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Research Articles

Research Initiatives in Exposure Assessment

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Abstract

Exposure assessment is an important component of the occupational exposure control strategy, in particular because it is used both to examine problems and confirm solutions. Three initiatives are discussed that are on the cutting-edge of current exposure assessment research: 1) direct-reading, near-real time monitors, 2) sampling and analytical methods of greater sensitivity and 3) models to assess exposure without measurement. Direct-reading, near-real time monitors are coming of age with the development of light-weight batteries, miniaturized detectors and computer chip technologies. They present challenges in use in that the amount of information increases and it is available to the worker as well as hygienist. This challenge is explored in relation to the development of coal-mine dust and diesel exhaust monitors. Exposure guidelines are continually set lower with consequent impact on the ability of standard sampling and analytical methods to make useful measurements. It is now usually necessary to develop both the sampling and analytical portions of the method to meet this challenge. Examples where lower limit values have recently been proposed include wood dust, respirable silica, and beryllium. Asbestos is an example of where a limit value has been frozen at the limits of method capability. Sophisticated analytical methods may be expensive and beyond the reach of many professionals in poorer countries. Models that assess exposures without measurements are becoming popular, but must be validated through testing in well-measured environments.

Keywords: Exposure assessment, Air sampling, Direct-reading instruments, Threshold limit values, Control banding

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Introduction

Exposure assessments may be performed for several reasons. One reason is to provide information that can be used to develop procedures to reduce exposures, another is to provide data that can be compared to limit values, and a third is to be able to recommend appropriate controls. The greatest effort with respect to developing exposure assessment methodologies took place in the 1970' s when the Standards Completion Program (SCP) resulted in the current NIOSH Manual of Analytical Methods (NIOSH, in series). Similar efforts by government and others covered similar ground (OSHA, in series; HSE, in series). These methods were able to determine compliance with limit values of the time and were supported by sampling strategies developed with compliance in mind (Leidel et al., 1977). Thus there appeared to be little additional research necessary, apart from occasionally updating the manual with methods for a few new substances each year. Many new exposure assessment methods are developed and published by academia and government agencies such as the US Departments of Defense and Energy that have a need for new or improved methodologies. Today, there is pressure to research both old and new avenues. Hygienists want information to that will assist with reducing exposures without waiting for results to return from the laboratory weeks later, and they can see the benefit of interacting with the worker by means of direct-reading instruments. Many of the methods developed under the SCP are unable to generate useful data for comparison with lowered limit values, so that more sensitive techniques are required involving changes to both sampling and analytical method components. Finally, it has been recognized that exposure assessment tools are also needed where measurements are not being made, and probably will not be made due to lack of resources. These three issues of direct-reading instruments, challenges to current sampling and analytical methods and the concept of qualitative exposure assessment and management ("control banding") are described in more detail below.

Direct-reading Instruments

Direct-reading instruments have been part of the industrial hygiene tool kit for many years (Woebkenberg and McCammon, Jr., 2001; Pui and Chen, 2001). During that time, the importance of these devices has been recognized by industrial hygienists, but they have usually been developed for the hygienist and there is a mind-set that a skilled practitioner is needed to select the appropriate tool, know its limitations, and interpret the results. However, it is only recently that miniaturization of detectors, electronics and, most importantly, batteries has allowed them to really be used as personal monitors. Miniaturization has also led to cost reduction and this is also an important step in making a personal monitoring system available to all workers. While a hygienist may have control of the selection of monitors, and be aware of their limitations, the availability of personal monitors to all workers presents a challenge to the role of the hygienist in

interpretation. Unless the device is simply a data-logger with information only relayed after the fact, real-time outputs will be obvious to the worker. It will not be possible for a single industrial hygienist to be the interface between possibly dozens of workers and the devices they are wearing that are providing a stream of constantly updated data. However, real-time data can only be used to its full potential in real-time. There are three alternative options:

1) telemeter the data from each monitor to a central location where the hygienist can interpret data from several workers simultaneously, and who would be able to set an alarm or call the worker if necessary. Clearly, this is cumbersome and reaction to adverse situations may be slower than necessary,

2) reduce the decision heuristic to a software program and incorporate it into the technology. If a computer can be programmed to beat a world chess champion, is alarming at a set-point so difficult? However, the factors that go into many hygienic decisions are complex, involving aspects of the interaction of the worker and the emissions sources that are not so simply quantified as a concentration exceeding pre-set value,

3) teach the worker to interpret the data stream and appropriately respond. Workers have experience of instruments with alarm thresholds but may be much less likely to understand the concepts of integrated exposure logging. Potential problems include both misunderstanding and non-compliance.

It is likely that some combination of approaches will provide the best results. NIOSH is currently developing two direct-reading instruments for aerosols in mining, one for coal mine dust (Page et al., 2008) and one for diesel particulate matter (DPM). Neither device is currently commercially available.

Coal Mining Dust

To monitor coal mine dust, a personal dust monitor (PDM) built into the miners' cap lamp battery, employs a combination of the above approaches to reduce mine workers exposure.

1.Exposure data, environmental data (in-line and ambient temperature, in-line relative humidity and ambient pressure), and mechanical operational data is recorded and stored in the instrument for periodic downloading and transmittal to experts. This information could be used to assess validity of sample, compliance, need for additional controls and so forth. This post-sampling analysis is superior to the current periodic sampling approach because the occupational health and safety expert has personal, real-time data, and operational data.

2.The software in the instrument has some intelligence to determine if operational parameters exceed preset limits and the user and data file is flagged with that information. However, extensive modeling is required to interpret all possible situations and thus determine reliably if a sample is valid. For example, a rapid mass increase could be caused by a rapid increase in concentration or by a cyclone inversion or other accident. Sophisticated software may be able to distinguish these situations, which generally are not detected on the current long-term filter samples. Complications also arise when other decisions must be made,

such as how do you predict if an overexposure is imminent, or what is the impact of short term exposures on the long term disease development risk. The rules in industrial hygiene are not as proscribed as chess.

3.Education of the worker to respond to the information provided by a direct-reading monitor shows significant promise. An illuminated data display on the top of the PDM continuously shows the dust concentration for the previous 30 min, cumulative mass concentration to that point in the shift, and a projected end-of shift concentration. NIOSH studies on how workers respond to PDM information have shown that workers can act to reduce their exposures based upon the real-time data (Peters et al., 2007).

The power of using and combining these approaches to sampling for the purpose of improving worker health is just beginning to be understood. The ability of management to use direct-reading monitors as a tool to educate and involve the worker in their own health maintenance offers a new approach for industrial hygiene.

Diesel Particulate Matter

The diesel particulate matter (DPM) direct reading device is new to the mining community and is being evaluated for different purposes (Janisko and Noll, 2008). The standard method (collecting on a filter with off-site laboratory analysis) can take weeks to get results and only gives results for the average of the entire shift. This makes evaluating control technologies very difficult. The DPM direct reading device has the potential to be used to evaluate control technologies more efficiently which would result in lower DPM exposures. The principle of operation is based on the transmission of an optical laser through the sample filter (Noll and Janisko, 2007). In future work, the DPM direct reading device might be used to determine where miners may safely work outside of vehicle cabins. The device may also be put in different areas of the mine so that it would be possible to control the concentration of DPM by limiting the number of vehicles permitted to operate in those areas. Currently, mines usually have a few personnel carry direct reading devices that measure gaseous contaminants (e.g. nitrogen dioxide) through the mine to evaluate safe and unsafe areas. A direct-reading DPM instrument can be added to this suite of instruments, and, initially, this is how the DPM direct reading device will probably be used. However, this device also can be worn by miners, used as a diagnostic tool, placed on vehicles beside the miners, or used as an area sampler. Future work will investigate the potential for miners to regulate their own exposure.

Analytical Sensitivity

There have been very few occasions where exposure limit values have been revised upwards and the overwhelming trend is for downward revisions. In many cases, downward revisions are challenging the sensitivity of sampling and analysis methods that were developed around much higher concentrations. The preferred sensitivity is for the limit of quantitation (LOQ) of the method to be less than one-tenth of the

exposure limit value for a sample taken by the usual method, over the averaging time (short or long) covered by the limit value (Kennedy et al., 1995). This allows shorter intervals to be sampled accurately when necessary, and even task-based measurements to be made. Where one-tenth of the exposure limit value is not possible to measure quantitatively, and no alternative methods are available, an LOQ at one-fifth of the value has been used instead. An LOQ greater than one-half the exposure limit value has little practical value, since measurements are often used to characterize the distribution of exposures within a group of employees and over time, and it is not practicable to assess the degree of non-compliance with a standard if a large proportion of the results are only qualitative estimates. Four substances (wood dust, silica, beryllium and asbestos) are selected below to illustrate the point.

Wood Dust

In 2005, the American Conference of Governmental Hygienists (ACGIH) finalized a Threshold Limit Value (TLV®) for wood dust (ACGIH, 2005), which had been under Notice of Intended Change (NIC) since 2001(ACGIH, 2001). The value selected for all dusts (except Western Red Cedar) was 1 mg/m^3 to be sampled in accordance with the inhalable convention. At the same time French national Decree 2003-1254 also came in to force with the same limit value (French national legislation, 2003). Not only was the value selected lower than any recommended or required anywhere else, but the concept of the "inhalable" sampling convention was also relatively new and controversial with respect to wood dust. Different samplers have been used throughout the world for wood dust (Kauppinen et al., 2006). Due to the cubic relationship between mass and volume, large particles when present in the aerosol contribute significantly to the mass collected. Woodworking can produce many particles larger than 10 μm aerodynamic equivalent diameter. Thus even slight differences in the collection efficiency of large particles can result in large differences in concentration values derived from different samplers. Many "total" dust samplers under-sample large particles in comparison to the human mouth and nose and for this reason a sample in accordance with the inhalable convention will result in a greater mass concentration (Lidén and Kenny, 1994). The European SCOEL came to the conclusion that a "total" dust standard of 0.5 mgm-3 was warranted for wood dust, which was supposed equivalent to an inhalable limit value of around 1 – 1.5 mg/m^3 (Kauppinen et al., 2006) based on a study of exposures of woodworkers across the European Union. In this study it was necessary to reconcile measurements made with the standard methods of individual member states with the inhalable convention. Danish and French "total dust" results using the 37 mm closed-face plastic cassette popular in the USA were multiplied by 1.59 to convert them to inhalable dust, this conversion being based on a field study in Denmark of generally well-controlled workplaces. However, this may be an underestimate of the inhalable fraction that would have been measured, since many other published field comparison studies in workplaces with generally higher

average wood dust concentrations in the USA, Canada, Australia and Korea have determined higher ratios, with median ratios clustering around 3-3.5 (Pisaniello et al., 1991; Perrault et al., 1996; Kim and Lee, 1996; Martin and Zalk, 1998; Davies, et al., 1999; Tatum et al., 2001; Harper et al., 2002). A Swedish study with the 25 mm open-face cassette also gave a regression slope of 3.0 (Lidén et al., 2000). Thus the WOODEX estimates of European woodworkers exposed to different inhalable concentrations are also likely to be underestimates, even though the Danish and French results were combined with values from Germany and the U.K. which were obtained using inhalable samplers. The WOODEX study concluded that about 560,000 workers (16% of exposed across 25 EU countries) may be exposed to a level exceeding 5 mg/m^3, 1.5 million workers (41%) may be exposed above 2 mg/m^3 and 2.2 million (62%) may be exposed above 1 mg/m^3. If this is an underestimate, we may have a situation that is rather unusual in modern times: an occupation where perhaps as many as three-quarters of the workforce are exposed above the guideline, and where a substantial proportion of workers is exposed to levels many times higher.

Leaving aside the risk analysis question as to whether there is sufficient evidence of disease in the current "overexposed" working population to support such a limit value and the risk management question of whether the level of disease justifies the cost to industry to implement the controls necessary for compliance, we need to ask whether there is even the possibility of measuring lower concentrations of wood dust. In wood-working shops where wood dust limit values are high the total mass of an air filter sample can be assumed to be wood, since the contribution from other particles is not significant. However, in some occupations, especially in the construction sector, there may be a substantial contribution to the aerosol from cutting, grinding or sanding other materials, for example, brick dust, plaster and cement, and also from disturbed soil. Silica exposures in these trades may complicate the epidemiological interpretation of disease, further supporting the need for an analytical determination of wood dust. With lowered limit values there is a greater rationale for attempting to exclude these interfering dusts. In addition, the lower end of the working range (limit of quantitation) of filter mass measurements is generally thought of as around 0.1 mg (NIOSH, 1994a), equivalent to 0.1 mg/m^3 at a typical sampling rate of 2 liters/min over an 8-hour sample, but very close to the limit value for shorter samples of one hour or less. Inhalable samplers are available at flow-rates up to 10 liters/min (Görner et al., 1999). Also, an analytical method, which uses FTIR analysis of cellulosic components (e.g. lignin, hemicellulose), shows promise in being able to separate wood dust from other components (Rando et al., 2005). This method so far has only been validated in a single laboratory, and it is being evaluated in at least one other. It may be that a method using combination of high-flow sampling and instrumental analysis will be needed, for example, when wishing to take shorter samples to examine the efficiency of process controls. Finally, there is a need to consider the most appropriate type of sampler. Several

samplers that meet the inhalable convention are available, but the inhalable convention fails to intersect zero sampling efficiency before 100 μm aerodynamic equivalent diameter (AED), and says nothing regarding the sampling efficiency of larger particles. Inhalable samplers differ widely in their efficiency for sampling particles that are very large. Recent studies on human inhalability suggest that there is size beyond which particles are not inhaled, and that is somewhere between 80 and 150-200 μm, depending on breathing style (nasal or oral) and other individual factors, such as physiognomy, sex, age, etc. (Lidén and Harper, 2006). At least one commercial inhalable sampler is extremely good at collecting particles that have little chance of inhalation, but which contribute greatly to the total sample mass because of the cubic relationship between mass (volume) and diameter (Harper et al., 2004). The sample would therefore be an overestimate of actual exposure. There are several current research efforts investigating the most appropriate sampler for wood dust.

Silica

It has long been recognized that there is evidence of a silicosis risk at working lifetime exposures below current limit values for respirable crystalline silica (RCS). NIOSH has a Recommended Exposure Limit (REL) for RCS exposure of 0.05 mg/m^3 (NIOSH, 2002). However, the UK Health & Safety Executive has since quantified a risk of 1 in 40 workers (2.5%) developing silicosis after 15 years exposure at 0.1 mg/m^3 and a 1 in 200 (0.5%) risk at 0.04 mg/m^3 (Health & Safety Executive, 2002). The ACGIH recently reduced their TLV for RCS to 0.025 mg/m^3 (ACGIH, 2006). Organizations responsible for setting exposure limits in other countries are considering similar changes. In the USA, the standard cyclone for respirable sampling is operated at 1.7 liters/min, so that a full-shift (8 hr) sample consists of 0.8 m^3, which at the REL is a sample which comprises 80 μg silica. It has long been known from the results of Proficiency Analytical Testing (PAT) samples provided by the American Industrial Hygiene Association (AIHA) that the uncertainty in silica analysis rises as the mass of silica is reduced below 50 μg but is reasonably constant and in an acceptable range at the REL (Eller et al., 1999a). Thus a full-shift sample can be used to demonstrate compliance, but there is little option for doing anything else, such as epidemiological examination of lower exposures or using shorter sampling times to assess task-based exposures. The analytical finish matters little; both X-ray diffraction (XRD) and Infra-red (IR) analyses can give very low limits of quantitation when state-of-the-art equipment is used by careful practitioners following published procedures correctly and with best practice in choice of calibration material, frequency of calibration and numbers of levels of calibration (Eller et al., 1999b). However, some of the laboratories participating in the AIHA PAT program do not fall within this description. The AIHA has trained their site assessors to be sensitive to the issues behind poor performance. Increased focus does appear to have improved practice. Nevertheless, uncertainty increases

below 50 μg, and there is no data on performance below about 25 μg, which was the lower limit for PAT samples at the time because a precise method for loading test filters with lesser amounts was not available. The loading of silica on a full-shift sample at the new TLV using 1.7 liters/min is 20 μg. The implication is that it might not be even possible to defend a result as being below the TLV.

Again, there are two approaches that can be used to address the issue of sensitivity. One is to improve the analytical technique. There is much debate over the relative merits of XRD and IR, but also about sample preparation. "Direct" on-filter analysis minimizes the additional uncertainty from treatment, but treatment ("indirect" analysis) allows improvement in uncertainty through removal of interfering substances or from concentrating the sample into a smaller area for interrogation. Other issues include calibration material purity and particle size. Much of this discussion is being incorporated in an ISO Draft Standard on the analysis of RCS (ISO, 2008). Performance can only be tracked well when proficiency test samples are available in the range of interest. A new methodology has been developed for preparing proficiency samples at low concentrations with much less inter-sample variability, thus allowing analytical variance to be tested (Hayes et al., 2006). The second approach is to increase the size of sample. Cyclone size-selectors are now available to match the various respirable size fractions at higher flow-rates, including one as high as 10 liters/min (Cossey and Vaughan, 1987), and other types of samplers are also available that will operate at this flow-rate (Courbon et al., 1988). One of the problems with this approach is that higher flow-rates also collect more non-silica dust, and both XRD and IR are sensitive to sample thickness. This should be evaluated before high flow-rate samplers are recommended. Again, as with wood dust, it is likely that a combination of approaches, larger samples and improved analysis, will be the optimal approach.

Beryllium

The recent ACGIH Notice of Intended Change (ACGIH, 2001) for the beryllium TLV includes a short-term exposure limit (15-minute sample) of 0.5 $\mu g/m^3$ which at a sampling flow-rate of 2 liters/min results in a sample of just 6 ng. NIOSH method 7102 for beryllium and compounds has a lower range of application (i.e. limit of quantitation) of 50 ng (NIOSH, 1994b). A new method using fluorimetry of a chromophore complex has a limit of quantitation of 5 ng (NIOSH, 2007). The situation with respect to the full-shift TLV-TWA is better. Using the NIC limit of 0.2 $\mu g/m^3$ and a 2 liters/min sampling rate the sample is 200 ng, but even there NIOSH Method 7102 could not be used to quantify one-fifth of the limit value. As before, increased sample size can also be used. Personal sampling pumps are now available at flow-rates up to 15 liters/min. Although these pumps could not operate at such a flow-rate in conjunction with a 0.8 μm pore-size filter, but it has been shown that filters with nominal pore dimensions of up to 8 μm have good capture efficiency from air streams and therefore minimal losses of respirable particles (Liu et al.,

1981). Once again, a combination of improved analysis and larger sample appears to be the optimal situation.

Asbestos

When the OSHA PEL for asbestos was set during a period when carcinogens were considered to have no "safe" level, it was relatively common for limit values for carcinogens to be set at the limit of quantitation. The value for asbestos fibers of 0.1 fibers/mL is the limit of quantitation for a typical sample of two hours at one liter/min with 40 fields counted when using the NIOSH 7400 method (NIOSH, 1994c). This specific combination of flow-rate and concentration results in a count of approximately 20 fibers or approximately ten times the limit of detection of the method, 7 fibers/mm^2, where 2 fibers would be expected in 40 fields (NIOSH, 1976). However, there is evidence that exposure at this level for a working lifetime is associated with a residual risk of lung cancer and so methods that could quantify lesser fiber concentrations would be useful. Phase-contrast optical microscopy is only considered an index of exposure, in that not all airborne asbestos fibers can be seen under the optical microscope, even with the assistance of the phase-contrast highlighting. Transmission electron microscopy (TEM) sees more fibers, but is expensive, and cannot be used in the field. Scanning electron microscopy is cheaper than TEM, but still not as cheap as optical microscopy and not field-portable. Thus improvements to the optical method would be preferred. Increasing magnification actually has the drawback of reducing the number of fibers counted, because counters generally spend the same examination time per graticule area. Increasing magnification increases the area covered by the graticule, thus decreasing the time spent per unit area, increasing the chance that thin fibers will be missed. Large increases in magnification would also require the greater burden of oil immersion techniques. A method for increasing the resolution of objects at the same magnification is to increase the contrast with the surroundings, and this can be done with a DM ("dark-medium") objective available from certain microscope manufacturers. This is a phase-contrast objective containing a dark phase ring. These objectives are designed to be used to achieve high image contrast with specimens having small phase shifts or refractive index differences, such as fine fibers. A project to investigate the use of the DM objective in a round-robin with other laboratories would be an interesting avenue of research.

Assessing Exposure Without Measurement

Measurements, whether quantitative or qualitative, are made for a purpose. One purpose is to demonstrate compliance with an exposure limit, and this is impossible to do convincingly in a court of law without measurements. Another purpose is to determine whether action is necessary, and, if so, of what kind, and whether or not it is effective. This question can be answered on the basis of less accurate information than is provided by measurements. Actions are normally required where workers are highly exposed. However,

the upper tail of the exposure distribution is very difficult to assess accurately, even with multiple measurements (Rock, 2001). The upper tail of the distribution of exposures must be modeled when it cannot be measured. The models are based on known facts about the chemical and the process, and the model may be good even in the absence of supporting measurements. This is the thesis of the exposure prediction part of "control banding". Control banding is a paradigm that is based on needs of small and medium-sized enterprises that do not have the expert assistance necessary to make or interpret measurements, and it is very useful in poorer regions where the cost of measurements or experts is prohibitive (AIHA, 2007). Control banding posits that there are only a few outcomes to a decision on selection of control, so that each control must be appropriate to a wide band of exposures, the level of which depends on the toxicity characteristics of the material. Two materials with the same toxicity would have the same airborne exposure limit, but the actual level of exposure in the workplace would vary with the volatility (of a liquid) or the dustiness (of a solid) and the amount and the way it is used (hot process vs. cold, dust producing vs. less dusty). Thus one material might require a higher level of control than the other. Similarly, two materials used in similar quantities and with similar tendency to become airborne, but which have very different toxic effects would also require different degrees of control. The choices for control are limited, and basically comprise four increasing levels, or bands – general area ventilation, local exhaust ventilation, personal protective equipment, and isolation. Each control band therefore covers a wide range in concentration for any particular chemical, generally about a decade, and so it might not be necessary to know whether the concentration of, for example, acetone is 5 ppm or 50 ppm if the same control would be applied regardless. Predicting exposure through a model may have the accuracy necessary for such a control decision (Jones and Nicas, 2006). One such model is known as EASE (Estimation and Assessment of Substance Exposure, version 2.0 is currently available), which is intended as a tool for expert use (HSE, 2003). It was developed by the UK Health & Safety Executive and it can presumably be obtained from them, although it is unclear how this might be done. COSHH (Control of Substances Hazardous to Health) Essentials is a simpler package developed from the EASE model and intended for non-experts (Russell et al., 1998). There are differences; for example COSHH Essentials includes the amount of the chemical in use, but the EASE model does not. Making an assessment with COSHH Essentials can be easily accomplished at www.coshh-essentials.org.uk, but the model itself is not generally available. Stoffenmanager (version 3.5) is another model based on very large data sets from different occupations including the integration of video and real-time exposure monitoring (Marquart et al., 2008; Teilemans et al., 2008). It is available without cost at www.stoffenmanager.nl. The EASE Model was validated against the UK HSE database of exposure measurements, but these measurements were used as the basis of the COSHH Essentials and so could not be

used for validation of that model. The exposure assessment model of COSHH Essentials therefore was validated against a German database of measurements (Tischer et al., 2003). Many of the measurements in national databases were made for compliance purposes and so might be skewed towards the higher exposures in an industry. It would be better if the exposure assessment models were validated against databases that reflected the true distribution of exposures for a particular situation, both the range of variation of measurements between workers within a group, and also the range of variation over time. However, a lot of measurements are required in order to make the critical comparison of the upper edge of the model prediction with the upper tail of log-normally distributed exposure measurements that include both between-worker and day-to-day variation (Rappaport et al., 1995). It is unusual to find such large data sets since the probability of encountering over-exposures to legal limits increases with the number of measurements.

The toxicity assignment (hazard) of a chemical is as important as the exposure assessment in predicting the risk, and, therefore, the appropriate level of control. Exposure limit values are an excellent guide to relative toxicity and are used in the most refined models. However, exposure limits are not used in COSHH Essentials as the model was developed for use by those who did not understand the concept of exposure limits, and also for application to chemicals which have no limit value (actually a majority of chemicals). COSHH Essentials uses instead the R-phrase, a European concept related to the critical health effects (Russell et al., 1998). For example, R36 (irritant to eyes) is considered less hazardous than R20 (harmful by inhalation), which is in turn considered less harmful than R37 (respiratory irritant), and which is itself considered less harmful than R26 (very toxic by inhalation). The difference between some of these categories may not be well defined, for example between "harmful" and "very toxic", but the consequence of confusion in this case is an entire control band. While the consequences of being told local exhaust ventilation is not required when in fact it is required are clearly threatening to life or health, the consequences of being told to install local exhaust ventilation when it is not required are also problematic, especially for employers whose business is only marginally profitable. The user therefore absolutely requires the source of the R-phrase (e.g. the Material Safety Data Sheet) to be accurate. Companies that have a fear of punishment if they underestimate the hazard have an incentive to apply more severe R-phrases than necessary, while others may make an unwitting error. Global harmonization is required (AIHA, 2007). NIOSH has projects relating to the evaluation of such tools for exposure assessment and control.

Conclusions

Exposure assessment research in the past concentrated on simple sample collection devices with off-site laboratory analytical methods. Direct-reading instruments were neither sufficiently small nor sufficiently cheap to allow their widespread

use. Besides, a focus on compliance with full-shift time-weighted average limit values does not require real-time measurements. Today, direct-reading instruments are becoming smaller and cheaper, and the advantages of on-the-spot output of information in preventing disease are becoming better known. A significant issue still to be studied is the interaction of the worker with a direct-reading device.

Exposure assessment research in the past concentrated on sampling and analytical methods development for compliance with limit values. Re-assessments of older methodologies may be required by recent severe reductions in limit values. A research capacity needs to be maintained in order to improve existing methods or to develop new methods perhaps based on novel techniques.

Exposure assessment research in the past concentrated on sampling strategies to determine compliance of workplaces with limit values. As the number of samples increases, so does the probability of a value exceeding the limit value, which is a disincentive to collecting samples in any case. In addition, many employers did not understand limit values or how they should be used and preferred to protect workers through a task-control approach. Since there are only a limited number of control approaches ("bands") available, wide ranges of pollutant concentrations are actually controlled through a single band. Thus the accuracy required for a compliance sample is not required in estimating exposures for a control approach, and a simple, but well-validated, model of exposure may be sufficient.

These three new frontiers are not considered as representing the only facets of exposure assessment in industrial or occupational hygiene where research is necessary, but they represent some useful and topical areas.

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論文

暴露評估之研究領域

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摘 要

暴露評估常被使用於診斷問題和確認解決之道，為職業暴露控制策略重要的一環。目前暴露評估研究的三個尖端研究領域分別是：1.直讀式接近即時監控監測器；2.更高敏感度之採樣與分析方法；3.無須量測之暴露評估模式。隨著輕量電池、小型化偵測器與電腦晶片技術的發展，直讀式即時監測器的時代已來臨。直讀式即時監測器使用上所呈現的挑戰在於勞工和職業衛生師都可使用資訊量的增加。因應標準採樣與分析方法的改變，一直以來暴露規範都在逐漸地降低，以做更有效的量測。必須要發展採樣與分析點的方式來符合這些挑戰。例如木材灰、可呼吸性二氧化矽和鈹為最近被提出具較低閾值的例子。石綿為另一個因分析能力的限制而無法降低閾限值的例子。在許多財務較困難的國家，精密的分析方法可能太過昂貴而超出專業人員所能負擔。於充分測量驗證下，不需量測數據的評估模式將越來越普遍。

關鍵詞：暴露評估、空氣採樣、直讀式儀器、閾值

民國97年接受。

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Abstract

暴露評估常被使用於診斷問題和確認解決之道，為職業暴露控制策略重要的一環。目前暴露評估研究的三個尖端研究領域分別是：1.直讀式接近即時監控監測器；2.更高敏感度之採樣與分析方法；3.無須量測之暴露評估模式。隨著輕量電池、小型化偵測器與電腦晶片技術的發展，直讀式即時監測器的時代已來臨。直讀式即時監測器使用上所呈現的挑戰在於勞工和職業衛生師都可使用資訊量的增加。因應標準採樣與分析方法的改變，一直以來暴露規範都在逐漸地降低，以做更有效的量測。必須要發展採樣與分析點的方式來符合這些挑戰。例如木材灰、可呼吸性二氧化矽和鈹為最近被提出具較低閾值的例子。石綿為另一個因分析能力的限制而無法降低閾限值的例子。在許多財務較困難的國家，精密的分析方法可能太過昂貴而超出專業人員所能負擔。於充分測量驗證下，不需量測數據的評估模式將越來越普遍。

Exposure assessment is an important component of the occupational exposure control strategy, in particular because it is used both to examine problems and confirm solutions. Three initiatives are discussed that are on the cutting-edge of current exposure assessment research: 1) direct-reading, nearreal time monitors, 2) sampling and analytical methods of greater sensitivity and 3) models to assess exposure without measurement. Direct-reading, near-real time monitors are coming of age with the development of light-weight batteries, miniaturized detectors and computer chip technologies. They present challenges in use in that the amount of information increases and it is available to the worker as well as hygienist. This challenge is explored in relation to the development of coal-mine dust and diesel exhaust monitors. Exposure guidelines are continually set lower with consequent impact on the ability of standard sampling and analytical methods to make useful measurements. It is now usually necessary to develop both the sampling and analytical portions of the method to meet this challenge. Examples where lower limit values have recently been proposed include wood dust, respirable silica, and beryllium. Asbestos is an example of where a limit value has been frozen at the limits of method capability. Sophisticated analytical methods may be expensive and beyond the reach of many professionals in poorer countries. Models that assess exposures without measurements are becoming popular, but must be validated through testing in well-measured environments.

Keyword(s)	暴露評估,空氣採樣,直讀式儀器,閾值;Exposure assessment,Air sampling,Direct-reading instruments,Threshold limit values,Control banding
CEPS	Subject Catagory>Social Science>Sociology

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