

Occupational hygiene science and its application in occupational health policy, at home and abroad*

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This paper examines the role of occupational hygiene in the overall framework of occupational health. It draws attention to the unique combination of required individual science subjects, and to the way in which occupational hygiene science contributes to the practice of occupational hygiene in the real world. It focuses in particular on occupational exposure standards. The paper provides, as an example, the specific case of occupational aerosol exposures. It is here that scientific research has made a notable impact on standards and led to a considerable degree of international harmonization. Finally, some broader insights into occupational exposure standards are given, based on experience gained during visits to a number of contrasting countries. The similarities and differences between the various national approaches help indicate what is generic in how standards are set. Such insights provide a basis for further international harmonization in the future. It is concluded that occupational exposure standards appear to be most effectively applied in countries where there are strong occupational hygiene cultures.

Key words: Aerosols; international issues; occupational exposure limits; occupational health policy; occupational hygiene.

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INTRODUCTION

The subject of occupational health touches on many disciplines. An occupational health policy is the outcome of political behaviour by which individuals or groups of individuals strive to influence a given piece of occupational health-related legislation. It is an envelope that identifies the scope for implementation of a given regulation. By contrast, a standard (*e.g.*, such as an occupational exposure standard) is a measurable reference point by which the success of the desired policy can be evaluated. Much of what is embodied within occupational health standards policy is influenced by considerations of both social and natural science. Although the dynamics of the development and implementation of occupational exposure standards are complex, it is nonetheless clear

that occupational health standards require a large contribution from scientists.

Occupational exposure standards set out to minimize occupational sickness and injury arising from occupational exposure to hazardous substances or agents. Here, occupational hygienists are an important interest group. These are people with broad multidisciplinary scientific training, traditionally grounded in the physical, life and, increasingly, behavioural sciences. Their mission — defining the field of occupational hygiene itself — is the anticipation, recognition, evaluation and control of potential hazards in the working environment. Thus, occupational hygienists are seen to be partners with occupational health physicians, toxicologists and nurses. This ‘team approach’ concept has become a central philosophy in the study and practice of modern occupational health. Ronald E. Lane, the first professor of occupational medicine at a British university, noted in his 1978 memoir¹ that ‘... the establishment of occupational hygiene ... was, in my view, a logical and essential development. Without the hygienists’ accurate measuring techniques, the doctor in industry has a very restricted value. It is important to realize, however, that our

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spheres of action are complementary; the hygienist cannot replace the doctor any more than the doctor can work effectively without the hygienist'. This paper identifies the role of occupational hygiene science in occupational health standards policy, and illustrates the nature of occupational hygiene science by reviewing a long-standing area of interest and its development in recent years. Finally, it discusses how this all plays out in the international arena, attempting — in the process — to draw together some of the various threads in this complex multi- and interdisciplinary scenario.

A FRAMEWORK FOR OCCUPATIONAL EXPOSURE STANDARDS

In the context of occupational health, the term 'hazard' is used to refer to an intrinsic property of an agent that reflects its potential to cause harm. In turn, 'risk' reflects the probability of actual harm. However it is perhaps more helpful to think in terms of 'exposure', which might be defined as '... the intensity, time-averaged in some appropriate way, of the agent of interest at the relevant interface between the environment and the biological system representing the worker'. If the definition given is applied to an airborne chemical which may be inhaled, the 'intensity' is the airborne concentration (say, in mg/m^3). The 'relevant interface' is the region of the respiratory tract where the agent first comes into contact with the exposed subject at a location where it can influence the outcome of the disease in question. So, for example, for dust exposure which can cause ill-health regardless of where in the body the particles are deposited (*e.g.*, particles containing lead), the relevant interface is anywhere in the respiratory tract. So the concentration of interest is that (say, in mg/m^3) which passes through the nose and/or mouth during breathing.

From the definition of exposure comes the concept of an occupational exposure limit (OEL), reflecting the maximum level of exposure that can be accepted (according to whatever definition of 'acceptable' is applied). In turn the OEL is an important component in an occupational exposure standard, but is not the only one. A more general, ideal, health-based standard should contain:²

- criteria for exposure, which identify the agent and its specific physical, chemical and/or biological properties relevant to a specific adverse health outcome;
- reference to monitoring instruments and analytical methods with performance characteristics matching the defined exposure criteria;
- reference to a monitoring strategy which sets out to assess exposure in a manner which is representative of the temporal histories and variability of workers' exposures;

and finally, and only after full consideration of the preceding:

- a health-based OEL derived from considerations of the effects of exposure at various levels, known incidences of the prevalence of the health outcome in

question, and what might be an 'acceptable' level of risk.

An occupational exposure standard might also include considerations of the control of workers' exposures, including not only engineering control of the environment itself, but also control by the deployment of personal protective equipment, management systems and behaviour modification. So, in effect, occupational exposure standards define the whole field of occupational hygiene and identify the range of sciences that are encompassed. Table 1 summarizes this view, where the list is comprehensive, but not necessarily exhaustive. It provides the basis for the education and training of occupational hygiene professionals in the modern era. The importance of this view is acknowledged particularly strongly in the United States, where the discipline of occupational hygiene (or 'industrial hygiene' as it is still widely referred to there) has been formally recognized for over 60 years. In the USA, occupational hygiene is a major component of the occupational health and safety postgraduate training programmes publicly funded by the National Institute for Occupational Safety and Health (NIOSH), most notably at its 15 multi- and interdisciplinary Educational Resource Centres (ERCs) located at major universities throughout the country. Individual occupational hygiene programmes at these centres are assessed on the basis of their commitment to recognizing occupational hygiene as a scientific field, and how they relate in an integrated way with the other occupational health disciplines. In fact, such centres are required to contain at least three of the following elements: occupational hygiene, occupational medicine, occupational health nursing and occupational safety. In addition, they are required to provide programmes in continuing education for active occupational health professionals.

OCCUPATIONAL HYGIENE SCIENCE: A CASE IN POINT

A case in point to illustrate the importance of occupational hygiene science relates to the aerosol exposures that occur in so-called 'dusty industries'. Those aerosols may include not only dusts originating from the mechanical handling of dry materials but also mists arising from mechanical disruption of liquids and fumes arising from the condensation of vapour and aggregation of primary particles. So the industries in question range from mining and quarrying, to smelter and refining, to welding and brazing, *etc.*

The history of aerosol science in the context of occupational hygiene is reviewed in a recent essay by Walton and Vincent.³ An underlying thread is the role of particle size. It governs (a) the nature of human exposure, inhalation and deposition in the respiratory tract; (b) aerosol exposure measurement and (c) the technical control of exposure as required by standards. As early as 1913, McCrea⁴ first noted that it was the finer particles that penetrated deep enough into the lung to be associated with pneumoconiosis. Subsequently, for many years, the

Table 1 Scope of occupational hygiene science and how it relates to: (a) the scope and definition of an occupational exposure standard and (b) the widely-accepted definition of the occupational hygiene discipline in terms of the 'anticipation, recognition, evaluation and control' of potentially hazardous exposures in the workplace

Component	Specific science subjects featured ^a
Criteria for exposure assessment ('Anticipation')	Physical properties of matter Physical agents (noise, heat, light) Radiation physics (ionizing and non-ionizing) Aerosol science Fluid mechanics Organic chemistry Physiology
Instrumentation ('Evaluation')	Aerosol science Fluid mechanics Analytical chemistry Engineering Computers and computing
Exposure assessment strategies ('Anticipation and evaluation')	Statistics
Occupational exposure limits ('Recognition')	Toxicology Epidemiology Human diseases (or introductory medicine)
Control of exposures ('Control')	Engineering (mechanical and chemical) Aerosol science Fluid mechanics Physical properties of matter Physiology Ergonomics Behavioural sciences Management sciences

^a Core general scientific disciplines: physics, chemistry, biology, mathematics.

number count concentration of particles in the range of geometric diameter (as measured by light microscopy) below about 5 μm was used as the metric for the health-related exposures of workers in many dusty industries. In 1943, however, Bedford and Warner⁵ showed that, at least for certain types of dust-related lung disease, the mass concentration of particles is a more appropriate exposure metric. Later, with the emergence of results from inhalation research employing human volunteer subjects, the definition of the size of particles penetrating into the respiratory tract in terms of particle aerodynamic diameter was found to be more appropriate. This metric incorporates the effects not only of the physical size of the particle but also its shape and density. It underpinned the 1952 British Medical Research Council's (BMRC) definition⁶ of what has been referred to ever since as 'respirable aerosol', defining particles of sufficient aerodynamic fineness to be able to penetrate into the alveolar region of the lung. From this starting point, occupational exposure standards began to emerge in the 1960s for many substances defined in terms of the mass concentration of particles conforming to the definition of respirable aerosol. In the late 1970s, the international occupational hygiene community embarked on consolidation and extension of the ideas that had been evolving for the past several decades, initially through the activities of an ad hoc working group of the International Standards Organization (ISO),⁷ later to be joined by the American Conference of Governmental Industrial Hygienists (ACGIH)^{8,9} and the Comité Européen Normalisation (CEN).¹⁰ In the new rationale that emerged, it was decided that occupational exposure standards

should be defined for each substance occurring as aerosol in terms of the particle size fraction most relevant to the health effect in question. Three aerosol fractions were proposed:

1. *Inhalable aerosol*: This represents the fraction of total airborne particles that enters through the nose and/or mouth during breathing. It is appropriate for substances which represent a systemic health risk after deposition anywhere in the body (*e.g.*, lead, cadmium) or are associated with local effects high up in the respiratory tract (*e.g.*, nickel, chromium, wood dust, *etc.*).
2. *Thoracic aerosol*: This represents the fraction of inhalable particles that penetrate down past the larynx and into the lung. It is appropriate for substances (*e.g.*, sulphuric acid mist, some types of metal working fluid, cotton dust, *etc.*) which represent a health risk through effects in the airways of the lung.
3. *Respirable aerosol*: This represents the fraction of inhalable particles that may penetrate down to the alveolar region of the lung. It is appropriate for substances (*e.g.*, coal and other mineral dusts) which represent a health risk only through effects in the deep lung.

By the mid-1990s, there had emerged widespread international agreement about these criteria.¹¹ Now — at the time of this writing — occupational exposure standards around the world are being increasingly framed in these terms. Such harmonization is due in no small measure to the consensus that had emerged within the occupational hygiene community about the scientific

principles concerning exposure characterization and assessment.

Recent research in this area has focused on three main areas. These are: (a) the development of sampling instruments that can measure aerosol exposures in a manner which is physically consistent with one or more of the above criteria; (b) their implementation in actual workplace exposure assessments and (c) the impact of such changes on occupational exposure standards. Some of this is summarized in what follows.

Aerosol sampling instruments

Aerosol samplers have continued to be an important tool by which to assess the occupational exposures of workers to airborne particles. Since the 1950s, aerosol science has taught us that it is not sufficient simply to use a pump to draw air through a filter in a filter holder of arbitrary design. The aerodynamics of particle transport in the distorted air flow around the sampler, or more especially around a sampler mounted on the body of a worker (as is the case in personal sampling), dictate that some particles are collected more efficiently than others. Sampling efficiency depends on the particle aerodynamic diameter, the shape and size of the sampling device, the external wind speed and direction, and the size and shape of the body on which the sampler is worn. The physics of this scenario is very complicated, and to this day remains poorly understood. This in turn is continuing to stimulate research, mainly in Europe and the United States, into the basic sampling process. Such knowledge will permit the design — from first principles — of more representative or relevant aerosol samplers. In the meantime, however, the design of samplers matching the listed criteria is being carried out empirically, frequently using 'cut-and-try' procedures guided by what limited basic knowledge is available. This is particularly true for samplers for the inhalable fraction, which are particularly sensitive to the external factors summarized above. Full reviews of the state of aerosol sampling science are given elsewhere.^{2,12}

Implementation of new sampling instruments

Currently there is considerable interest in implementing new samplers that demonstrably collect the inhalable aerosol fraction. The intention is that such samplers should replace the present conventional approach of collecting so-called 'total' aerosol, since — as we now know — the latter is highly dependent on the particular instrument used, and so provides results that are entirely arbitrary in relation to health effects. This, of course, has implications for standards because changing the sampling instrument is very likely to change the level of measured exposure. This may occur even in situations where exposure may not have actually changed. The ACGIH, in its successive annual lists of occupational exposure limits (known as 'threshold limit values', or 'TLVs') from about 1993 to 1995, acknowledged this as a problem. So, prior to actually introducing new TLVs based on the inhalable fraction, ACGIH called for ' . . .

side-by-side sampling studies, using older "total" and newer inhalable . . . sampling techniques . . . to aid in the appropriate replacement of current "total" particulate TLVs'.

With this in mind, comparative studies have been carried out by a number of research groups in Scandinavia, Europe, the United States and Australia. These involved the assessment of exposures of workers within well-defined similarly-exposed groups (SEGs) in a wide range of industrial settings in which the workers in question wore two samplers simultaneously for full working shifts. Most of the sampler pairs comprised: (1) a sampler which had been demonstrated as having met the inhalability criterion (*e.g.*, the IOM inhalable aerosol sampler first proposed by Mark and Vincent¹³) and (2) a sampler which was previously — and in most cases is currently — used for collecting 'total' aerosol. The latter varied from study to study depending on the sampler most widely used by occupational hygienists in the country where the study was carried out. The results are summarized in Table 2, and these have been discussed in detail elsewhere.¹⁴ They show a very consistent tendency in which inhalable aerosol exposures are greater than the corresponding 'total' aerosol exposures, regardless of the 'total' aerosol sampler used. They also show that the differences between inhalable and 'total' aerosol exposure tend to be greater for workplaces where the aerosol is coarser, and this is as would be expected on the basis of the physics of aerosol sampling.¹²

Two of the latest studies include those by Werner *et al.*¹⁵ for a Norwegian nickel refinery and one by Terry and Hewson¹⁶ for Australian mining operations. The Terry and Hewson study is particularly relevant to British standards. Here, a three-way comparison was made between the IOM inhalable aerosol sampler, the 37-mm closed-face sampler that is widely used in many countries around the world, and the so-called '7-hole' sampler. The latter is currently the basis of aerosol standards in both Australia and Britain. In both countries, occupational exposure limits for many aerosols are expressed in terms of the inhalable fraction, and it is assumed that the 7-hole sampler is a suitable sampler.¹⁷ One of the rows in Table 2, where the 7-hole and 37-mm samplers are compared, reflects this assumption. But, in fact, this has been known for some time to be erroneous, based on both earlier and more recent wind tunnel studies of personal aerosol sampler performance.^{13,18,19} This was confirmed in the real world in a study by Terry and Hewson, who found that the 7-hole sampler undersampled with respect to the IOM sampler (which is generally considered to be the best reference for inhalable aerosol), although not by as much as the 37-mm sampler.

Impact on occupational exposure standards

The switch to new sampling methods for inhalable aerosol derives from improved understanding of the nature of human exposure to aerosols and how that relates to health effects, as well as the corresponding development of new instrumentation. It is therefore driven strongly by

Table 2 Summary of results available so far from intersampler comparisons in workplaces (as summarized by Werner *et al.*,¹⁴ and including recent new results from Werner *et al.*¹⁵ for exposures at a Norwegian nickel refinery and Terry and Hewson¹⁶ for exposures in the Australian mining industries)

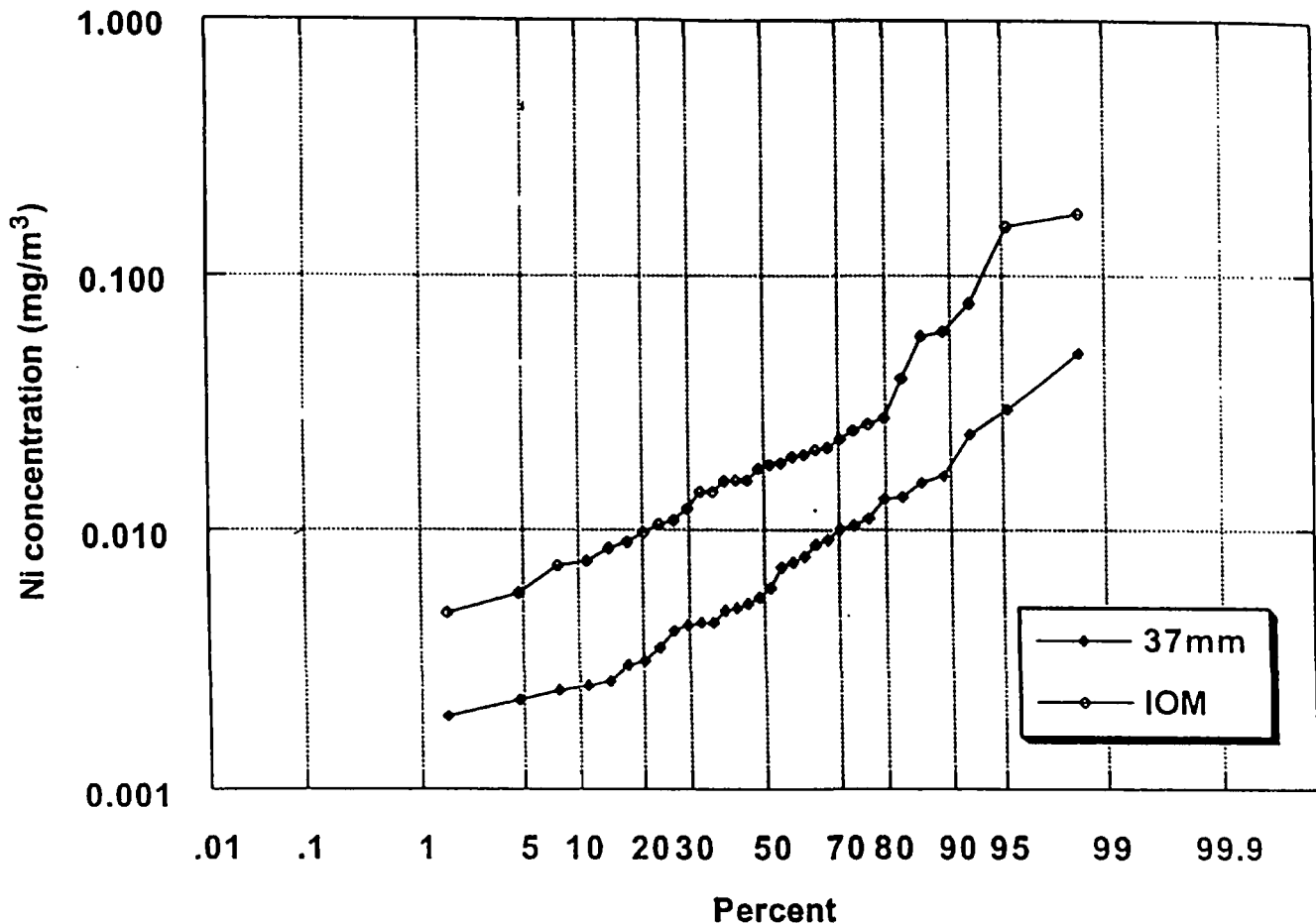
Industry (country)	Sampler for 'total'	Sampler for inhalable	Aerosol	n	S
Bakeries (Sweden)	37-mm (open)	IOM (filter only)	Total aerosol	29	1.82
Borates/boric acid (Europe/USA)	37-mm (closed)	IOM	Total aerosol	58	2.20
Ni Mine (Canada)	37-mm (closed)	IOM	Ni	32	3.20
Ni Mill (Canada)	37-mm (closed)	IOM	Ni	21	2.72
Ni Smelter A (Canada)	37-mm (closed)	IOM	Ni	35	1.65
Ni Smelter B (Canada)	37-mm (closed)	IOM	Ni	23	2.84
Ni Refinery A (Canada)	37-mm (closed)	IOM	Ni	36	2.12
Ni Refinery B (Norway)	37-mm (closed)	IOM	Ni	50	2.05
			Cu	38	2.24
			Co	35	2.23
			Fe	37	2.16
			Pb	22	1.70
Ni Alloy (USA)	37-mm (closed)	IOM	Ni	46	2.29
Ni Electroplate A (USA)	37-mm (closed)	IOM	Ni	21	2.02
Ni Electroplate B (USA)		IOM	Ni	21	3.01
Pb Smelter (USA)	37-mm (closed)	IOM	Pb	151	1.77
			Cd	54	1.76
Machine shop	37-mm (closed)	IOM	Straight cutting oil	23	2.96
Woodwork (Norway)	Closed-face cassette, 4-mm entry	IOM	Wood dust	10	1.79
Repair shop (welding) (Norway)	Closed-face cassette, 4-mm entry	IOM	Total aerosol	15	0.95
			Al	15	1.36
Lead battery (Norway)	Closed-face cassette, 4-mm entry	IOM	Total aerosol	11	2.36
Lead battery (Norway)	Closed-face cassette, 4-mm entry	IOM	Pb	11	1.29
Aluminum foundry (Norway)	Closed-face cassette, 4-mm entry	IOM	Total aerosol	36	3.57
Woodwork (Denmark)	Closed-face cassette, 5.6-mm entry	IOM	Wood dust	40	1.79
Mining (Australia)	7-hole	IOM	Total aerosol	27	2.13
Mining (Australia)	37-mm (closed)	IOM	Total aerosol	22	3.02
Mining (Australia)	37-mm (closed)	7-hole	Total aerosol	18	1.64

progress in occupational hygiene science, both in the laboratory and in the field. But such changes may produce significant impacts on the practice of occupational hygiene. Firstly, aerosol exposure levels will appear to rise, and in turn so too will the exceedance probability for compliance with existing standards. Secondly, they will have an impact on the process of setting new occupational exposure standards, since it is now necessary to think of exposures in the exposure-response scenario as being expressed in terms of the new health-related criteria.

To examine the effect on compliance with existing standards, Figure 1 shows a typical set of exposure data for the nickel exposures of workers in a deep nickel mine. They are plotted as cumulative distributions for both inhalable aerosol (as measured using the previously-mentioned IOM sampler) and 'total' aerosol (as measured using the 37-mm sampler which is widely used by occupational hygienists in North America). When plotted as shown on log-probability axes, the observed straight-line tendency indicates that both exposure distributions are approximately log-normal. The state of exceedance with respect to any exposure limit, whether expressed in terms of 'total' or inhalable aerosol, may be ascertained most simply by visual inspection of such a figure. Bearing in mind that the current TLV recommended by ACGIH for nickel is 1 mg/m³ expressed in

terms of 'total' aerosol and the proposed new TLV is 0.2 mg/m³ expressed in terms of inhalable aerosol,⁹ it is clear from Figure 1 that exceedance probabilities for both standards are very small. Thus, in reality, there are no serious concerns about health effects in that group of workers, and there is likely to be no serious impact arising from adoption of the proposed new TLV. However, if we were to assume — hypothetically — that the exposures to nickel had all been an order of magnitude higher (as might well be the case in some industrial settings), then the picture would be completely different. First, by reference to the 'modified' Figure 1, simply switching from a TLV based on 'total' aerosol to one based on inhalable aerosol (without changing the numerical value) is seen to result in an increase in exceedance probability from less than 1% to greater than 5%. Most occupational hygienists would regard that situation as continuing to be acceptable. But if, at the same time as the change in criterion, the proposed reduction in the numerical value of the TLV were to be applied, the exceedance probability would increase sharply to about 40%. This would no longer be acceptable. A standard based on the new TLV (new criterion plus lower numerical value) would have considerable implications for the industry in question, in terms of both the requirement to carry out more stringent control measures and, consequently, the increased cost.

Figure 1. Cumulative nickel aerosol exposures of workers in a deep nickel mine, for both inhalable nickel (as measured using the IOM inhalable aerosol sampler) and 'total' nickel (as measured using the 37-mm closed-face sampler).



On the question of standards setting itself, information like that summarized in Table 2 needs to be interpreted carefully. Although it might at first seem tempting, a simple across-the-board upwards-scaling of occupational exposure limits (*e.g.*, TLVs) is not appropriate. This is because each workplace would have a different scaling factor depending on local conditions, even for the same substance. Instead, therefore, it is recommended that any scaling of data should take place at the stage of considering the exposure-response relationship for each substance. If data relevant to that relationship were originally available from workplace exposure assessments, and those data were expressed in terms of 'total' aerosol, they should then be scaled appropriately before the exposure-response relationship is used to determine the limit value. If no such data are available (*e.g.*, the information for the standard is to be based primarily on animal inhalation data), then it has to be assumed that the original intention of the exposure data was to reflect actual inhalation. In that case there should be no scaling.

This brief overview of one area of work-related hazard reveals that the field of occupational hygiene science can play a vital role at all stages of the process of setting and complying with occupational exposure standards. This complements the contributions from the 'traditional' fields of occupational medicine and epidemiology.

THE INTERNATIONAL DIMENSION

Any occupational exposure standard requires agreement between all the influential parties. Which parties are influential and which are not is dependent on the type of society in which the standard is expected to operate. In most modern societies, however, science plays an important role, at the very least in placing the standard in the right 'ball-park' where it may be effective in protecting worker health. How effective science is in that role, and how far it can go, is governed by the extent to which scientists can agree on the principles, interpretation of the data and their application. Referring again to standards for occupational aerosol exposures, occupational hygiene science has been very successful in guiding the path towards international harmonization of exposure criteria. By the early 1990s, most of the major standards-setting bodies throughout the world — led by the ISO, CEN and ACGIH — had agreed on both the principles of particle size-selective sampling and on the quantitative definitions of the various health-related fractions. The way is now clear for new standards based on these. Such a degree of harmony is perhaps surprising, but it should be noted that the process towards achieving just that one point took over 10 years. On the other hand, from previous experience with changes in occupational health standards, perhaps we learn that the apparently slow

Table 3 Summary of the main features of occupational exposure standards in several countries, also including reference to the American Conference of Governmental Industrial Hygienists (ACGIH)

Country	Basis	Health-based?	Remarks
United States	'... protects nearly all workers'	As a starting point, then modified on basis of feasibility, cost-benefit analysis, etc.	Strong occupational hygiene history and culture
United Kingdom	'... protects workers with reasonable certainty'	Yes, where the proposed health-based standard is feasible; otherwise on the basis of feasibility, cost-benefit analysis, etc.	Strong occupational hygiene history and culture
Australia	'... protects nearly all workers'	As a starting point.	Growing occupational hygiene culture
Norway	'... administrative norms	Not explicitly	Growing occupational hygiene culture
Russia	'... protects all workers	Yes, according to strict toxicological principles	No coherent occupational hygiene culture
plus ACGIH	'... protects nearly all workers'	Yes, according to pragmatic occupational hygiene, toxicological and epidemiological principles	A professional body whose activities revolve around occupational hygiene practice and science

pace of the change is not itself so surprising. Nor is it necessarily undesirable, since it would not be good policy to change the basis of a standard every time new knowledge comes to light. Such new knowledge must be fully disseminated and digested.

Agreement about aerosol exposure criteria is only the first, and perhaps a small, step along the way towards fulfilling international harmonization of standards. However it is clear that, in the part of the standard where we come to discuss numerical values for OEL, there is scope for wide disagreement even among scientists. The situation is compounded still further by the fact that many of the scientific issues raised cut across scientific disciplinary boundaries.

Health-based standards, which have been the subject of all the preceding discussion, represent the ideal by which we would expect to be able to protect the health of all workers. An idealist might argue that nothing less should be accepted. But, in the real world, we have the type of standard that is embodied in public policy and hence is enforceable by law. Public policy can not be determined only by scientists, but must also involve those who are ultimately accountable to society at large. Hence, other forces come into play such that a regulatory standard inevitably includes not only the scientific argument about how much exposure leads to how much ill-health but also considerations of technical feasibility and socioeconomic and sociopolitical factors. In addition, the contribution of cultural and moral dimensions cannot be ignored. The result is often a pragmatic OEL that, hopefully, represents a fair compromise between all the competing influences. It is inevitable that this may be set at a higher level than the corresponding health-based OEL.

The issues and dilemmas raised above are implicit in the differences which are found between nations. In a recent study involving visits by the author to several countries, the various national approaches to occupational exposure standards were reviewed. The countries studied were Australia, Norway, Russia, the United Kingdom and the United States. The purpose of the

study was to examine similarities as well as differences, and so to identify what is generic — and hence may be fertile ground for international harmonization — and what is driven by local concerns, politics and cultures. The full details of the study are published elsewhere.²⁰ The main features are summarized in Table 3. In this table, in addition to the five national standards, the ACGIH approach — which is not regulatory, but aimed at providing guidelines for professional occupational hygienists — is included by virtue of the fact that it remains highly influential in the deliberations of most national bodies. Indeed, arguably, it remains the most widely respected standards-setting body by virtue of the pragmatic application of sound science that it has brought to bear on occupational exposure standards for more than 50 years.

Table 3 includes situations where the explicit intention is to protect all workers all of the time (*e.g.*, Russia), or where the intention is to protect most of the workers most of the time (*e.g.*, the United Kingdom, the United States and Australia). Elsewhere, the actual level of protection afforded by the standard, which would acknowledge the existence of some sort of 'safe' threshold, is not explicitly stated (*e.g.*, Norway). Some standards reflect — to a greater or lesser extent and in different ways — the feasibility that a given standard can actually be achieved in the real world (*e.g.*, Australia, Norway, the United Kingdom, the United States) while others are based entirely on health effects (*e.g.*, Russia, ACGIH). Of the systems listed, the Russian approach is the most stringent, since its limit values are toxicologically based on the estimated level of exposure corresponding to the '... minimum dose that would trigger changes beyond the limits of physiological adaptation reactions' (Sanotsky *et al.*²¹). By virtue of this definition, Russia sets regulatory limit values that, for most substances, are much lower than elsewhere. However, information about the level of compliance with such limits is scarce, and limited by the amount of exposure assessment that is routinely carried out. Indeed, it is interesting to note that personal sampling, which has long been the cornerstone

of occupational hygiene practice in the West, is almost unheard of in Russia (Vincent *et al.*²²).

What is interesting to note in Table 3, and may be true elsewhere, is the role of the occupational hygiene discipline, in terms of both occupational hygiene science and practice. In some countries, it is strong, in some cases dating back more than 50 years (*e.g.*, the United Kingdom and the United States). In other countries, it is growing rapidly (*e.g.*, Australia and Norway). In such countries, occupational exposure standards contain a strong element of pragmatism, derived directly from the central occupational hygiene considerations of exposure anticipation, recognition, evaluation and control. But in Russia, even though the discipline of occupational medicine has been very well developed for many years (and, in fact, its own system of occupational exposure standards pre-dates even those of the United States), a strong occupational hygiene culture seems to be notably lacking. Here, the standards-setting process is dominated by occupational physicians. So too is the process of enforcing them through inspections. The important component of exposure assessment and control, the foundations of the occupational hygiene discipline, appears to be largely absent. From this it may be argued that implementation of Russian standards, and/or the setting of more realistic ones, will be achieved in that country only when a strong and distinctive occupational hygiene community has been established.

CONCLUDING REMARKS

The insights provided by Professor Lane and other such enlightened occupational health practitioners and scholars rightly propelled occupational hygiene towards its current status as a 'discipline'. As it has matured, occupational hygiene has established its twin branches of practice and science, the latter clearly carried out in support of the former. In the United States, a very strong culture has emerged along these lines. This is underscored, and indeed perpetuated, by the 20-plus years of experience with the 15 NIOSH-funded ERCs for interdisciplinary occupational health education and training. There are now 15 such centres in number, and they are located at major universities throughout the country. Importantly, most such programmes are located within Schools of Public Health, and so become integrated within a wider culture where public health and all its sub-disciplines are uniformly valued. The continuing public support of the individual NIOSH-ERCs depends on their commitment to the interdisciplinary linking of occupational medicine, occupational health nursing, occupational safety and, of course, occupational hygiene, and in turn to the strong underlying requirements to link the practice and the science of occupational health. The strength of this culture is further reflected in the number of senior academics and researchers who are active specifically in occupational hygiene, to an extent which is not at present matched elsewhere.

As has been stated, a strong occupational hygiene culture, deeply rooted in science, is an important part of the process of developing realistic yet meaningful occupational health standards. It is also important in ensuring that these are followed up through actions on the parts of employers as required by appropriate occupational health standards policies. Experience suggests that countries strongest in occupational hygiene have occupational health standards that not only are sufficiently protective of workers but are also the most pragmatic and fair to employers. As a result, in those countries, enforcement is more achievable — and hence actually achieved.

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