Journal of Occupational and Environmental Hygiene, 12: S1–S3
ISSN: 1545-9624 print / 1545-9632 online
Published with license by Taylor & Francis
DOI: 10.1080/15459624.2015.1091263

The Past and Future of Occupational Exposure Limits

Jonathan Borak[1] and Lisa M. Brosseau[2]

[1]Clinical Professor of Epidemiology & Public Health, Clinical Professor of Medicine, Yale School of Medicine, New Haven, Connecticut
[2]School of Public Health, Division of Environmental and Occupational Health Sciences, University of Illinois at Chicago, Chicago, Illinois

Address correspondence to Jonathan Borak, Yale School of Medicine, 234 Church Street (6th floor), New Haven, CT 06510; e-mail: Jonathan.Borak@Yale.edu

The development of Occupational Exposure Limits (OELs) is thought to have begun with reports published in 1883 by Max Gruber, a German scientist who studied the effects of carbon monoxide at varying air concentrations by exposing both himself and laboratory animals.[1,2] His conclusions reflected the relative imprecision of then available analytical methods: "The boundary of injurious action of carbon monoxide lies at a concentration in all probability of 500 parts per million, but certainly not less than 200 parts per million."[1] K.B. Lehmann, beginning in 1886,[3] and over a career spanning more than 50 years, described a database of exposure limits that were derived from controlled exposure studies in humans and animals. His work, which continues to be cited in the modern literature, represents the scientific origin of contemporary workplace exposure standards.

In the U.S., the first compilation of exposure limits appeared in a technical paper published in 1921 by the Bureau of Mines, which described odor and irritation thresholds of 33 substances frequently encountered in workplaces and mines.[4] That document, along with pioneering research in animal physiology and toxicology by scientists such as Flury and Lehmann,[5] Sayers,[6] Henderson and Haggard,[7] and Bowditch,[8] laid the groundwork for state agencies, public health services, and professional organizations such as the American Conference of Governmental Industrial Hygienists (ACGIH) to develop and disseminate comprehensive lists of scientifically-based exposure standards.

The first systematic collection of "modern" OELs was developed in 1946 by an ACGIH subcommittee (that eventually became the TLV® Chemical Substances Committee), which had been directed to derive and maintain such a system of exposure limits. The ACGIH Committee on Industrial Hygiene Codes had been charged "to promote uniformity of thought and action with regard to adoption of rules and regulations for the control of industrial environmental conditions affecting health."[9] That first set of ACGIH OELs relied mainly on data originally compiled in 1945 by Warren Cook,[10] a legendary figure in early industrial hygiene, along with a smaller number of standards established by the Z-37 committee of the American Standards Association (now known as ANSI).[9] Cook's list, which included 132 specific chemicals plus X-rays, was itself derived from exposure limits that had been earlier recommended by the American Standards Association, U.S. Public Health Service and six states (California, Connecticut, Massachusetts, New York, Oregon, and Utah). The 1946 ACGIH list consisted of a table of Maximal Allowable Concentrations presented without guidelines, explicit definitions, or technical documentation.[11] In response to criticisms that the list lacked descriptions and explanations, a preface and documentation were added in 1953. In 1956, the term Threshold Limit Value (TLV) was adopted in lieu of the term Maximal Allowable Concentration.

Looking back in time, it is interesting to see how limited were the scientific rationales used in setting those early OELs. For a general overview, consider that Cook's 1945 compilation of 132 chemicals included a total of only ten pages of technical documentation (admittedly the type font was very small!).[10] Presented below are a few examples of the OEL justifications quoted from the Cook compilation. They provide a window on the then state-of-the-science underlying OEL development:

Acetaldehyde (MAC: 200 ppm): "... cats showed no noticeable effects on seven hours exposure to 280 ppm. The value of 200 ppm is based on this brief exposure since the immediate irritative effect of low concentrations appears to be more prominent than systemic effects."

Arsenic and Arsenic Trioxide (MAC: 0.15 mg/m^3): "... allowable concentration ... was based on analogy with other metals such as cadmium and lead ...: exposures in manufacturing operations ranging from 0.007 to 0.60 mg/m^3

as As_2O_3 resulted in no clinical symptoms attributable to arsenic except in a few isolated workers during a short period of unusually heavy exposure."

Ethylene Oxide (MAC: 100 ppm): ". . . 250 ppm caused no symptoms on exposure of animals for 480 minutes. With lack of long-time animal experiments and no published data on prolonged exposures of the workers at known concentrations, a value of 100 ppm is arbitrarily suggested."

Formaldehyde (MAC: 10 ppm): "The principal effect of exposure to low concentrations of formaldehyde is irritation . . . Barnes & Speicher . . . exposed themselves to 20 ppm for a short length of time. From the discomfort and lachrymation produced, it was their opinion that somewhat lower concentrations would be desirable for continued exposure. It is generally accepted that exposures should not exceed 10 ppm."

Lead (MAC: 150 mg/m^3): ". . . when the air of work rooms regularly contain no more than 0.15 mg/m^3, cases of disabling lead intoxication do not occur and cases of questionable or mild intoxication are rare."

What is striking is not just how much less protective those OELs were than their current counterparts, but also the relatively informal and risk-tolerant tones of their justification. Albeit a great step forward for industrial hygiene and a landmark in worker protection, those early OELs reflected efforts to set exposure levels that would minimize or prevent significant acute toxicity as indicated by the occurrence of gross abnormalities after relatively short-term exposures. There was essentially no consideration of toxicological mechanisms of action, outcomes were viewed as dichotomous, and only minimal efforts were made to address the uncertainties inherent to such standard setting.

By contrast, the ten articles in this supplement of the *Journal of Occuapational and Environmental Hygiene* provide a window into the future of OEL development. A combined effort by scientists at the National Institute for Occupational Safety and Health (NIOSH), Toxicology Excellence for Risk Assessment (TERA) and others, they present a systematic approach that begins with an understanding of systems biology, mechanisms of action and the early (i.e., "pre-clinical") effects of toxic exposures including genetic and epigenetic phenomena. They incorporate novel approaches to exposure assessment and inhalation dosimetry, contemporary methods in risk assessment, statistics and decision logic, and considerations of the need to harmonize standards across the world.

These articles make clear that the future of occupational exposure limits is promising, but also faces a number of important barriers.

Perhaps the most important barrier to developing an OEL is lack of data, and in particular, data that are relevant to human exposures in occupational settings. Each of the articles in this issue addresses at least one aspect of missing data, describes common solutions, and discusses or proposes new approaches. Many of these articles describe new technologies and data analytic methods that may be useful in overcoming data issues. The use of better models that address both uncertainty and variability in biological systems and exposure assessment offers particular promise.

Another important barrier to the development, selection, and application of OELs is the issue of global harmonization. This is not a new problem, although its importance continues to increase with on-going global expansion of industrialization accompanied by greater regulation of workplace exposures. The number and types of chemicals and products, technologies, production processes and uses continues to increase, all of which can result in new and unexpected workplace exposures. While global harmonization of OELs may be an unfeasible goal, more transparency and better communication about their underlying differences—both scientific and political—would contribute to more informed risk assessment by occupational health and safety professionals.

A third important barrier to the on-going relevance of OELs is the lack of systematic approaches for their development, selection and application, especially in the contexts of missing data and global harmonization. Occupational exposure assessment, in the last 40 years, has experienced a rapid expansion in the development of more systematic quantitative and qualitative approaches. If accompanied by appropriate validation and transparency about assumptions and limitations, these approaches can lead to more informed decision-making about workplace hazards. Given the limitations described above, such approaches are needed for OELs as important tools in occupational exposure assessment. There is some concern, however, that over-reliance on OELs derived from qualitative, non-numerical, or low or no data approaches, may contribute in the long run to the on-going lack of relevant experimental and epidemiologic data needed to validate such approaches. It is important not to jettison the baby with the bathwater.

The invention and adoption of numerical OELs mark a key innovation underlying the practice of occupational health and safety. Without such limits—whether derived from "perfect" human epidemiological datasets or in a more imperfect manner—one must rely on the appearance of gross adverse health outcomes, placing employees at potentially significant risk of morbidity and mortality. While never perfect, OELs will and should always be an important and essential tool for anticipating, recognizing and controlling workplace hazards.

REFERENCES

1. **Cook, W.:** Occupational Exposure Levels Worldwide 1987. American Industrial Hygiene Association, 1987.
2. **Paustenbach, D.J.:** Occupational Exposure Limits. In *Encyclopaedia Of Occupational Health And Safety*. 4th Ed. (Vol. 1), J. M. Stellman (Ed.) Geneva: International Labour Office, 1998. Pp. 30.27–30.34.
3. **Lehmann, K.B.:** Experimentelle Studien Uber Den Einfluss Technisch Und Hygienisch Wichtiger Gase Und Dampfe Auf Den Organismus; Ammoniak Und Salzsauregas. *Arch. Hyg. 5*:1–12 (1886).
4. **Fieldner, A.C., S.H. Katz, and S.P. Kenney:** *Gas Masks For Gases Met In Fighting Fires. Bureau Of Mines Technical Paper 248*. Washington, Dc, 1921.
5. **Lehmann, K.B., and F. Flury:** *Toxikologie Und Hygiene Der Technischen Losungsmittel*. Berlin: Julius Springer Verlag, 1938.

6. **Sayers, R.R.:** *Toxicology Of Gases And Vapors. International Critical Tables Of Numerical Data, Physics, Chemistry And Toxicology*. New York: Mcgraw-Hill, 1927.
7. **Henderson, Y., and H.W. Haggard:** *Noxious Gases and the Principles of Respiration Influencing Their Action*. 2nd ed. New York: Reinhold, 1943.
8. **Bowditch, M.**, **D.K. Drinker**, **P. Drinker**, **H.H. Haggard, and A. Hamilton:** Code for safe concentrations of certain common toxic substances used in industry. *J. Ind. Hyg. Toxicol. 22*:251 (1940).
9. **Corn, J.K.:** *Protecting The Health of Workers: The American Conference of Governmental Industrial Hygienists 1938–1988*. Cincinnati: American Conference Of Governmental Industrial Hygienists, 1989.
10. **Cook, W.A.:** Maximum allowable concentrations of industrial atmospheric contaminants. *Am. Ind. Hyg. Assoc. Quart. 6*:936–946 (1945).
11. **American Conference of Governmental Industrial Hygienists:** *Report of the Sub Committee on Threshold Limits. Maximum Allowable Concentrations of Air Contaminants for 1946 (Tlv Booklet)*. Cincinnati: ACGIH, 1946.