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Occupational exposure limits: A comparative study

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Abstract

Occupational exposure limits (OELs) are used as an important regulatory instrument to protect workers' health from adverse effects of chemical exposures. The OELs mirror the outcome of the risk assessment and risk management performed by the standard setting actor. In this study we compared the OELs established by 18 different organisations or national regulatory agencies. The OELs were compared with respect to: (1) what chemicals have been selected and (2) the average level of exposure limits for all chemicals. Our database contains OELs for a total of 1341 substances; of these 25 substances have OELs from all 18 organisations while more than one-third of the substances are only regulated by one organisation. The average level of the exposure limits has declined during the past 10 years for 6 of the 8 organisations in our study for which historical data were available; it has increased for Poland and remained nearly unchanged for Sweden. The average level of OELs differs substantially between organisations; the US OSHA exposure limits are (on average) nearly 40 % higher than those of Poland. The scientific or policy-related motivations for these differences remain to be analysed.

Keywords: Occupational exposure limits; Risk assessment; Risk management; Chemicals regulation; ACGIH

1. Introduction

People are exposed to a variety of chemicals during their lives, and working life may be a major contributor to such exposures. To protect the health of people exposed in their workplaces, authorities and organisations, among other measures, set Occupational exposure limits (OELs).[1] How these exposure limits are determined and what they are supposed to protect against varies to some degree between the countries and organisations that set the limits. The purpose of this paper is to systematically compare the lists of OELs for 18 organisations concerning two different aspects: selection of substances and over-all level of exposure limits.

Lists of OELs were introduced as risk management tools in the 20th century. In 1938 The American Conference of Governmental and Industrial Hygienists (ACGIH) was formed. It soon became one of the most influential organisations worldwide when it comes to occupational health regulations (Piney, 1998; Hansson, 1998). According to the ACGIH webpage (www.acgih.org) the original goal of the organisation was: "to encourage the interchange of experience among industrial hygiene workers and to collect and make accessible such information and data as might be of aid to them in the proper fulfilment of their duties". In 1946 the first list of Threshold Limit Values (TLVs), then called Maximum Allowable Concentrations were published, as a "simple table of figures" (Piney, 1998). Approximately 130 substances were included. The fact that the limit values were referred to as "maximum allowable concentrations" without further definition led to criticism for

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[1] *Abbreviations used*: ACGIH, American Conference of Governmental and Industrial Hygienists; CAS, Chemical Abstracts Service; EC, European Commission; EU, European Union; JSOH, Japan Society for Occupational Health; OEL, Occupational exposure limit; OSHA, Occupational Safety and Health Administration; STEL, Short Term Exposure Limit; TLV, Threshold Limit Value; TWA, Time Weighted Average.

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conveying an impression of truly safe-level thresholds. Today the TLVs are published with a documentation, and the definition of the protection offered is no longer all-encompassing: "TLVs refer to air borne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse health effects./.../ The TLVs are intended for use in the practice of occupational hygiene as guidelines or recommendations to assist in the control of potential workplace health hazards and for no other use. These values are not fine lines between safe and dangerous concentrations and should not be used by anyone untrained in the discipline of industrial/occupational hygiene." (ACGIH, 2005). The ACGIH TLVs are claimed to be based "solely on health factors" and no consideration is said to be given to either economical or technical feasibility when determining them (http://www.acgih.org/Products/tlvintro.htm). The ACGIH TLVs have been adopted by many regulatory agencies worldwide (Piney, 1998). This took place mainly in the 1950s and 1960s. After that, national agencies gradually developed their own OELs. Today a large number of countries have national lists of OELs, covering hundreds of different chemicals and other exposures.

OELs are set as limits of concentrations of harmful substances in the air, averaged over a period of time. Time weighted averages (TWAs) are usually set for an 8 h day during a 40 h week. They are intended to protect the worker from most dangerous effects, while short term exposure limits (STELs) are set to help prevent effects that may occur following a short exposure. STELs usually limit a concentration for a 15 min period.

Previous studies of occupational exposure limits have shown that there are large and unsystematic differences between risk management decisions made for different chemicals with similar adverse health effects (Hansson, 1998; Hansson and Rudén, 2006). Case studies concerning certain occupations (Haber and Maier, 2002; Bigelow et al., 2004) or certain chemicals (Taylor et al., 2007; Cunningham et al., 1998) also show that there are national differences in the risk assessment and management of occupational chemical exposure. Haber and Maier (2002) discovered that differences in methodology and scientific policy lead to large variations in the OELs set for Chromium, even if similar data was reviewed.

Taylor et al. (2007) reviewed the implementation of the regulations on lead issued by the EU. They concluded that the biological limit value for lead varied considerably between countries (ranging from 20 to 80 μg/100 ml blood). The OELs did not vary as much between the included countries; probably since the EU has set a binding OEL for lead. But still 5 out of 15 countries had set a lower limit. Also some countries defined special arrangements for gender differences or young workers. Probable reasons as to why these differences exist were not offered. Bigelow et al. (2004) reviewed the ACGIH TLVs and the British Columbia OELs for a number of substances in an effort to evaluate the differences and what implications a change from the latter to the first would have for healthcare workers in British Columbia. A number of discordances between the British Columbia 8 h TWA OELs and the ACGIH TLVs were revealed. For 49 substances the British Columbia OELs were lower, while in 8 instances the ACGIH TLVs would be lower. A review of six of these chemicals indicated that there was a potential for increased health-risks. Bigelow et al. (2004) point out that the ACGIH is a US Organisation and the method of setting the TLVs is thus weighted toward concerns of workers in the US. This may need to be reflected on before adopting the ACGIH TLVs in other countries. The ACGIH TLVs have been subject to criticism on several other occasions. Cunningham et al. (1998) discussed the justification of the 10-fold increase of the TLV in 1992 for amorphous silica fume. Their conclusion was that the health evidence supports an OEL of 0.3 mg/m^3 instead of the then adopted 2 mg/m^3. Castleman and Ziem (1988) showed that for more than one-sixth of the approximately 600 TLVs of 1986 the TLV Documentation placed important or total reliance on unpublished corporate communications. Roach and Rappaport (1990) analysed the references of the 1976 TLV Documentation and concluded that the TLVs had a stronger correlation to the measured exposure in industry than to the levels associated with negative health effects. The scientific basis of the ACGIH TLVs was again subject of scrutiny in Rappaport (1993) where ACGIH and the US OSHA were compared, resulting in the conclusion that the TLV setting procedure of ACGIH depends heavily on the assessment of achievability of the TLVs.

There are several studies about the decision-making process and the regulatory statuses of OELs. In Bal and Halffman (1998) some contributions like Piney (1998) are specifically about occupational exposure limits. The most recent contribution is Walters and Grodzki (2006) whose main topic is to describe the different systems for setting and using OELs in 15 EU member states. Not many studies have to our knowledge addressed the issue of the over-all level of exposure limits, comparing entire lists, one of the few is Hansson (1998).

An interesting aspect of OELs is that they tend to decrease gradually over time as they are revised. This is shown e.g. in Hansson (1998) which includes a review of the Swedish OELs from 1969 to 1994 as well as the ACGIH TLVs from 1946 to 1996. Greenberg (2006) made a review of the published material concerning the derivation of British asbestos exposure limits from 1898 to 2000 and Markowitz and Rosner (1995) reviewed the TLV for silica from 1935 to 1990. Both these studies show that the OEL are lowered as more, and better information on adverse effects becomes available and the protection of workers' health has been given higher priority. Also, better measuring techniques are available today, improving the possibility to control the working environment.

The level of the OELs depends on the outcome of the risk assessment and risk management processes for the corresponding substances. Comparisons of the OELs can be a first step in uncovering instances where risk assessment has led to discordant results or where principles of risk management differ. Further steps of this process require a possibility to scrutinise the documentation and other bases for the OELs in question, which in turn requires a transparent risk decision process. The OELs are exact numerical values, which simplifies evaluation since it enables quantitative comparisons and statistical analyses. As a consequence OELs probably are the risk management method most often scrutinised. Clearly a comparison of OELs without further study of the documentation for the exposure limit in question does not allow any conclusions of whether the difference lies in the risk assessment or the risk management part of the process. However, such comparisons can identify the specific cases where discordances exist, and generate hypotheses for further study. This study is a systematic comparison of the OEL-lists of 18 different organisations; the major variables that are examined are coverage of individual chemical substances and levels of exposure limits. Our aim is to describe and analyse differences between countries and organisations concerning occupational exposure limits, thus generating hypotheses for further studies of risk assessment and risk management procedures.

2. Methods

2.1. Our database

This study is a review of the standard setting documents collected in published form or via the websites of, or e-mail communication with, the authorities and organisations in question. The number of chosen organisations was limited to the availability of the lists of OELs through these forums. Fifteen regulatory agencies of different countries or territories and three organisations are included. For eight lists our database also includes lists of OELs published in preceding regulations. These are used for further analyses of the development during the ten past years. Two of the organisations are non-governmental (year of collected lists in brackets); the ACGIH (1995; 2000; 2005) and the Japan Society for Occupational Health (JSOH, 2000; 2005). The European Union issues both mandatory and indicative exposure limits (EU, 1991; 1996; 1998; 2000; 2003; 2004; 2006). The fifteen countries or territories are Alberta (Canada, 2003), Australia (1995; 2005), British Columbia (Canada, 2004), California (USA, 2006), Estonia (2001), Finland (1993; 2002; 2005), France (2005), Germany (1995; 2000; 2005), New Zealand (2002), Ontario (Canada, 2005), Occupational Safety and Health Administration (OSHA) of the United States (2004), Poland (1998; 2002; 2005), Quebec (Canada, 2004), Sweden (1996; 2000; 2005) and the United Kingdom (1995; 2000; 2005).

The database used for the analyses contains only substances specified with a CAS number. CAS stands for Chemical Abstracts Service and the CAS number is a unique numeral combination used to identify chemical substances. To include only substances with CAS designations is a simplification to ease cross-referencing within the material. The chemical naming systems are not concordant; the same chemical can have several different accepted names. The CAS designations are therefore used to minimise confusion. This simplification unfortunately excludes some substances and mixtures from the analysis but we still consider the selection to be representative for the regulations of the different organisations. The final database used in this study contains 1341 substances with CAS identification numbers.

2.2. The geometric means method

Lists of OELs record the risk assessment and management decisions made by regulatory agencies, and they can therefore be used to compare these risk decisions. A comparison between two lists of exposure limits should refer to all substances that have exposure limits on both lists. For each substance, the quotient between its values on the two lists is the best indicator of the difference. The geometric mean has been calculated of all these ratios to represent the over-all level of the complete list. This method was applied to OELs by Hansson (1998) and will be referred to as the geometric means method in this paper. An important reason for the choice of geometric means over median or arithmetic means is that for any two lists, say A and B, the geometric mean of A/B ratios is above 1 if and only if that of the B/A ratios is below 1 (the product of the two values is always 1). Using arithmetic means will not be satisfactory in this respect; which list is perceived as having the higher level can depend on which list is used as the denominator. Consider the example of List A and List B both having three OELs. List A has for substance I 20 ppm, substance II 15 ppm and substance III 10 ppm, List B on the other hand has the OELs 200 ppm for substance I, 15 ppm for substance II and 1 ppm for substance III. The arithmetic mean of the ratios of B/A ($(10 + 1 + 0.1)/3 = 3.7$) gives the impression that B has the higher values. Taking the arithmetic means of the A/B ratios also results in 3.7, giving the impression that List A has the higher OELs. In both these instances the geometric mean equals 1, showing that concerning the average level the two lists do not differ. For further elaboration on why this method was chosen see Hansson (1998, Appendix A).

For comparison between several lists, a standardised comparison list should be used to which all other lists compared. It would perhaps be natural to assume that such a standard, or comparison list, has to be toxicologically reasonable, in other words that it should contain medically sound OELs, but since our knowledge of dose–response relationships is only fragmentary for most substances, such a standard would be very difficult to establish. Fortunately, due to our choice of geometric means for aggregation, the relationships between different lists (i.e. the ratios between the overall values) will be the same irrespectively of the values on the comparison list. What *is* important, however, is the choice of substances to be included. The comparison list should contain mainly substances that can be found on most lists of OELs, so that regulatory decisions concerning substances only regulated by very few countries do not have an impact on the average level calculated. One list stands out as the one that best satisfies this criterion: the first list of ACGIH TLVs from 1946. Another influential set of OELs of more recent origin are the binding and indicative OELs set by the EU. For this study a comparison list has been constructed using the limit values first presented by the ACGIH in 1946 combined with the EU list of OELs, resulting in a comparison list of 191 exposure limits, henceforth called the combined comparison list. For 32 substances both the EU OELs and the ACGIH 1946 TLVs have set exposure limits; in these cases the values from the ACGIH list are used in the calculations.

For many substances, OELs are given in both ppm and mg/m^3. When recalculating from ppm to mg/m^3 the standard setter has usually rounded off the values. In some cases this leads to considerable differences in the ratios depending on whether OELs in ppm or mg/m^3 are used. In such cases, preference is given to ppm values. In this way the anomaly caused by the rounding off of OELs will be minimised. When lists have defined the OEL in different units, conversion of mg/m^3 to ppm has been performed in the following manner:

Concentration in ppm = (*Concentration in mg/m^3* × *24.1 (l/mol)*)/*Mol weight (g/mol)*

24.1 being the molar volume of air at 20 °C and 101.3 kPa (AFS, 2005).

The ACGIH's 1946 values should be interpreted as time-weighted averages for a whole working day (TWAs). The combined comparison list only contains 8 h time-weighted averages (TWAs). When individual lists have only given short term exposure limits (STELs), these have been adjusted with the factors recommended by the ACGIH (as first defined by the ACGIH 1963, specified in Hansson, 1998, see Table 1).

Table 1
Multiplicative factor used to recalculate the 8 h time weighted average exposure limit of the comparison list to a corresponding short term exposure limit

TWA (ppm or mg/m^3)	C factor[a]
$X \leqslant 1$	3
$1 < X \leqslant 10$	2
$10 < X \leqslant 100$	1.5
$100 < X \leqslant 1000$	1.25
$1000 < X$	1

[a] These conversion factors were first suggested by the ACGIH (1963, see Hansson, 1998).

2.3. Yearly decrease rate and half-life

When OELs are revised, decreases are much more common than increases. The yearly decrease rate of an OEL for a particular substance can be calculated as $(b/a)^{(1/n)}$, b being the OEL n years after the year that a was the OEL for that same substance. The decrease rate of a list is the geometric mean of the decrease rates of all its substances. The decrease rate can also be expressed as the half-life of an exposure limit. If the OEL was 200 ppm in 1990 and 100 ppm in 2005 the exposure limit has been halved in 15 years, which corresponds to an average yearly decrease of 4.5% ($1–0.5^{(1/15)}$). It should be noted that the OELs in actual fact are changed in a step-wise fashion, whilst half-life is based on a linear model.

2.4. Multivariate analysis of similarity between the OEL-lists

As part of the analysis of which substances are chosen to be regulated by OELs a non-metric multidimensional scaling plot was produced. This plot is a two dimensional representation of the similarity between organisations concerning the choice of substances. The set of defining features was presence or absence of the 1341 substances for each organisation. If two lists contain the same substances, the distance between them is zero. The more differences in the coverage of substances shown by two lists, the larger is the distance between them in the plot. The dissimilarity measure used was Euclidean distances. The distance matrix and the non-metric multidimensional scaling plot have been produced using the statistical software Primer v6.

3. Results

3.1. Selection of substances

Table 2 lists the number of substances regulated by each organisation and the number of substances regulated only by that organisation. The total count of OELs includes both substances with CAS designations and those without. Furthermore every exposure limit has been counted even if there are several limits for the same substance (e.g. respirable or inhalable dust and total dust). The numbers in Table 2 may therefore sometimes be higher than the organisations' own estimates. The numbers are taken here as an indication of the substance coverage of the regulations. The number of OELs in each list varies between 300 and 800, which should be compared to the total number of substances with CAS designations that have an OEL on at least one of the lists, which is 1341. Most of the lists do not even cover half of these.

As shown in Table 3 about one-third of the substances in this study are only regulated by one organisation. Finland has an extraordinarily large number of uniquely regulated substances; 189 substances with CAS designations are only regulated by Finland. Poland is second with 51 substances that are unique for the Polish list. Due to the influence of the ACGIH one would expect that the ACGIH list to have a low number of substances not already assimilated

Table 2
Number of regulated substances in each individual list and number of substances regulated uniquely in those lists

Country/organisation	Total no. of OELs	No. of CAS-designated OELs[a]	No. of unique OELS[b]
ACGIH[c]	763	714	2
Alberta, Canada	765	664	5
Australia	696	616	1
British Columbia, Canada	795	685	24
California, USA	732	659	24
Estonia	436	352	5
EU	105	102	0
Finland	760	742	189
France	556	514	5
Germany	325	313	30
JSOH[d]	196	192	13
New Zealand	660	636	17
Ontario, Canada	750	677	34
OSHA[e], USA	543	455	4
Poland	541	490	51
Quebec, Canada	686	628	18
Sweden	436	385	28
United Kingdom	414	358	10

[a] Number of different CAS designations.
[b] Number of substances specified with CAS designations that are only regulated in that list.
[c] American Conference of Governmental and Industrial Hygienists.
[d] Japan Society for Occupational Health.
[e] Occupational Safety and Health Administration.

Table 3
The distribution of number of substances that are present on one or several lists

No. of organisations	No. of substances[a]
1	460
2	117
3	52
4	38
5	33
6	21
7	30
8	22
9	48
10	71
11	61
12	79
13	65
14	47
15	62
16	59
17	51
18	25

[a] With CAS designations.

by another list. This also is the case since only two substances are solely on the list of ACGIH. No substances are uniquely regulated by the EU, which was also expected.

Only 25 substances are regulated by all organisations in this study. As can be seen in Table 4 most of these substances are liquid at 20 °C and normal atmospheric pressure. According to the NIOSH pocket guide of 2005, all these 25 substances have inhalation as one of the main exposure routes. All of these substances were also on the first ACGIH list from 1946. Some substances that one would expect to be on this list are in fact not, e.g. asbestos, benzene, lead and silica. One explanation for this is that we have used CAS-numbers as the sole identifier for the cross-referencing analyses. Asbestos and silica are groups of substances that have several different CAS number designations, and the use of these is not completely harmonised. Lead is part of a multitude of different compounds, most with their own CAS numbers but the lists often specify the OELs as "Lead and its compounds" without further CAS specifications. Benzene is on the list of 17 of the organisations in our study, it is not on the German list since it is a category I carcinogen and those are not given a regulatory OEL but a technical OEL which have not been included in our study.

The more substances two organisations have in common, the smaller is the distance between them on the non-metric multidimensional scaling plot (Fig. 1). According to Piney (1998) all the countries in our study, except Estonia and Poland, used the ACGIH TLVs as their first set of OELs. This took place mostly in the 1960's and 1970's; the extent to which these organisations are still influenced by the ACGIH could to some degree be discerned in this plot. The non-European countries, except the JSOH, are all closer to the ACGIH than the European countries, except France. Organisations that have few uniquely regulated substances (Table 2) tend to be closer to the ACGIH in this plot. The European countries do not cluster around the EU in the same way. Finland stands out, as can also be seen in Table 2 the number of substances only regulated in Finland (189) is exceptionally high.

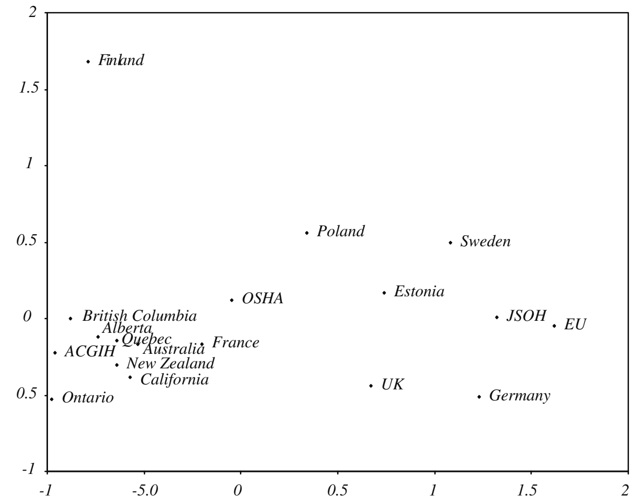

Fig. 1. A non-metric multidimensional scaling of the coverage of substances. The distance matrix was based on the options presence or absence of the 1341 substances in our data base. The stress value of this plot is 0.08. Euclidean distances are used and the statistical software is Primer v6. ACGIH, American Conference of Governmental and Industrial Hygienists; JSOH, Japan Society for Occupational Health; OSHA, Occupational Safety and Health Administration.

Table 4
List of substances[a] that are present on all 18 lists in our selection

CAS	Chemical name	Phase[b]
7783-07-5	Hydrogen selenide	Gas
10026-13-8	Phosphorus pentachloride	Solid
108-10-1	Methyl isobutyl ketone (4-methyl-2-pentanone)	Liquid
108-88-3	Toluene	Liquid
108-90-7	Monochlorobenzene (chlorobenzene)	Liquid
109-89-7	Diethylamine	Liquid
109-99-9	Tetrahydrofuran	Liquid
110-82-7	Cyclohexane	Liquid
127-19-5	*N*,*N*-Dimethylacetamide	Liquid
141-43-5	Ethanolamine	Liquid
60-29-7	Ethyl ether (diethyl ether)	Liquid
64-18-6	Formic acid	Liquid
67-56-1	Methanol (methyl alcohol)	Liquid
67-64-1	Acetone	Liquid
67-66-3	Chloroform (trichloromethane)	Liquid
71-55-6	Methyl chloroform	Liquid
75-04-7	Ethylamine	Liquid
75-34-3	1,1-Dichloroethane (ethylidene dichloride)	Liquid
75-44-5	Phosgene	Gas
7647-01-0	Hydrogen chloride	Gas
7664-39-3	Hydrogen fluoride	Gas
7664-41-7	Ammonia	Gas
7697-37-2	Nitric acid	Liquid
7803-51-2	Phosphine (hydrogen phosphide)	Gas
78-93-3	Methyl ethyl ketone (2-butanone)	Liquid

[a] With CAS designations on all lists.
[b] Physical state at 20 °C and 101.3 kPa.

The update procedures for the lists differ between organisations. Many do not specify any interval for update in the texts enclosed to the lists of OELs. Some organisations publish new lists every year, e.g. ACGIH, JSOH, The German Forschungs Gemeinschaft and the UK Health and Safety Executive. Others aim at producing a new list with a few years interval, how many is not specified. Of course a new publication of the list does not mean that all OELs on it are revised from the previous list. Of the organisations in our study only Sweden and JSOH specifies which year the OEL is determined or last revised. This information is also discernible for the EU OELs from the way in which they are published; a directive is issued defining the new or newly revised OELs.

3.2. Values: The level of the exposure limits

In this section the level of exposure limits will be examined. The over-all levels of the OELs of each organisation are shown as geometric means in Table 5 and Fig. 2. A

Table 5
Geometric mean of ratios between the exposure limits of each organisation and the combined comparison list and the number of ratios that the geometric mean is based on

Country/organisation	Mean[a]	No.[b]
ACGIH[c]	0.347	172
Alberta	0.385	173
Australia	0.377	167
British Columbia, Canada	0.336	174
California, USA	0.326	168
Estonia	0.313	130
EU	0.584	102
Finland	0.301	175
France	0.360	173
Germany	0.352	102
JSOH[d]	0.282	95
New Zealand	0.394	152
Ontario, Canada	0.308	114
OSHA[e] USA	0.608	162
Poland	0.228	171
Quebec, Canada	0.413	169
Sweden	0.286	145
United Kingdom	0.365	130

[a] Geometric mean of ratios based on the combined comparison list.
[b] Number of congruent values between the individual lists and the combined comparison list.
[c] American Conference of Governmental and Industrial Hygienists.
[d] Japan Society for Occupational Health.
[e] Occupational Safety and Health Administration.

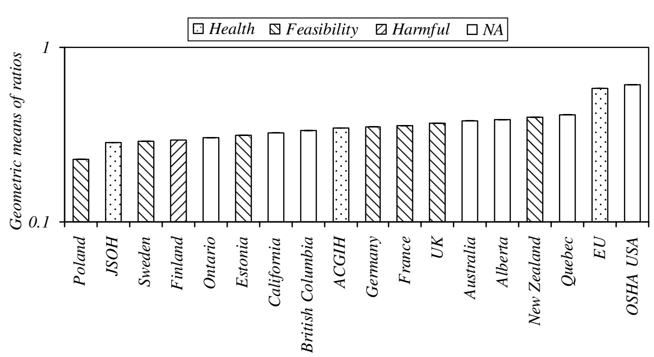

Fig. 2. The geometric means of ratios based on the combined comparison list in ascending order. The lower the geometric mean the lower is the over-all level of the exposure limits of that list. Thus Poland has by far the lowest level of exposure limits, whereas the EU and US OSHA have the highest. The pattern of the bars represents the factors taken into consideration when setting the OELs. Health means purely health based. Feasibility means that economical and technical factors are also taken into consideration. The designation Harmful is only applicable to Finland's list of OELs that are said to include harmful concentrations. ACGIH, American Conference of Governmental and Industrial Hygienists; JSOH, Japan Society for Occupational Health; OSHA, Occupational Safety and Health Administration.

low geometric mean of ratios implies a low over-all level of exposure limits.

The geometric means of ratios are below one for all organisations, which can be expected since most of the reference values on the comparison list are from the first ACGIH TLV list of 1946, whose exposure limits are higher than most exposure limits today. Most organisations have a geometric mean between 0.28 and 0.41, with only three exceptions. Poland has a geometric mean of ratios of 0.23 which is by far the lowest over-all level of OELs. The highest levels are those of the European Union and the US OSHA, with 0.58 and 0.61, respectively. The bars in Fig. 2 are coded after what level of protection the OELs are intended to offer. Most countries take economical and technical feasibility, as well as human health, into account when setting exposure limits. The aim of the EU is that its indicative OELs should be health-based in those cases that a clear threshold value can be identified (EC, 2006). For substances with a linear dose–response relationship an OEL is established at a concentration that is claimed to bring a sufficiently low risk. For binding OELs, economical and technical feasibility is usually taken into consideration as well as human health (Feron, 2003). Since 100 out of 102 entries on the EU list are indicative OELs, the EU list is considered in Fig. 2 to be health-based. However, the claim by the EU that only human health is taken into consideration is difficult to reconcile with its comparatively high over-all level of OELs. The Finnish list is the only one that claims to list concentrations that have been found to be hazardous (Social- och hälsovårdsministeriet, 2005); the relatively low level of these OELs puts the health protection claim of other organisations, especially those with higher over-all levels of OELs, in perspective. The countries of the Baltic Sea area generally seem to have a lower level of acceptance towards occupational exposures than the other countries under study, at least the geometric means of their lists are comparatively low.

Fig. 3 and Table 6 show the over-all level of the OELs as geometric means of the ratios based on the combined comparison list for those eight organisations for which we have data covering approximately the 10 past years. The over-all level of the exposure limits have decreased for most organisations. There are two exceptions to this trend; the Swedish and, even more noticeably, the Polish lists of exposure limits. The over-all level of the ratios has increased for the Polish lists while the over-all level of the Swedish list has not changed noticeably from 1996 to 2005.

Table 7 includes a measure of the yearly rate of change and the associated half-life of exposure limits for the organisations. This measure is based on changes made to already existing OELs, so that substances added during the 10 year period do not influence the rate of change. Finland has the fastest decreasing levels, while Poland did not lower its OELs at any significant rate. JSOH has not revised any of its OELs at all since 2000 (whereas new exposure limits have been added). A previous study of the Swedish OELs showed that during a period of 25 years (1969–1994) the average half-life of a Swedish OEL was approximately 17 years (Hansson, 1998, p. 76). This decrease rate has clearly diminished; the half-life calculated from the 1996 and 2005 list is 139 years. Only a few of the Swedish exposure limits have been lowered during this period of time.

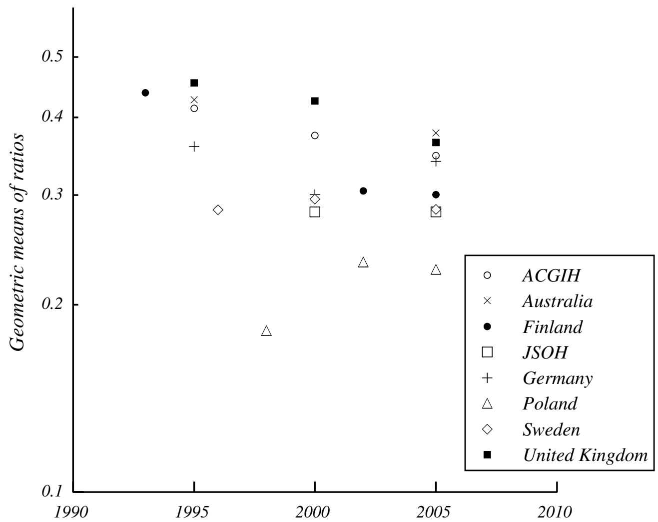

Fig. 3. The geometric means of ratios based on the combined comparison list over time. The trend seems to be a decline in the over-all level of the OELs, thus the exposure limits are getting lower in more recent lists. Poland is a noticeable exception to this trend as the over-all levels of its lists are increasing. The level of the Swedish lists has not changed noticeably over the last 9 years. ACGIH, American Conference of Governmental and Industrial Hygienists; JSOH, Japan Society for Occupational Health.

Table 6
The geometric mean of ratios for each organisation, level of OELs based on the combined comparison list

Organisation	Period	Initial level	Last level
ACGIH[a]	1995–2005	0.414	0.347
Australia	1995–2005	0.427	0.377
Finland	1993–2005	0.438	0.304
Germany	1995–2005	0.498	0.352
JSOH[b]	2000–2005	0.300	0.284
Poland	1998–2005	0.182	0.228
Sweden	1996–2005	0.284	0.290
UK	1995–2005	0.455	0.368

[a] American Conference of Governmental and Industrial Hygienists.
[b] Japan Society for Occupational Health.

Table 7
The rate of change per year and the half-life of the OELs

Organisation	Period	Rate of change	Half-life (years)
ACGIH[a]	1995–2005	0.985	45
Australia	1995–2005	0.993	104
Finland	1993–2005	0.980	34
Germany	1995–2005	0.974	26
JSOH[b]	2000–2005	1	NA
Poland	1998–2005	0.9996	1569
Sweden	1996–2005	0.995	139
UK	1995–2005	0.986	48

Based on a comparison between the OELs for substances that were present on both the initial and the last list for each country in our selection. Substances added during the period of time in question do not influence these variables.
[a] American Conference of Governmental and Industrial Hygienists.
[b] Japan Society for Occupational Health.

4. Discussion and conclusions

The ACGIH TLVs have been widely accepted internationally. The extensive use of the ACGIH TLVs has been subject to criticism since the 1950's, and the implications have been discussed by Rudén (2003), Hansson (1998), Ziem and Castleman (1989), Castleman and Ziem (1988) and others. One aspect of the criticism is that the ACGIH TLVs are supposed to be used by trained industrial health professionals; this assumption is often not transferred into the national regulations when adopting the TLVs. The protection offered by the TLVs has also been questioned; the TLVs have been accused of representing the prevailing levels of chemicals in the workplace air rather than being health-based (Roach and Rappaport, 1990).

In our study the influence of the ACGIH can be discerned for some organisations, both concerning which substances are included in the different lists, and concerning the level of OELs (Figs. 1 and 2). Some occupational health and safety documents still refer to the ACGIH as a major source of documentation for OELs (e.g. National Occupational Health and Safety Commission of Australia, 2005).

Our final database includes 1341 substances with CAS numbers. Most of the studied countries regulate a few hundred substances; no organisation has more than eight hundred entries. There is a discrepancy between countries concerning coverage, as is shown in Tables 2, 3 and Fig. 1. One-third of all substances in our database are only included in one list. That the selection of substances is not more harmonised can probably to some extent be explained by the national differences in industrial structure. More than 40% (189 out of 460) of the uniquely regulated substances are regulated by Finland (Table 2), and 11% (51 out of 460) are regulated only by Poland.

The 25 substances that are regulated by all organisations (Table 4) all have inhalation as the main exposure route. Thus there is a clear rationale of setting an exposure limit in the form of an allowable air concentration for those substances. They were all included in the ACGIH 1946 list which indicates that the harmful properties have been well known for a long time. The presence of these substances on all lists is thus not surprising.

Structural differences in the OEL decision making process, for example what substances are chosen for regulation, what health impacts are deemed important, and the legal status of the final exposure limits are examples of factors that may influence the level of the OELs. The federal system, described as "the cumbersome regulatory machinery" in Rappaport (1993), through which the OSHA permissible exposure limits are set can very well explain the high level of the OSHA OELs. However, some of the differences visualised in Table 5 and Fig. 2 are not explainable by that line of reasoning. Hence in Fig. 2 the bars have different patterns indicating the level of protection claimed to be offered. For some organisations the documents studied have not provided full information about the intended level of protection. None of the lists are promulgated with a claim that they protect the most sensitive persons. A more notable difference is that: Finland's OEL list is said to contain concentrations of airborne substances "known to be hazardous". The values on this list are not mandatory but intended to be used for the assessment of air quality and work exposure (Social- och hälsovårdsministeriet, 2005). The other lists define airborne concentrations that are said to be safe or acceptable, considering an 8 h exposure a day and a 40 h working week. Considering this it is surprising to find that the overall level of the Finnish list is relatively low in comparison to the other lists in our study. Three organisations besides Finland have clearly stated a purely health-based approach: ACGIH, JSOH and the EU. The comparatively low levels of the ACGIH and JSOH OELs are in line with the rationale that lower exposure limits are generally more protective of human health, even though it should be noted that their over-all level is by no means the lowest. The exposure limits of the EU on the other hand have a substantially higher level than all the other organisations except the US OSHA. A comparison between the indicative OELs of the EU that are claimed to be health-based and the Finnish OELs shows that contradictory assessments have been made within in the range of our survey. Obviously a study of the level of exposure limits does not allow any conclusions about actual working conditions.

In Table 7 the decrease rate and the average half-life of the OELs are listed. As was pointed out in the introduction previous research shows that OELs tend to be gradually lowered as they are revised. Our study confirms this, but the rate of decrease may have slowed down. In Hansson (1998) the average half-life of a Swedish OEL between 1969 and 1994 was approximately 17 years, which can be compared to the half-life calculated from the data from 1996 to 2005 of 139 years. One possible explanation could be that high-level OELs have already been lowered, and the need to lower exposure limits is not as acute today as it once was. When lowering the exposure limits beyond a certain point the gain in health preservation might no longer be defensible with respect to the economic costs of further reduction.

The need to harmonise Occupational Health and Safety regulations and the OELs has been brought up by different actors. One of them is the EU which has actively been involved in the issue since 1978 when an action programme on health and safety at work was formulated (CEC, 1980). Trade and multinational corporate business are other driving factors; partly because a common set of standards simplifies for the multinational companies but also because it reduces competition at the expense of workers' safety and health. It is not unreasonable to perceive a transfer of production to countries with lesser demands on a safe working environment as an economic advantage. A minimal level of occupational safety concerning chemicals in the air of the working environment is a way of reducing this possibility. Harmonisation also has draw-backs, centralising the decision-making could lead to decreased transparency as the distance between the regulators and the public increases.

EU membership has been targeted as one very important factor for the post-communist countries in Eastern and Central Europe to change their different administrations and regulations. In our study this region is represented by Estonia and Poland. The former USSR had a very high number of OELs, and they were set at an extraordinarily low level (Hansson, 1998). This was explained in Calabrelse (1978) by the more sensitive endpoints that Soviet scientists were using compared to western and predominantly US scientists, who focused on the pathologic responses. Both Estonia and Poland have established a new list of OELs. Poland still has very low exposure limits, considerably lower than the rest of the organisations in our study, while the Estonian OELs are of intermediate level today.

Our results show that the occupational exposure limits still vary considerably amongst countries. We have not found any evidence of this variation being explainable by differences in legal status or by deviations in the principles for risk assessment and risk management explicitly stated, such as the intended level of health protection. A more in-depth investigation might reveal policy-related motivations for these differences. Also, there might be scientific controversy regarding some substances that lead to different conclusions being drawn from the risk assessments.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.yrtph.2007.12.004.

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