to establish negligence or the existence of defects without such a report.

The common law right of recourse survives in Britain, where recently a claim by a number of miners and ex-miners suffering from pneumoconiosis against the National Coal Board for pecuniary damages in respect of loss of health and amenities was settled out of court by the establishment of a £100 million trust fund by the government for the benefit of all men suffering from pneumoconiosis contracted in coal mining. It is at least arguable that under certain circumstances a miner (or ex-miner) falling within the ambit of the Occupational Diseases in Mines and Works Act 78/1973 also retains a right of recourse against his employer in respect of occupational diseases covered by the Act, although as noted above his right of recourse in respect of other occupational injuries is barred in terms of section 7 of Act 30/1941.

Some of the arguments used against the common law remedy are undoubtedly valid, but the fact remains that without the remedy workmen exposed to excessive risk in hazardous occupations may have no legal redress for occupational injuries apart from meagre statutory benefits, and without the threat of litigation and its attendant publicity an employer may persist in exposing workmen to high risks. The position of workmen in this type of situation can be viewed in the light of what Drucker (119), one of the leading management pundits of the 'fifties and 'sixties, has stated to be the first function of management

Management must always, in every decision and action, put economic performance first. It can only justify its existence and its authority by the economic results it produces. There may be great non-economic results: the happiness of the members of the enterprise, the contribution to the welfare or culture of the community, etc. Yet management has failed if it fails to produce services desired by the consumer at a price the consumer is willing to pay. It has failed if it does not improve or at least maintain the wealth-producing capacity of the economic resources entrusted to it.

Views on the functions of business management have in all probability changed considerably since Drucker wrote in 1954, and of course he was not addressing himself specifically to hazardous industries, but nevertheless the quotation does emphasize a basic conflict which has been referred to from time to time in this address. In these circumstances statutory health and safety regulations assume greater significance because their enforcement constitutes a workman's principal protection against negligence and breaches of the common law duty on the part of the employer, as well as protecting him from hazards for which the employer bears no legal liability.

8. THE US FEDERAL COAL MINE HEALTH AND SAFETY ACT OF 1969

The doctrine of *laissez-faire* which so characterised attitudes toward occupational health and safety in Britain during the Industrial Revolution took root readily in the United States with the widespread industrial development which followed the American Civil War (1861-65), and probably nowhere was the doctrine more manifest than in US coal mines. In terms of the prevailing *credo* it was open to anyone with the necessary title and capital to exploit a natural resource for his own maximum financial benefit without let or hindrance, and if the work happened to be particularly dangerous the law of supply and demand determined appropriate rates of pay. As in other mining jurisdictions, the limited data available suggest that injury rates before the introduction of safety regulations were exceptionally high, with firedamp explosions, fires and falls of ground constituting the main sources of injury.

In 1865 an attempt was made in the US Congress to establish a Federal mines authority, but the measure was blocked by protagonists of State autonomy. Four years later Pennsylvania became the first State to enact legislation requiring mines to be ventilated (the act called for 'an adequate amount of ventilation' based on the 1855 British rule) but initially the regulations only applied to anthracite mines in one county. In the next few years the regulations were extended in stages to all anthracite and bituminous coal mines in Pennsylvania, and other coal-mining States gradually followed suite. In each case the State concerned was responsible for enforcing its own safety legislation.

In the light of similar experiences elsewhere it is perhaps not surprising that the regulations enacted by various States in the last third of the 19th century were neither specific enough nor enforced vigorously enough to contain injury rates. Thus it is recorded (120) that 2 492 miners died in coal mine disasters (i.e. accidents involving the death of more than 5 men) in the period 1906-10 — of which four disasters alone accounted for 1 013 deaths — but the furore created by the disasters paved the way for Federal legislation to be passed authorising the establishment of the US Bureau of Mines.

Although the Bureau was ostensibly established to exercise a watching brief over the health and safety of US miners, the enabling act specifically excluded 'any right or authority in connection with the inspection or supervision of mines or metallurgical plants in any State', and for the first thirty years of its existence the Bureau was broadly confined to the conduct of research work, the compilation of safety codes, and the provision of a technical advisory service when called upon to do so. In May 1941, shortly before Pearl Harbour, limited mine inspection powers were extended to the Bureau but no enforceable standards were specified. Six years later, shortly after World War 2 ended, American coal mines were

placed under military control due to labour difficulties and during this period the Bureau's inspection and enforcement powers were increased considerably for the duration of military control. In 1950 the Bureau assumed responsibility for investigating all fatal coal mine accidents and publishing inquiry reports but nevertheless between 18 January 1951 and 7 March 1952 seven disastrous accidents occurred, as a result of which the Congress enacted the Federal Coal Mine Safety Act of 1952.

The 1952 Act made provision for more specific mine inspections and more onerous ventilation standards, but until 1966 the Bureau had very limited powers in respect of mines employing less than 15 persons underground. Also prime responsibility for enforcement remained in the hands of the States. By 1968 the Bureau had made some progress in enforcing regulations, but in that year several minor gas explosions culminated in the disastrous explosion at Farmington, West Virginia, in November which killed 78 miners. The explosion unleashed a public outcry which in turn initiated an unprecedented flurry of legislative activity in the US Congress, and in the following months several bills of varying severity were introduced in both Chambers, and were followed by both House (121) and Senate (122) hearings. Eventually the more onerous House bill was passed by both House and Senate and after some hesitation on the part of President Nixon was eventually approved on 31 December 1969.

The 1969 Act was a momentous event in the history of coal mine health and safety in the United States, and will probably be extended, with appropriate modification, to all mines in the USA in the not too distant future; it will also undoubtedly exert a profound influence on similar legislation in other countries over the next few years, and with some justification the measure has been described as the most significant piece of social legislation to be enacted in the twentieth century.

The tone of the 1969 Act is set by section 2(a), which reads —

2. Congress declares that —

- (a) the first priority and concern of all in the coal mining industry must be the health and safety of its most precious resource — the miner;

The Act contains several noteworthy features —

- (a) a number of mandatory standards, including the well-known $2,0 \text{ mg/m}^3$ of respirable coal dust;
- (b) an obligatory mine inspection schedule;
- (c) provisions for inspections and investigations;
- (d) provision for the issue of withdrawal notices in the event of an imminent danger.
- (e) section 109(a)(1) provides for civil penalties to be assessed for violations of mandatory standards, up to a maximum of \$10 000. This section has been bitterly resisted by coal mine operators, whose refusal to pay many millions of dollars of assessed penalties has led to extensive hearings (123) and litigation. Revised procedures for assessing and collecting penalties have recently been issued.
- (f) Section 111(a) provides for all accidents to be investigated and subsection (b) states that ' . . . all records, informations, reports, findings, notices, orders, or decisions required or issued pursuant to or under this Act may be published from time to time, may be released to any interested person, and shall be made available for public inspection.
- (g) Title IV of the Act provides for the payment of black lung benefits to totally-disabled miners or their dependants. This title, like a similar proposal for uranium miners, was strenuously opposed by various factions, but survived. The title was amended in 1972 to liberalize the criteria for payment of benefits (124) and attempts are currently being made to further amend the title (125). At the present time benefits amounting to just under \$1 billion per annum are being paid by the Federal government.

The 1969 Act has had an extremely turbulent history in the 5½ years it has been on the statute book. Attempts to transfer the administration of the Act from the Secretary of the Interior to the Secretary of Labor were frustrated, but resulted in enforcement being transferred from the Bureau to a completely new

agency, the Mine Enforcement and Safety Administration (MESA) located in the interior department on a par with the Bureau. However further attempts may be expected to shift control from Interior to Labor.

9. CONCLUSIONS

In this address an attempt has been made to review the fundamental hazards experienced in mines, and it has been suggested that greater use should be made of risk concepts in the assessment and control of such hazards. In preparing the address the author has perused a wide variety of publications which seemed relevant to the title of the address, but of which only a fraction are referred to in the text. Some impressions emerge very clearly from this protracted study. *Firstly*, in view of the considerable mass of material reviewed it is surprising that no previous attempt to review the field of occupational health and safety in mines has been encountered. Studies in the field seem to be highly compartmentalized. *Secondly*, one is struck by the many similarities in the development of the various hazards reviewed here, and in particular by the delays in recognizing hazards and the further delays before effective measures to abate the hazards are implemented. Unfortunately it is not even clear today that similar situations will not arise again. *Thirdly*, one wonders at the paucity of factual data available on mine hazards, and at the lack of meaningful analyses. In recent years the US Bureau of Mines has published contract reports illustrating very clearly how injury statistics can be usefully analysed (126) (127) (128).

Finally, it is hoped that, if nothing more, the address may have identified a field, or topics within a field, worthy of more profound study.

10. ACKNOWLEDGEMENTS

The author is grateful to many confreres in South Africa and overseas who have provided information, publications and ideas used in the preparation of this address; however, direct quotations apart, the author alone is responsible for all views and opinions expressed in the address. The author also gratefully acknowledges the helpful assistance of several librarians in obtaining material.

LIST OF REFERENCES

1. FORBES, R. J. Studies in Ancient Technology — Volue 7 (2 ed). Leiden, Brill, 1966.
2. SUMMERS, R. Ancient Mining in Rhodesia. Salsibury, National Museum of Rhodesia, 1969. (NMR Memoir 3).
3. SYMPOSIUM ON ANCIENT MINING AND METALLURGY IN SOUTHERN AFRICA. J. S.A. Inst. Min. Met., Vol. 74, 1973-74, pp. 211-272.
4. ANSTED, D. T. On the Methods of Working and Ventilating the Coal-mines of the North of England, with reference to the Accidents that occur in such Mines from the Explosion of Firedamp. Trans. Br. Assoc. Adv. Sc. (Geology Section), 1845, pp. 53-56.
5. ATKINSON, J. J. On the Theory of the Ventilation of Mines. Trans. N. Eng. Inst. Min. Engrs., Vol. 3, 1854-55, pp. 73-222.
6. SOUTH AFRICA (R). Government Gazette. No. 4586 (RG 2113). Pretoria, 14 February 1975, pp. 28-29.
7. SIGERIST, H. E. Introduction to reference 11.
8. BRYAN, A. Cadman Memorial Lecture — Safety in Mines. J. Roy. Soc. Arts, Vol. 99, 1950-51, pp. 828-842.
9. SIMPSON, D. M., WINKLER, B. C. and TATTERSALL, J. O. On the use of the risk concept and cost-benefit analysis in the safety assessment of nuclear installations. In Population Dose Evaluation and Standards for Man and his Environment — Proceedings of a Symposium held at Portoroz, 20-24 May 1974. Vienna, IAEA, 1974. (IAEA-SM-184/31).
10. UNITED STATES — ATOMIC ENERGY COMMISSION. The Safety of Nuclear Power Reactors (Light Water-Cooled) and Related Facilities (Final Draft). Washington DC, USAEC, July 1973. (WASH — 1250).
11. ROSEN, G. The History of Miners' Diseases. New York, Schuman's, 1943.
12. COLLIS, E. L. Industrial Pneumoconiosis — Milroy Lectures, 1915. London, HMSO, 1919.
13. AGRICOLA (GEORG BAUER). De re metallica (First published 1556). Hoover translation: London, Mining Magazine, 1912.

Presidential Address

14. PARACELSUS, B. ab H. Von der Bergsucht und anderen Bergkrankheiten (First published 1567). Rosen translation in Four Treatises of Paracelsus (Ed. SIGERIST, H. E.). Baltimore, John Hopkins, 1941.
15. RAMAZZINI, B. Diseases of Workers (First published in 1717). Wright translation: New York, Hafner, 1964.
16. BOYDELL, T. Presidential Address (N. Staffs. Inst.) — Accidents in Mines and Progress in Mining Legislation. Trans. Instn. Min. Engrs., Vol. 74, 1927-28, pp. 167-173.
17. JEVONS, H. S. The British Coal Trade (First published 1915). Reprint: Newton Abbot, David & Charles, 1969.
18. BRITAIN — DEPARTMENT OF TRADE AND INDUSTRY. Report of HM Chief Inspector of Mines and Quarries . . . for 1972. London, HMSO, 1973.
19. EZRA, D. Address to National Union of Mineworkers, Llandudno 2 July 1974. London, NCB, 1974.
20. BRITAIN. Report of the Royal Commission on Safety in Mines (Chairman Baron Rockley). London, HMSO, 1938. (Cmnd 5890).
21. DUCKHAM, H. and B. Great Pit Disasters. Newton Abbot, David & Charles, 1973.
22. TYE, J. and ULLYETT, K. Safety — Uncensored. London, Transworld (Corgi), 1971.
23. MACDONAGH, O. O. G. M. Coal Mines Regulation: The First Decade, 1842-52. In Ideas and Institutions of Victorian Britain (Ed ROBSON, R.). London, Bell, 1967.
24. ZUID-AFRIKAANSCH REPUBLIEK. Staatscourant. Deel 6, No. 295, Pretoria, 15 September 1886.
25. LETCHER, O. The Gold Mines of Southern Africa. Johannesburg, Letcher, 1936.
26. WITWATERSRAND CHAMBER OF MINES. Eighth Annual Report for the Year Ending 31st December 1896. Johannesburg, Argus, 1897.
27. TRANSVAAL (C) — MINES DEPARTMENT. Half-yearly Report of the Government Mining Engineer for the Six-months ending December 31st, 1901. Pretoria, GPW, 1902.
28. BRITAIN — HOUSE OF COMMONS. Colonial Office Return — South African Mines (Mortality). London, HMSO, 10 June 1904.
29. CARTWRIGHT, A. P. Doctors of the Mines. Cape Town, Purnell, 1971.
30. ANGLO AMERICAN CORPORATION OF SOUTH AFRICA LIMITED. Medical Consultant's Report — 1970. Johannesburg, AAC, 1971.
31. CHAMBER OF MINES OF SOUTH AFRICA. Eighty-first Annual Report — 1970. Johannesburg, Chamber of Mines, 1971.
32. SOUTH AFRICA (R) — DEPARTMENT OF MINES. Mining Statistics 1970. Pretoria, GP, 1971. (RP 32-1971).
33. WILSON, F. Labour in the South African Gold Mines 1911-1969. Cambridge, CUP, 1972.
34. McEWEN, A. F. and BUIST, J. The Nature and Source of Dust in Mine Air, together with a Brief Reference to those Operations which Produce Dust. In Silicosis — Records of the International Conference held at Johannesburg 13-27 August 1930. Geneva, ILO, 1930, pp. 129-140. (Studies and Reports F13)
35. TRANSVAAL (C) — DEPARTMENT OF MINES. Annual Report of the Government Mining Engineer for the Year Ended 30th June, 1909. Pretoria, GPSO, 1909. (TG 3-1910).
36. TRANSVAAL (C). Report of the Miners' Phthisis Commission 1902-03 (Chairman H. Weldon). Pretoria, GPSO, 1903.
37. BOYD, J. Methods for Determining the Dust in Mine Air, as Practised on the Witwatersrand. In Silicosis — Records of the International Conference held at Johannesburg 13-27 August 1930. Geneva, ILO, 1930, pp. 141-150. (Studies and Reports F 13).
38. PENLERICK, S. Ventilation and Health Conditions on the Mines of the Witwatersrand, with Special Reference to the Ventilation System of the East Rand Proprietary Mines. J. Chem. Met. Min Soc. S. Afr., Vol. 11, 1910-11, pp. 59-69.
39. IRVINE, L. G., MAVROGORDATO, A. and PIROW, H. A Review of the History of Silicosis on the Witwatersrand Goldfields. In Silicosis — Records of the International Conference held at Johannesburg 13-27 August 1930. Geneva, ILO, 1930, pp. 178-208. (Studies and Reports F 13).
40. TRANSVAAL CHAMBER OF MINES. Fourteenth Annual Report for the Year 1903. Johannesburg, Argus, 1904.
41. TRANSVAAL CHAMBER OF MINES. Fifteenth Annual Report for the Year 1904. Johannesburg, Argus, 1905.
42. TRANSVAAL CHAMBER OF MINES. Sixteenth Annual Report for the Year 1905. Johannesburg, Argus, 1906.
43. TRANSVAAL CHAMBER OF MINES. Eighteenth Annual Report for the Year 1907. Johannesburg, Argus, 1908.
44. TRANSVAAL (C). Final Report of the Mining Regulations Commission (Chairman F. E. T. Krause): Volume 1 Report; Volume 2 Minutes of Evidence. Pretoria, GPSO, 1910.

Presidential Address

45. BOYD, J. The Estimation of Dust in Mine Air. In Proceedings of the Third (Triennial) Empire Mining and Metallurgical Congress (South Africa, 1930). Johannesburg, The Congress, 1930, pp. 175-196.
46. UNITED STATES — DEPARTMENT OF HEALTH, EDUCATION AND WELFARE. Criteria for a Recommended Standard — Occupational Exposure to Crystalline Silica. Washington DC, DHEW, 1974. (HEW Publication (NIOSH) 75-120).
47. BEADLE, D. G. and BRADLEY, A. A. The Composition of Airborne Dust in South African Gold Mines. In Pneumoconiosis — Proceedings of the International Conference: Johannesburg 1969 (Ed. SHAPIRO, H. A.). Cape Town, OUP, 1970, pp. 462-466.
48. SOUTH AFRICA (U). Final Report of the Miners' Pthisis Committee 1912-21 (Chairman R. N. Kotze). Pretoria, GPSO, 1919.
49. DU TOIT, R. S. J. The Functional Relationship between Dust Hazard and the Rate of Collecting Funds to Pay Compensation for Pneumoconiosis. J.S. Afr. Inst. Min. Met., Vol. 70, 1969-70, pp. 291-309. Contributions and Author's Reply in Vol. 71, 1970-71, pp. 41-53.
50. MARTINSON, M. J. Contribution in Pneumoconiosis — Proceedings of the International Conference, Johannesburg 1969 (Ed. SHAPIRO, H. A.). Cape Town, OUP, 1970, pp. 480-482.
51. SOUTH AFRICA (U) — DEPARTMENT OF MINES. Annual Report . . . of the Government Mining Engineer . . . for the year Ended 31st December, 1950. Pretoria, GP, 1952. (UG 43-1951).
52. RAPSON, W. S. Contribution to reference 49. J.S. Afr. Inst. Min. Met., Vol. 71, 1970-71, pp. 46-47.
53. BEADLE, D. G. An Epidemiological Study of the Relationship Between the Amount of Dust Breathed and the Incidence of Silicosis in South African Gold Miners. In Inhaled Particles and Vapours II. (Ed. DAVIES, C. N.). Oxford, Pergamon, 1967, pp. 479-491.
54. BEADLE, D. G. The Relationship Between the Amount of Dust Breathed and the Development of Radiological Signs of Silicosis: An Epidemiological Study in South African Gold Miners. In Inhaled Particles and Vapours III (Ed. WALTON, W. H.) — Volume 2. Old Woking, Unwin, 1971, pp. 953-964.
55. PAGE-SHIPPI, R. J. and HARRIS, E. A Study of the Dust Exposure of South African White Gold Miners. J. S. Afr. Inst. Min. Met., Vol. 73, 1972-73, pp. 10-24.
56. SOUTH AFRICA (U). Report of a Commission appointed to . . . Inquire into the prevalence of Miners' Phthisis and Pulmonary Tuberculosis on Mines (in) South Africa (Chairman S. V. van Niekerk). Pretoria, GP, 1912. (UG 19-1912).
57. SOUTH AFRICA (U). Report of the Departmental Committee of Enquiry into the Relationship between Silicosis and Pulmonary Disability and the Relationship between Pneumoconiosis and Tuberculosis (Chairman S. F. Oosthuizen). Pretoria, GP, 1955.
58. SOUTH AFRICA (R). Report of the Miner's Medical Bureau for the Period 1 April 1971 to 31 March 1972. Pretoria, GP, 1973 (RP 25-1973).
59. VILAKAZI, B. W. Zulu Horizons. Malcolm and Friedman translation: Cape Town, Timmins, 1962.
60. SOUTH AFRICA (R) — DEPARTMENT OF MINES. Recommendations of the Rock Burst Committee, 1964 (Chairman T. L. Gibbs).
61. TRANSVAAL (C) Report of the Ophirton Earth Tremors Committee (Chairman D. J. Schuurman). Published as Appendix 1 to reference 62.
62. SOUTH AFRICA (U). Report of the Witwatersrand Earth Tremors Committee 1915 (Chairman R. N. Kotze). Pretoria, GPSO, 1916. (UG 41-1915).
63. SOUTH AFRICA (U). Report of the Witwatersrand Rock Burst Committee 1924 (Chairman U. P. Swinburne). Cape Town, CT-GP, 1925. (UG 48-1925).
64. ORTLEPP, W. D. and STEELE, K. E. Rockbursts: The Nature of the Problem and Management Countermeasures on ERPM Ltd. Assoc. Mine Mgrs. S. Afr., circular 1/72, 10 January 1972.
65. LEITHEAD, C. S. and LIND, A. R. Heat Stress and Heat Disorders. London, Cassell, 1964.
66. WYNDHAM, C. J. A Survey of the Causal Factors in Heat Stroke and of their Prevention in the Gold Mining Industry. J. S. Afr. Inst. Min. Met. Vol. 66, 1965-66, 125-155.
67. JENSEN, A. Industrial Psychological Studies of Socio-technical groups in the South African Gold Mining Industry. Unpublished Ph.D. thesis. Johannesburg, University of the Witwatersrand, 1969.
68. JACOBS, G. F. Trends in Management Training. J. S. Afr. Inst. Min. Met. Vol. 61, 1960-61, pp. 351-366.
69. CLUVER, E. H. An Analysis of ninety-two Fatal Heat-stroke cases on the Witwatersrand Gold Mines. S. Afr. Med. J., Vol. 6, 1932, pp. 19-22.
70. DREOSTI, A. O. The Results of some Investigations into the Medical Aspects of Deep Mining on the Witwatersrand (Symposium (on) Temperature and Humidity on the Witwatersrand). J. Chem. Met. Min. Soc. S. Afr., Vol. 36, 1935-36, pp. 102-129.

Presidential Address

71. WYNDHAM, C. H. The Physiological and Psychological Effects of heat. Ch 7 in The Ventilation of South African Gold Mines. Johannesburg, MVSSA, 1974.
72. SOUTH AFRICA (U). Report of the Committee on Deep Level Mining (Chairman R. N. Kotze). Pretoria, GP, 1945. (UG 18-1945).
73. ARCHER, V. E., MAGNUSON, H. J., HOLADAY, D. A. and LAWRENCE, P. A. Hazards to Health in Uranium Mining and Milling. J. Occ. Med., Vol. 4, 1962, pp. 55-60.
74. UNITED STATES — FEDERAL RADIATION COUNCIL. Staff Report: Guidance for the Control of Radiation Hazards in Uranium Mining. Washington DC, USGPO/FRC, September 1967. (Report No. 8 Revised).
75. LORENZ, E. Radioactivity and Lung Cancer: A Critical Review of Lung Cancer in the Miners of Schneeberg and Joachimsthal. J. Nat. Cancer Inst., Vol. 5, 1944, pp. 1-15.
76. LUNDIN, F. E., WAGONER, J. K. and ARCHER, V. E. Radon Daughter Exposure and Respiratory Cancer — Quantitative and Temporal Aspects. Washington DC, USDHEW, 1971 (NIOSH/NIOSH Joint Monograph 1).
77. HOLADAY, D. C. Evaluation and Control of Radon Daughter Hazards in Uranium Mines. Rockville (Maryland), USDHEW, November 1974. (HEW Publication (NIOSH) 75-117).
78. UNITED STATES — JOINT (HOUSE & SENATE) COMMITTEE ON ATOMIC ENERGY. Hearings before the Subcommittee on Research, Development and Radiation on Radiation Exposure of Uranium Miners (Chairman M. Price). Washington DC, USGPO, 1967.
79. UNITED STATES — JOINT (HOUSE & SENATE) COMMITTEE ON ATOMIC ENERGY. Hearings before the Subcommittee on Research, Development and Radiation on Radiation Standards for Uranium Mining (Chairman M. Price). Washington DC, USGPO, 1969.
80. UNITED STATES. Federal Register. Vol. 35, No. 245, p., 19218, 18 December 1970.
81. UNITED STATES — NATIONAL COMMISSION ON STATE WORKMEN'S COMPENSATION LAWS. The Report (1972), Compendium on Workmen's Compensation (1973), Supplemental Studies Volumes I, II and III (1973). Washington D.C., USGPO for the Commission.
82. UNITED STATES — HOUSE OF REPRESENTATIVES COMMITTEE ON EDUCATION AND LABOR. Hearings before the Select Subcommittee on Labor on Uranium Miners Compensation (Chairman J. G. O'Hara). Washington DC, USGPO, 1968.
83. ETHEREDGE, D. A. Chairman's Statement to Shareholders of Vaal Reefs Exploration and Mining Company Limited (Accompanying 1974 Annual Report). Johannesburg, The Company, 11 March 1975.
84. BRITAIN — PAY BOARD. Special Report on Relative Pay of Mineworkers (Chairman F. Figgures). London, HMSO, March 1974. (Cmnd 5567).
85. TABERSHAW, L. R. Keynote Address on The Health of the Coal Miner — An Expendable Resource? In Papers and Proceedings of the National Conference on Medicine and the Federal Coal Mine Health and Safety Act of 1969, held at Washington DC on 15-18 June 1970. Berkeley, University of California School of Public Health, 1970.
86. HARTMAN, H. L. Mine Ventilation and Air Conditioning. New York, Ronald, 1961.
87. PURSALL, B. R. Ventilation Planning: Estimation of Air Quantity. Ch. 13 in Mine Ventilation (Ed ROBERTS, A. A.). London, Cleaver-Hume, 1961.
88. WILLIAMS, F. T. The Mine Climate: Air Conditioning in Hot and Deep Mines. Ch. 7 in Mine Ventilation (Ed. ROBERTS, A. A.). London, Cleaver-Hume, 1961.
89. GRAVE, D. F. H. Main and Ancillary Ventilation Practice in South African Gold Mines. Ch. 18 in The Ventilation of South African Gold Mines. Johannesburg, MVSSA, 1974.
90. HARGRAVES, A. J. Planning and Operation of Gaseous Mines. Bull. Can. Inst. Min. Met., March 1973, pp. 119-128.
91. RHODESIA. Report of the Commission of Inquiry into the Wankie Colliery Disaster and General Safety in Coal-Mines in Rhodesia 1973 (Chairman V. Quenet). Salisbury, GPSO, 1973. (Cmd. RR 4-1973).
92. TABOR, K. F. Justification and Installation of Replacement Main Fans. The Mining Engineer, October 1969, pp. 7-17.
93. McPHERSON, M. J. The Changing Techniques of Ventilation Planning. The Mining Engineer, Vol. 133 Aug./Sept. 1974, pp. 509-516.
94. ROCK, R. L. and WALKER, D. K. Controlling Employee Exposure to Alpha Radiation in Underground Uranium Mines (Volume 1 of two volumes). Washington DC, USBM, 1970.
95. ROCK, R. L. DALZELL, R. W. and HARRIS, E. J. Controlling Employee Exposure to Alpha Radiation in Underground Uranium Mines (Volume 2 of two volumes). Washington DC, USBM, 1970.
96. WILLIAMS, P. H. and ELLIS, J. K. W. Development of a Computer-based Production Scheduling and Metallurgical Accounting Information System. Trans. Inst. Min. Met., Vol. 83, July 1974, pp. A110-21.

Presidential Address

97. UNITED STATES — DEPARTMENT OF HEALTH, EDUCATION AND WELFARE. Criteria for a Recommended Standard (for) Occupational Exposure to Carbon Monoxide. Washington DC, DHEW, 1972. (HSM 73-11000).
98. CARROLL, H. B. and ARMSTRONG, F. E. Accuracy and Precision of Several Portable Gas Detectors. Washington DC, US Department of the Interior, 1973. (Bureau of Mines RI 7811).
99. BRYAN, A. M. Presidential Address: His Majesty's Inspectors of Mines — A Centenary Address. Trans. Instn. Min. Engrs., Vol. 109, 1949-50, pp. 875-887.
100. BRITAIN. Report of the Committee on Safety and Health at Work, 1970-72 (Chairman Lord Robens). London, HMSO, 1972. (Cmnd 5034).
101. BRITAIN — MINISTRY OF FUEL AND POWER. Coal Mining — Report of the Technical Advisory Committee (Chairman C. C. Reid). London, HMSO, 1945. (Cmd 6610).
102. ROGERS, T. A. Presidential Address (S. Wales): Safety in Coal Mines of the South-Western Division — Retrospect and Prospect. Trans. Instn. Min. Engrs., Vol. 115, 1955-56, pp. 375-386.
103. SPENCER, T. D. Effects of Carbon Monoxide on Man and on Canaries. Trans. Instn. Min. Engrs., Vol. 118, 1958-59, pp. 518-526.
104. WALTON, W. H. Progress of the 25-Pit Scheme. In Pneumoconiosis — Proceedings of the International conference, Johannesburg 1969 (Ed. SHAPIRO, H.A.). Cape Town, OUP, 1970.
105. SYMPOSIM ON ROCK MECHANICS AND STRATA CONTROL IN MINES. Johannesburg, SAIMM, 1965.
106. HYVARINEN, J., JOHNSON, L. H. and KENNEDY, D. O. Major Disasters at Metal and Nonmetal Mines and Quarries in the United States (Excluding Coal Mines). Washington DC, US Department of the Interior, April 1949. (Bureau of Mines IC 7493).
107. SUID-AFRIKA (U) — DEPARTEMENT VAN MYNWESE. Jaarverslag . . . van die Staatsmyningenieur vir die jaar geëindig 31 Desember 1956. Pretoria, Staatsdrukker, 1958. (UG 15-1958).
108. ZAMBIA. Final Report on . . . the Disaster which occurred at Mufulira Mine on the 25th September, 1970 (Chairman N. Mihailovici). Lusaka, 1971.
109. BRITAIN — DEPARTMENT OF TRADE AND INDUSTRY. Report on . . . the Inrush which occurred at Lofthouse Colliery Yorkshire, on 21 March 1973 (J. W. Calder). London, HMSO, 1973. (Cmnd 5419).
110. SOUTH AFRICA (R) — DEPARTMENT OF MINES. Report of . . . the Government Mining Engineer . . . for the year ended 31 December 1974. Pretoria, GP, 1975. (RP 59-1975).
111. BRITAIN. Report of the Tribunal appointed to inquire into the Disaster at Aberfan on October 21st, 1966 (Chairman H. E. Davies). London, HMSO, 1967. (HL 316, HC 553).
112. FINE, W. T. Mathematical Evaluations for Controlling Hazards. Silver Spring (Maryland), Naval Ordinance Laboratory, 8 March 1971. (NOLTR 71-31).
113. LANGLOIS, Lucille. A Monograph: The Cost and Prevention of Coal Workers' Pneumoconiosis. Washington DC, Appalachian Regional Commission, June 1971.
114. ANON. Putting a Dollar Sign on Life. Business Week, 21 January 1967.
115. SINCLAIR, T. C. A Cost-Effectiveness Approach to Industrial Safety (Research Paper for the Committee on Safety and Health at Work). London, HMSO, 1972.
116. MUNKMAN, J. Employer's Liability at Common Law (7 ed). London, Butterworths, 1971.
117. SOUTH AFRICA (U). Interim Report of the Miners' Phthisis Commission 1920 (Chairman J. de Villiers). Cape Town, CT-GP, 1921. (UG 35-1921).
118. ISON, T. G. The Forensic Lottery. London, Staple, 1967.
119. DRUCKER, P. F. The Practice of Management. London, Heinemann, 1956.
120. HARRINGTON, D., EAST, J. H. and WARNCKE, R. G. Safety in the Mining Industry. Washington DC, Bureau of Mines, 1950. (Bulletin 481).
121. UNITED STATES — HOUSE COMMITTEE ON EDUCATION AND LABOR. Hearings before the General Subcommittee on Labor on Coal Mine Health and Safety. (Chairman J. H. Dent). Washington DC, USGPO, 1969.
122. UNITED STATES — SENATE COMMITTEE ON LABOR AND PUBLIC WELFARE. Hearings before the Subcommittee on Labor on Coal Mine Health and Safety (Chairman H. A. Williams) Washington DC, USGPO, 1969).
123. UNITED STATES — HOUSE COMMITTEE ON GOVERNMENT OPERATIONS. Hearings before a Subcommittee on Enforcement of Federal Mine Health and Safety Laws (Chairman H. S. Reuss) Washington DC, USGPO, 1973.
124. UNITED STATES — SENATE COMMITTEE ON LABOR AND PUBLIC WELFARE. Hearings before the Subcommittee on Labor on Black Lung Legislation, 1971-72 (Chairman J. Randolph). Washington DC, USGPO, 1972.

Presidential Address

125. UNITED STATES — HOUSE COMMITTEE ON EDUCATION AND LABOR. Hearings before the Subcommittee on Labor Standards (Chairman J. H. Dent). Washington DC, USGPO, 1975.
 126. THEODORE BARRY AND ASSOCIATES. Industrial Engineering Study of Hazards Associated with Underground Coal Mine Production (Volume 1). Washington DC, December 1971. (USBM Contract Report S0110601).
 127. PFLEIDER, E. P. and KRUG, A. D. The Development of Health and Safety Indices for the Evaluation of Underground Coal Mining Systems. Washington DC, Department of the Interior, November 1973. (USBM Contract Report H0122628).
 128. THEODORE BARRY AND ASSOCIATES. Industrial Engineering Study of Hazards Associated with Surface Coal Mines (Final Report). Washington DC, Department of the Interior, June 1974. (USBM Contract Report H0230010).
-

VOTE OF THANKS BY DR. C. H. WYNNDHAM

Mr. Chairman, Ladies and Gentlemen,

I am delighted to have this opportunity of proposing the vote of thanks to our new President, Mr. Martinson for his thought-provoking presidential address. I say thought-provoking advisedly because Mr. Martinson has emphasized an aspect of ventilation control which is too often neglected by ventilation engineers. It is the criteria we must use to judge whether the levels of the hazard in the environment affect the health, the efficiency and the comfort of the workman. I am delighted that Mike Martinson has come down on the side of assessment of risk as the criterion for judging of environmental control. I say this because from 1950 when I started the Applied Physiology Laboratory in the mining industry, our endeavour has been to give factual data in terms of risks of heatstroke by which ventilation control should be judged. The extraordinary thing we found in 1950 was that we had the Wet Kata thermometer — but no-one could really tell us the wet kata reading at which there was a risk of heatstroke, nor could they tell us the level at which efficiency would be markedly affected and, least of all, could they tell us when individuals would be uncomfortable. This situation fortunately is changing very markedly as Mr. Martinson has very rightly said. We have spent the past 20 years in trying to give factual information on the levels of thermal stress at which we can quantitatively indicate the heat stroke risks. This has not been an easy task. First of all it has been difficult to try and put together the various factors in the thermal environment which are responsible for heat stress. I distinguish between heat stress which is the factor in the environment which causes strain-physiological response. This took a long time and finally Dr. Duncan Mitchell and Dr. Whillier a few years ago came up with specific cooling power as probably the best way of putting together the four factors of environmental heat-stress and we have in the last few years been able to link them with risks of heatstroke in specific quantitative terms, 1 in 1 000 to 1 in 1 000 000 at different specific cooling powers. We expressed this originally in terms of effective temperature but this can be readily changed to specific cooling power.

A point I want to make here is that this was not a simple task. As Mr. Martinson has again indicated it is a very difficult task indeed and we had to give these risks of heat stress in terms of acclimatised and unacclimatised people. Very roughly there is a 3 degrees wet bulb temperature difference between acclimatised and unacclimatised people, with acclimatised people being safe at 3 degrees wet bulb temperature higher than unacclimatised.

Perhaps even more astonishing in terms of the way in which we had been looking at this problem earlier, and this applies to every type of hazard, is that if you put a number of people, acclimatised or unacclimatised, into a hazardous condition then you get a wide range of individual variation in response and this makes the problem a very difficult one indeed to cope with. If we took a condition of, say 32°C, a fairly severe condition, and a standard work rate and we put 100 acclimatised men into that condition and measured oral temperatures, we found that the type of distribution we got was not the old gaussian curve but a curve which was very heavily skewed. A skew towards the right, towards the more

dangerous temperatures. Unless you take account of this in assessing any of your risk factors you can be led vastly astray.

Mr. Martinson has emphasized the need to base our environmental control of mine atmospheres on accurate estimates of the dose responses of any hazards that occur in the mines. I think that this is extremely timely. He has alluded to the classic studies of the late Derek Beadle in this regard. It is an astonishing situation that in 1975 we can only refer to one classic piece of work in this regard in South Africa. Surprisingly, though, Mr. Martinson has not referred to the new Occupational Diseases in the Mines and Works Act which I think is going to have tremendous impact on our thinking in this regard. I think this new Act is going to strengthen his thesis enormously. This new Act empowers the Minister of Mines to declare diseases, other than pneumoconiosis and tuberculosis, as due to risk work. The only way, which is fair to the employer and the employees, in which this Act can be made to operate, is by means of careful epidemiological studies of the dose response to underground hazards. The Minister has taken note of this problem and we are very hopeful that diseases will not be declared until there is sound epidemiological information that the disease is at greater risk in the mining population than a controlled population. This new Act is going to put the emphasis exactly in the direction Mike Martinson has emphasized. It is going to lead to a tremendous increase in epidemiological work which will give us the clue as to the level of the exposure to, not only dust, but also a whole host of other underground hazards. It will give us the level of exposure below which we should aim. On your behalf I would like to thank Mike Martinson again for an extremely timely paper.

SMRE ABSTRACTS

A STUDY OF THE INTERCHANGEABILITY OF GAS DETECTOR TUBES AND PUMPS

F.H. Colen

Am. Ind. Hyg. Ass. Jnl Nov. 1974 **35** (11) 686-694

This study investigates interchangeability of the length-of-stain gas detector tubes and sampling pumps of different manufacturers and the obtaining of acceptable results. Carbon monoxide was used as the contaminant and various relationships such as pressure-time, flow rate-time, and actual interchange data were evaluated. Interchanging gas detector tubes and sampling pumps of different manufacturers is not recommended. 3 refs., 5 figs., 5 tables.

EVALUATION OF PORTABLE, DIRECT-READING COMBUSTIBLE GAS METERS

C.S. McCammon

U.S. Natn. Inst. Occup. Saf. Health HEW 74-107

The National Institute of Occupational Safety and Health tested portable instruments designed to measure combustible gases for twenty specific design and performance characteristics. Nine totally portable combustible gas meters, each weighing less than 8 pounds and occupying less than 0.5 cubic feet of space, were tested. Known concentrations of hexane, benzene, and methane were dynamically generated in the range of 0-100% LFL to test the meters' performance. From the results of this test, realistic performance specifications are recommended for two classes of combustible gas meters. These specifications will be used as the basis for future NIOSH certification regulations for combustible gas meters. 1 ref., 7 figs., 17 tables.

EVALUATION OF PORTABLE, DIRECT-READING NO₂ METERS

B.A. Johnson

U.S. Natn. Inst. Occup. Saf. Health HEW 74-108

The National Institute for Occupational Safety and Health (NIOSH) has undertaken a program to evaluate the performance of many types of portable direct reading instruments. The purposes of this