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But They Are Not Thresholds: A Critical Analysis of the Documentation of Threshold Limit Values

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Threshold Limit Values (TLVs) represent conditions under which the TLV Committee of the American Conference of Governmental Industrial Hygienists (ACGIH) believes that nearly all workers may be repeatedly exposed without adverse effect. A detailed research was made of the references in the 1976 *Documentation* to data on "industrial experience" and "experimental human studies." The references, sorted for those including both the incidence of adverse effects and the corresponding exposure, yielded 158 paired sets of data. Upon analysis it was found that, where the exposure was at or below the TLV, only a minority of studies showed no adverse effects (11 instances) and the remainder indicated that up to 100% of those exposed had been affected (8 instances of 100%). Although, the TLVs were poorly correlated with the incidence of adverse effects, a surprisingly strong correlation was found between the TLVs and the exposures reported in the corresponding studies cited in the *Documentation*. Upon repeating the search of references to human experience, at or below the TLVs, listed in the more recent, 1986 edition of the *Documentation*, a very similar picture has emerged from the 72 sets of clear data which were found. Again, only a minority of studies showed no adverse effects and TLVs were poorly correlated with the incidence of adverse effect and well correlated with the measured exposure. Finally, a careful analysis revealed that authors' conclusions in the references (cited in the 1976 *Documentation*) regarding exposure-response relationships at or below the TLVs were generally found to be at odds with the conclusions of the TLV Committee. These findings suggest that those TLVs which are justified on the basis of "industrial experience" are not based purely upon health considerations. Rather, those TLVs appear to reflect the levels of exposure which were perceived at the time to be achievable in industry. Thus, ACGIH TLVs may represent guides of levels which have been achieved, but they are certainly not thresholds.

Key words: TLV, industrial experience, air contaminants, workplace exposures, irritation, health impairment, narcosis

INTRODUCTION

The list of Threshold Limit Values (TLVs) of the American Conference of Governmental Industrial Hygienists (ACGIH) has had a profound influence upon the

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state of occupational hygiene in the U.S. and, indeed, throughout the world. Although intended as unofficial guides of acceptable exposure to chemical and physical agents in the workplace, these limits are widely applied as official limits by many states and countries. In point of fact, in the U.S., the Occupational Safety and Health Administration (OSHA) has twice adopted essentially the entire list of TLVs for Chemical Substances as enforceable limits: first the 1968 list under a one-time provision made for incorporating existing federal and national consensus standards (Sect. 6(a), OSH Act) [OSH Act, 1970], and recently the 1987/88 list in an unprecedented action [OSHA, 1989]. ACGIH TLVs formed the basis of the West German list of maximum workplace concentrations (MAKs) [Henschler, 1984], the British list of occupational exposure standards (OESs) [Health and Safety Executive, 1989], the Japanese list of maximum permissible exposure limits (PELs) [Toyama, 1985], the Swedish list of hygienic limit values (HLVs) [Nordberg et al., 1988], and many other lists.

The ACGIH defines TLVs for chemical substances as follows [ACGIH, 1988]: "Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect." This statement clearly implies that the TLVs are based primarily upon health considerations since "nearly all" workers exposed at the level of the TLV over a working lifetime would be protected. The current Chair of the Chemical Substances TLV Committee confirmed this when he stated that [Mastromatteo, 1988], "TLVs are health-based recommendations derived from assessment of the available published scientific information from studies in exposed humans and from studies in experimental animals. For each TLV, there has to be a published documentation supporting the committee recommendation."

Given these statements, it is not surprising that the various practitioners of occupational health generally believe that the TLVs afford substantial protection to the working population. Yet recently, both the process by which the TLVs have been established [Castleman and Ziem, 1988] and the data supporting the limits [Henschler, 1984; Zielhuis, 1988] have been called into question. Furthermore, each year, some of the values are changed, and in the majority of instances they are reduced, sometimes to one-half or one-tenth of their previous value. A past Chairman and TLV Committee member, in a robust defense of TLVs, remarked recently that ". . . throughout all the more than 40 years existence of threshold limit values, there has been no instance of serious health effects, provided exposures were kept at or below the TLVs." [Stokinger, 1988] Why then, it may be asked, have TLVs for such chemicals as benzene, vinyl chloride, and methyl chloride come down from early values of 100 ppm, 500 ppm and 20,000 ppm [Cook 1945] to current levels of 10 ppm, 5 ppm and 1000 ppm [ACGIH, 1988], respectively? Since most values are eventually reduced, one cannot help but wonder if the TLVs, indeed, protected nearly all workers during the transition period.

Resolution of this apparent contradiction in the meaning of TLVs can perhaps be resolved by examining more closely the key phrase, "nearly all workers." Here again the current Chairman of the Committee offered the following clarification [Mastromatteo, 1988]: "TLVs are based on the belief in a threshold or thresholds below which no adverse health effects would occur in workers . . . although . . . some workers with individual susceptibility may not be protected by the recommended TLVs." This notion that the TLVs protect all workers save, perhaps, a sensitive

subpopulation of persons especially susceptible on grounds of abnormal heredity, sensitization, disease, habits, sex, or reproductive status [de Silva, 1986], is reaffirmed annually by the ACGIH as follows [ACGIH, 1988]:

> Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit: a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness.

This statement indicates that a "small percentage" would experience discomfort, as perhaps would occur with a respiratory irritant, and that "a smaller percentage" might contract a chronic disease at or below the level of the TLV. To find further enlightenment as to what is meant by "small percentage" and "smaller percentage," it is necessary to analyze the documentation supporting the TLVs in detail and the references given therein. A separate companion piece to the TLV booklet is issued by the ACGIH under the title, *Documentation of the Threshold Limit Values and Biological Exposure Indices* [ACGIH, 1986]. In the TLV booklet the reader is urged to consult this *Documentation* when TLVs are being used [ACGIH, 1988].

When evaluating the evidence compiled in the *Documentation* it becomes clear that the TLV Committee has traditionally placed greatest importance upon studies involving human experience. This was stated unequivocally by a former Chairman of the Committee, H. Stokinger, about 20 years ago [see Stokinger, 1984] and supported more recently by Smyth [1984], who indicated that evidence based upon animal experiments must only serve until it can be replaced with documented human experience. Some 10 years ago one of us studied the references to human experience listed under each substance in the *1976 Documentation of the TLVs for Chemical Substances* [Roach, 1982]. We have recently analyzed the 1986 *Documentation* [ACGIH, 1986] to investigate whether the situation has changed since 1976, and in what follows we will summarize our findings from both investigations.

1976 DOCUMENTATION

In the 1976 list there were TLVs for 488 chemicals of which 225 TLVs were based at least in part on human experience. Copies of all the original published references to human experience were sought. The major references were the ones most easily located and contained the most useful information. Older and more abstruse references were progressively more difficult to obtain. The search was discontinued when the arbitrary target of 80% of the published references to human experience had been acquired.

References where the atmospheric exposure of the persons was doubtful or was not measured were put to one side. References in which there were doubts about the incidence of the effect the TLV was designed to prevent were also put aside as were those where the number of exposed persons was unclear. This left references to 70 substances which included data for 158 different groups of employees varying in size from one to 1,802 employees (median 10–11 employees). Information derived from these references is comprehensively compiled in Appendices A–C according to the measured exposure and the nature of the effect which served as the basis for the TLV

(impairment of health, irritation, or narcosis). The key references from which the data were extracted are also indicated.

The pertinent results are summarized in Table I where the incidence of adverse effects is given for persons exposed at or below the TLV. Some studies did show every employee to be free of adverse effects when exposed at or below the TLV (11 instances). However, scrutiny of Table I shows that most studies demonstrated an incidence of adverse effects which was substantially above zero at the TLV and which was even 100% in some cases (8 instances). This was particularly true regarding exposure to irritants, where 93 of 174 individuals exposed at or below the TLV experienced effects. At exposure levels above the TLVs, the incidence of adverse effects tended to be higher when the basis for the TLV was irritation or narcosis than when the basis was impairment of health. When all studies in Table I are combined, 17% of employees exposed to a concentration at or below the level of the 1976 TLV were adversely affected.

When exposure is expressed as a multiple of the TLV and related to the incidence of adverse effects, as in Figure 1, it is apparent that there was no correlation between the two variables ($r^2 = 0.005$; $p = 0.39$). On the other hand, the correlation between the TLV adopted for a substance and the concentrations reported in the corresponding studies listed in the *Documentation* was highly significant (Fig. 2; $r^2 = 0.26$; $p < 0.001$). The implications of these observations will be discussed later.

1986 DOCUMENTATION

It is well known that over the years TLVs tend to have been lowered, in stages, sometimes by large factors. On the other hand, TLVs have been developed for substances new to the list each year. Consequently, the overall picture may or may not be changing. In order to examine whether the situation has changed in 10 years the 1986 *Documentation* was analyzed. The labor of the exercise was reduced by limiting the analysis to those published references which, on reading the *Documentation,* appeared to contain data relating to atmospheric exposures at or below the 1986 TLV. The idea was that these particular references would be the ones to show that "nearly all" employees did not have adverse effects when exposed at these levels.

In the 1986 *Documentation* there were TLVs for 600 different chemicals of which 127 of the TLVs were based at least in part on human experience at or below the 1986 TLV. Published references to human experience for these chemicals were sought and assembled. As in the previous investigation, references were then put to one side where, on close examination, it was found that exposures were either not measured or were doubtful. References in which there were doubts about the incidence of the effect the TLV was designed to prevent were also put aside as were those where the number of exposed persons was unclear. This left references to 29 substances. Data were available for 72 different groups of individuals, exposed at or below the 1986 TLVs, varying in size from one to 1,182 people (median 9–10); a comprehensive listing of these data is provided in Appendices D and E that again includes the key references from which data were extracted.

Although the number of references investigated from the 1986 *Documentation* was smaller, the picture which emerged was substantially the same as for the 1976 *Documentation.* The incidence of adverse effects at the TLV again ranged from zero

TABLE I. Individuals Exposed at or Below 1976 TLVs

Effect	Chemical	Exposed	Affected	Exposure/ TLV	% affected
Impariment to health	Acetonitrile	3	1	1.00	33
	Asbestos	57	1	0.96[a]	2
	Asbestos	22	0	0.70	0
	Benzene	47	6	0.72	13
	Beryllium	372	93	> 1.00	25
	Carbon disulfide	16	16	1.00	100
	Carbon disulfide	100	39	< 0.53	39
	Carbon disulfide	100	53	0.73[a]	53
	Carbon tetrachloride	6	0	1.00	0
	Chlorine dioxide	12	7	< 1.00	58
	Chlorodiphenyl-42% cl	14	7	0.10	50
	Ethylene oxide	37	0	0.15[a]	0
	Fluoride	189	48	0.66[a]	25
	Lead	143	21	0.93	15
	Magnesium oxide fume	4	1	0.58	25
	Magnesium oxide fume	4	2	0.41	50
	Mercury	3	0	0.80	0
	Mercury	9	1	0.40	11
	Mica	109	1	0.10	92
	Mica	61	20	0.50	33
	2-Nitropropane	2	0	0.80[a]	0
	Sulfuric acid	15	0	0.43[a]	0
	Tetryl	1182	50	1.00	4
	Toluene	3	1	1.00	33
	Toluene	2	1	0.50	50
	Toulene 2,4 diisocyanate	12	0	1.00[a]	0
	Total:	2524	369		14.6
Irritation	Allyl alcohol	6	2	0.39	33
	Butyl alcohol	10	10	0.50	100
	Butyl alcohol	10	10	1.00	100
	Cyanogen	5	0	0.80	0
	Ethyl acetate	10	10	1.00	100
	Ethyl ether	10	10	0.75	100
	Propylene glycol monomethyl ether	1	0	0.47	0
	Propylene glycol monomethyl ether	6	4	0.95	67
	Selenium	62	9	0.15[a]	15
	Styrene monomer	6	3	0.99	50
	Styrene monomer	3	0	0.51	0
	Vanadium pentoxide	8	8	0.72	100
	Vanadium pentoxide	24	20	0.40[a]	83
	Vanadium pentoxide	5	5	0.40	100
	Vanadium pentoxide	2	2	0.20	100
	Vinyl chloride	6	0	0.30	0
	Total:	174	93		53.4
Narcosis	Perchloroethylene	8	2	0.96	25

[a]Exposure assigned at midpoint of range.

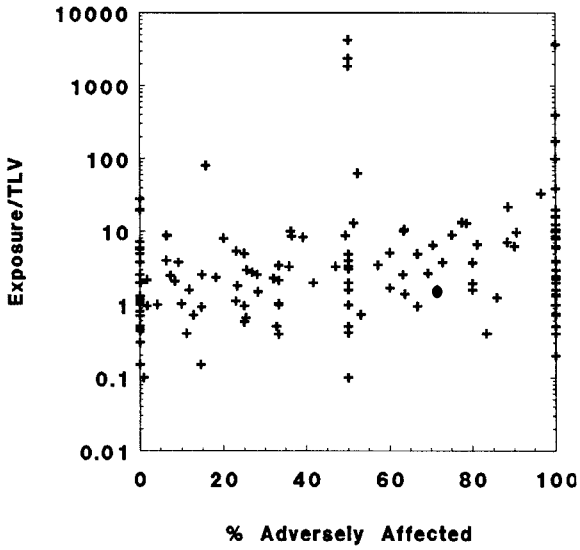

Fig. 1. Exposure expressed as a multiple of the TLV vs. the percent of individuals adversely affected. From references to human experience given in the 1976 *Documentation* of TLVs. (Data given in Appendices A–C.)

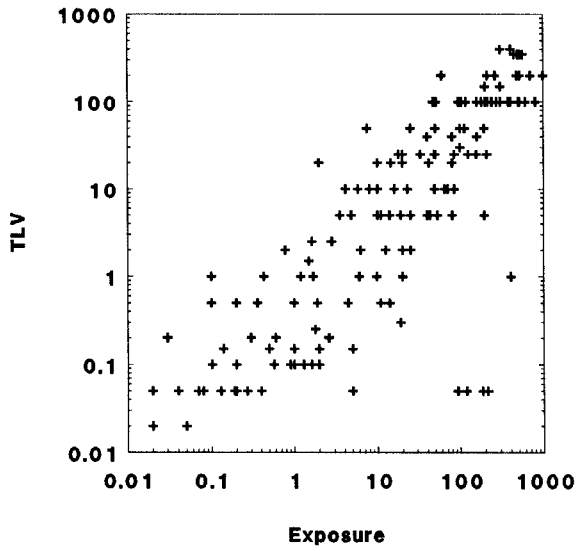

Fig. 2. TLV vs. the exposures reported in all studies for particular air contaminants. From references to human experience given in 1976 *Documentation* of TLVs. (Data given in Appendices A–C.)

(13 instances) to 100% (3 instances) and, as shown in Table II, it appeared that, overall, 14% of employees exposed at or below the 1986 TLV were adversely affected. Unlike the data gleaned from the 1976 *Documentation,* there was a weak but statistically significant linear correlation between exposure, expressed as a multiple of the TLV, and the percent of individuals affected (Fig. 3; $r^2 = 0.17$; $p = <0.001$).

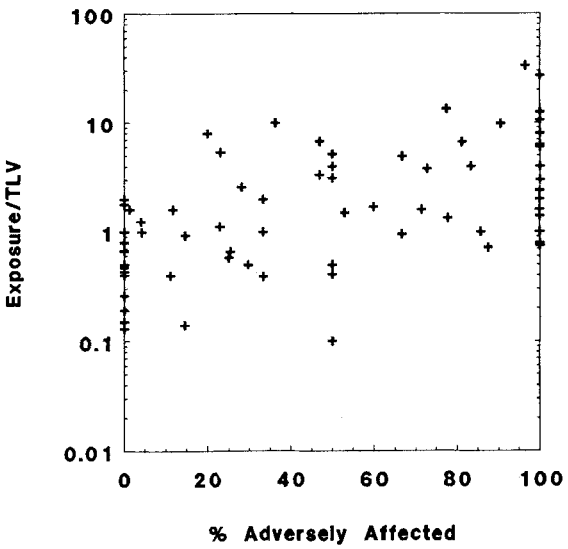

Fig. 3. Exposure expressed as a multiple of the TLV vs. the percent of individuals adversely affected. From references to human experience given in the 1986 *Documentation* of TLVs. (Data given in Appendices D, E.)

However, as shown in Figure 4, the correlation between the TLV adopted and the concentrations reported in the studies of particular contaminants was very strong ($r^2 = 0.61$; $p < 0.001$).

VALIDATION OF THE TLVS?

The above finding that, at or below the TLV, the incidence of adverse effects ranged from 0–100% and that overall one employee in 6 or 7 was adversely affected is clearly at odds with the official definition of TLVs. Indeed, we were so struck by this apparent contradiction arising from the very studies which were offered by the ACGIH as validation for its limits that we thought our results might have arisen from incorrect interpretations of the effects which the Committee intended to protect against with the TLVs. Thus, we returned to the 1976 *Documentation,* for which all references to human experience had been sought, and reexamined all of the papers which provided information about humans exposed *below* the 1976 TLV. Of these 40 papers, 70% were obtained which referred to 28 substances.

Upon reviewing each of the published articles, extracts were obtained which summarized the salient findings on these 28 substances. As far as possible the extracting was done without altering the words employed by the original authors. Statements about the effect(s) against which the 28 TLVs were meant to guard were also extracted from the 1976 *Documentation.* Both sets of statements are juxtaposed for quick reference in the following compilation. We added the words shown in italics to link pieces of information derived from portions of the papers.

TABLE II. Individuals Exposed at or Below 1986 TLVs

Effect	Chemical	Exposed	Affected	Exposure/TLV	% affected
Impairment to health					
	Acetonitrile	3	1	1.00	33
	Carbon disulfide	100	39	< 1.00	39
	Chlorine dioxide	12	7	< 1.00	58
	Chlorodiphenyl-42% Cl	14	7	0.10	50
	Cyclonite	558	0	0.19	0
	Fluoride	189	48	0.66[a]	25
	Hexane	10	0	1.00	0
	Lead	143	21	0.93	15
	Magnesium oxide fume	4	1	0.58	25
	Magnesium oxide fume	4	2	0.41	50
	Mercury	18	0	0.26[a]	0
	Mercury	3	9	0.80	0
	Mercury	9	1	0.40	11
	Nitroglycerine	8	7	0.72	88
	Nitroglycerine	7	6	1.00	86
	Propylene glycol dinitrate	3	0	0.40[a]	0
	Quartz	784	233	0.50	30
	Sulfur dioxide	3	0	0.50	0
	Sulfur dioxide	3	0	0.15	0
	Sulfuric acid	15	0	0.43[a]	0
	Tetryl	1,182	50	1.00	4
	Toluene	3	1	1.00	33
	Toluene	2	1	0.50	50
	Total:	3077	425		13.8
Irritation					
	Acetone	4	0	0.13	0
	Acetone	4	0	0.67	0
	Allyl alcohol	6	2	0.40	33
	Cyanogen	5	0	0.80	0
	Ethyl acetate	10	10	1.00	100
	Ethyl alcohol	3	3	0.79[a]	100
	Ethyl ether	10	10	0.75	100
	Propylene glycol monoethyl ether	6	4	0.95	67
	Selenium	1	0	0.47	0
	1,1,2-Trichloro-1,2,2-trifluorethane	62	9	0.14[a]	15
	Total:	50	0	0.67	0
		161	38		23.6

[a]Exposure assigned at midpoint of range.

Acetaldeyde

Effect. "The TLV, 100 ppm, is recommended to prevent excessive eye irritation and potential injury to the respiratory tract." [ACGIH, 1976].

Validation? "Several *of 12 volunteers* objected . . . strenously even at 25 ppm . . . A majority . . . experienced . . . eye irritation at 50 ppm." [Silverman et al., 1946].

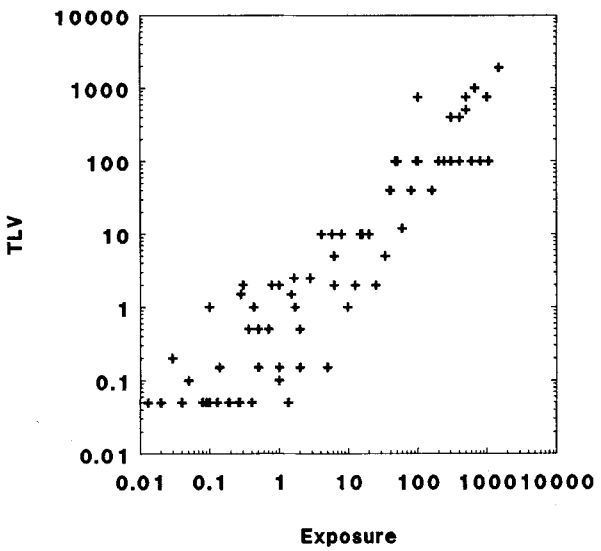

Fig. 4. TLV vs. the exposures reported in all studies for particular air contaminants. From references to human experience given in the 1986 *Documentation* of TLVs. (Data given in Appendices D, E.)

Acetone

Effect. "In view of the widespread use of acetone, its volatility and the paucity of reports of illness, it must be considered one of the least toxic of the common solvents. A limit of 1,000 ppm is recommended." [ACGIH, 1976].

Validation? "Acetone produced slight irritation at 300 parts per million, but 500 ppm was still tolerated by most *of 10* subjects." [Nelson et al., 1943].

Allyl Alcohol

Effect. "The threshold limit of 2 ppm would appear to provide protection against systemic effects and injury to superficial areas of the body, and to provide a reasonable freedom for most individuals from irritation." [ACGIH, 1976].

Validation? "Slight nose irritation *was* checked off by *2 of 6* volunteers exposed to *0.78 ppm* in an exposure room *which was* specially designed for the purpose." [Dunlap et al., 1958].

Allyl Propyl Disulfide

Effect. *TLV 2 ppm* "to minimize irritation and lacrimation." [ACGIH, 1976].

Validation? "Personal observation revealed that the general workroom atmosphere in the onion dehydration plant *where the concentration of allyl propyl disulfide was 1.7 ppm* caused marked irritation to the eyes, nose and throat . . ." [Feiner et al., 1946].

Asbestos

Effect. "On present evidence, this interim standard (5 fibers/ml longer than 5 microns) should afford protection against asbestosis and reduce to an acceptably low risk the development of neoplasms." [ACGIH 1976].

Validation? "In a recent study . . . of men from a factory processing chrysotile asbestos *none of 22* exposed to a mean dust concentration *of* 3.5 fibres/cm^3 *had* basal rales, *which were* considered as the key symptom *of* the earliest demonstrable effects on the lung due to asbestos." [BOHS, 1968].

Benzene

Effect. "A TLV of 25 ppm is believed low enough to prevent serious blood changes." [ACGIH, 1976].

Validation? *In* "a study . . . of the benzene exposure of workers in the rubber coating industry . . . the *measured* benzene vapor concentrations *averaged 18 ppm* and *6 of 47* employees show(*ed*) a lowered hemoglobin *of* below 13.5 grams." [Pagnotto et al., 1961].

2-Butanone

Effect. "A TLV of 200 ppm should prevent any injurious effects and minimize complaints about odor and irritation." [ACGIH, 1976].

Validation? "Butanone produced slight nose and throat irritation *in some of 10 volunteers* at 100 ppm." [Nelson et al., 1943].

Butyl Alcohol

Effect. "In view of the apparent potential of n-butyl alcohol to increase hearing loss in the younger age group of workers and to impair vestibular function at levels somewhat below 110 ppm, a TLV of 50 ppm as a ceiling value is recommended." [ACGIH 1976].

Validation? "Butyl alcohol, at 25 ppm *irritated the eyes, nose and throat of the majority of 10 volunteers* . . . At 50 ppm there was a unanimous feeling of pronounced throat irritation, *in 10 volunteers.*" [Nelson et al., 1943].

Carbon Disulfide

Effect. "The limit, 20 ppm, although protecting against serious systemic effects, would appear to have little margin of safety, especially for those with mineral-deficient diets." [ACGIH, 1976].

Validation? *At a plant where* "concentrations of carbon disulfide . . . are less than 10 ppm for long exposures, with occasional scattered higher figures in some areas for short exposures . . . *in* a group of 100 employees . . . objective neurological signs were noted in 39 subjects who had one or more deviations from the average." [Rubin et al., 1950].

Chlorine Dioxide

Effect. "The recommended limit of 0.1 ppm is . . . to prevent irritation and possible bronchitis." [ACGIH, 1976].

Validation? "At a factory for the production of sulfite-cellulose . . . extensive investigations . . . showed the occurrence of slight bronchitis in 7 of 12 workers exposed to chlorine dioxide . . . *at* concentrations lower than 0.1 ppm." [Gloemme and Lundgren, 1957].

Chlorodiphenyl--42% Chlorine

Effect. "It is believed that this limit, 1 mg/m^3, will offer reasonably good protection against systemic intoxication but may not guarantee complete freedom from chloracne." [ACGIH, 1976].

Validation? "In a chemical plant concerned with organic chemical production *where* the chlorinated diphenyls in the actual breathing zones of the workers *were* 0.1 mg/m^3 of air . . . seven cases of mild to moderate chloracne of the face and head occurred among 14 chemical operators exposed . . ." [Meigs et al., 1954].

Cyanogen

Effect. " . . . to prevent irritation, as well as systemic effects, a TLV of 10 ppm is recommended." [ACGIH, 1976].

Validation? " . . . no effects from a concentration of eight ppm *were* experienced . . . by three males and two females . . . exposed in a sealed room." [McNerney and Schrenk, 1960].

Ethyl Acetate

Effect. "The threshold limit, 400 ppm, is believed to provide a level with a large safety factor from the standpoint of health, but may prove mildly irritating to some workers unaccustomed to the exposure." [ACGIH, 1976].

Validation? "Ethyl acetate at 200 ppm was objectionable to some *of 10 volunteers* because of the strong odor at that concentration." [Nelson et al., 1943].

Ethyl Ether

Effect. "Regular exposure at this concentration (400 ppm, the TLV) should cause no demonstrable injury to health nor produce irritation or signs of narcosis among workers." [ACGIH, 1976].

Validation? "Complaints of nasal irritation began at 200 ppm *in the majority of 10 volunteers.*" [Nelson et al., 1943].

Ethylene Oxide

Effect. "The results of these investigations of the chronic toxicity of ethylene oxide indicate that a threshold limit value of 50 ppm offers an adequate margin of safety from ostensible systemic effects." [ACGIH, 1976].

Validation? *At a* "plant *where* chemical operators engaged in the manufacture of ethylene oxide who had been exposed for many years to sub-threshold-limit-value (*TLV*) levels of this chemical . . . the general level of long-term exposure for the operators appeared to be in the order of 5 to 10 ppm . . . *A* thorough study of *the* over-all health level of . . . 37 individuals . . . failed to reveal evidence that the study group had suffered any ill effects from their exposure." [Joyner, 1964].

Fluoride as F

Effect. "The limit, 2.5 mg/m^3, is sufficiently low to prevent irritative effects and to protect against disabling bone changes." [ACGIH, 1976].

Validation? *At a factory where the concentration of fluorides ranged from 0.14 to 3.13 mg/m^3* "radiological examination revealed signs of osteosclerosis in *48 of 189 workers.*" [Largent, 1961].

Isopropyl Acetate

Effect. "The limit, 250 ppm, . . . is considered adequate to prevent significant irritation of the eyes and respiratory passages." [ACGIH, 1976].

Validation? "We found that at 200 ppm, the majority of . . . twelve subjects of both sexes . . . experienced some degree of eye irritation." [Silverman et al., 1946].

Magnesium Oxide Fume

Effect "The limit, 10 mg/m^3, is recommended on the basis that this value represents a maximal desirable limit for dusts of relatively minor hazard." [ACGIH 1976].

Validation? *In 1 of 4 subjects exposed to an average concentration of magnesium oxide of 5.8 mg/m^3 and in 2 of 4 subjects exposed to an average concentration of magnesium oxide of 4.1 mg/m^3* "was found . . . a leukocytosis and a fever resembling those caused by the heavy metals." [Drinker et al., 1927].

Mercury

Effect. "Following a study in the chlorine industry it was concluded in general that exposure at 0.1 mg/m^3 produced no significant incidence of mercury poisoning but contained little or no margin of safety." [ACGIH, 1976].

Validation? "Symptoms or signs of chronic mercury poisoning were found in *1 of 9 and in none of 3* men . . . engaged in repairing D.C. meters . . . *where* the concentration of mercury in the atmosphere *averaged 19 and 40 μg/m^3, respectively.*" [Bidstrup et al., 1951].

Mica

Effect. "The limits of 20 mppcf . . . should prevent disabling pneumoconiosis, but may not be sufficiently low to eliminate positive chest x-ray findings in workers with many years' exposure." [ACGIH, 1976].

Validation? "In mica factories . . . the exposure to dust is limited to muscovite mica only, . . . *which* contains less than 1% free silica. *When* the dust concentrations to which most workers were exposed ranged from 2 to 21 mppcf, with an average of 10 mppcf, . . . 27 *of 61* workers examined had ground-glass 2 readings *of their* chest x-rays." [Heimann et al., 1953].

Propylene Glycol Monomethyl Ether

Effect. "It can be concluded that the methyl ether of propylene glycol is low in systemic toxicity but that the vapors should be controlled to 100 ppm, . . . the TLVC, . . . to avoid complaints from the odor." [ACGIH, 1976].

Validation? "Upon entering the exposure chamber containing *47.3 ppm propylene glycol monomethyl ether* . . . a physician . . . perceived the odor to be moderately strong, not objectionable. When six subjects entered the chamber containing *95.0 ppm* . . . four immediately asserted that the odor was too strong to be tolerated and expressed a desire to promptly terminate the experiment." [Stewart et al., 1970].

Selenium

Effect. "The limit of 0.2 mg/m^3 for elementary selenium and its common inorganic compounds is believed low enough to prevent systemic toxicity and to minimize irritation of eyes and respiratory passages." [ACGIH, 1976].

Validation? *In the* "manufacture of rectifiers . . . conjuctivitis and slight tracheo-bronchitis were present in 9 of 62 workers . . . The atmospheric concentrations at different stages of the process varied from 0.007 to 0.05 mg/m^3, nowhere reaching the recommended MAC of 0.1 mg/m^3" [Kinningkeit, 1962].

Styrene (monomer)

Effect. "On the basis of human responses at the 100 ppm level, . . . mild, untoward, but transient subjective responses in half of those exposed . . . , a time-weighted average concentration of 100 ppm is recommended for a TLV." [ACGIH, 1976].

Validation? "Three of . . . six subjects exposed to 99 ppm styrene vapor . . . noted mild eye or throat irritation developing 20 minutes after the exposure had begun . . . No untoward subjective symptoms or objective signs of illness were noted during . . . the vapor exposure *to 51.4 ppm for 1 hour.*" [Stewart et al., 1968].

Sulfuric Acid

Effect. "The TLV of 1 mg/m^3 is recommended to prevent irritation of respiratory passages and injury to the teeth." [ACGIH, 1976].

Validation? "Sulfuric acid mist . . . could not be detected by odor, taste or irritation . . . *by* 15 subjects *exposed* at 0.35 to 0.5 mg/m^3." [Amdur et al., 1952].

Toluene

Effect. "On the basis of the above data . . . human subjects exposed at 200 ppm suffered slight but definite changes in muscular coordination, . . . prolongation of reaction time, decrease in pulse rate and in systolic blood pressure, . . . a reduction in the TLV for toluene to 100 ppm is recommended." [ACGIH, 1976].

Validation? "During exposure to 100 parts per million of toluene in air . . . for 8 hours, . . . two (*of three*) subjects . . . had no subjective complaints except for moderate fatigue and sleepiness, . . . the third . . . complained of a slight headache, in addition to fatigue and sleepiness, on one occasion . . . With exposure to 50 parts per million of toluene in air . . . for 8 hours, . . . one (*of two*) subjects(s) had no subjective complaints, whereas the other complained toward the end of the experiment, of drowsiness and very mild headache." [von Oettingen et al., 1942].

Turpentine

Effect. "A TLV of 100 ppm is . . . recommended to prevent chiefly irritative effects." [ACGIH, 1976].

Validation? "Turpentine at 75 ppm, caused nose and throat irritation in several *of 10 volunteers.*" [Nelson et al., 1943].

Vanadium Pentoxide Dust

Effect. "The ceiling limit of 0.5 mg/m^3 for the dust of V_2O_5 . . . is currently under review . . . in the light of the above reports, . . . of upper respiratory tract irritation in the form of persistent productive cough at an average concentration of 0.2 mg/m^3." [ACGIH, 1976].

Validation? "All five volunteers . . . exposed for an eight-hour period *at* 0.2 mg/m^3 . . . developed a . . . persistent . . . loose cough the following morning . . . When two . . . volunteers were subjected to an eight hour exposure of vanadium pentoxide dust at a concentration of 0.1 mg/m^3, a distinct clinical picture of pulmonary irritation appeared." [Zenz and Berg, 1967].

Vinyl Chloride

Effect. "A time-weighted average threshold limit value of 200 ppm vinyl chloride (with a few ppm vinylidene chloride) seems appropriate to prevent systemic effects from long-continued daily exposure." [ACGIH, 1976].

Validation? "No significant untoward effects were noted by . . . six subjects exposed to *a 59 ppm time weighted average concentration based on 7.5 hours including a 0.5-hour lunch period in an uncontaminated area* . . . The exposure had no noticeable effect on neurological responses, nor did it produce significant changes in the results of mental, coordination, or manual dexterity tests conducted during the exposure period. All clinical laboratory studies performed in the post exposure period were normal and not significantly different from pre-exposure values." [Baretta et al, 1969].

Even a cursory inspection of the quotations given above indicates that adverse effects had, in 1976, long since been reported in people exposed below the levels of 21 of 28 TLVs. Also, in one further case, carbon disulfide, exposure to the substance may have contributed to the signs reported and in one other, fluoride, the radiological effects may have been forewarnings of some risk of health. In the remainder, although only 5 substances, the conclusions of the original authors and of the TLV Committee appear to have been consistent. Among these 5 substances, it is interesting to note that to date, since 1976, three of the TLVs have come down (asbestos, ethylene oxide, and vinyl chloride), and 2 have remained the same (cyanogen and sulfuric acid), the latter being the only ones out of 28 to have retained their unequivocal validation.

DISCUSSION

Health-effects data from industrial surveys in which the environment and the health of employees were measured at the same time are notable for their paucity. Published survey data upon which TLVs are based refer to 200 or so substances but the total number of employees in all these surveys added together amounted to less than 10,000. Nonetheless, because the TLV Committee placed great weight upon such data when they were available, we felt compelled to conduct this investigation of the original references used by the Committee in assigning the limits.

Individual TLVs are supported by data obtained from such small numbers of persons that a single study showing alarmingly high prevalence of adverse effects could perhaps, by itself, be dismissed as a chance error lacking real significance. It is the multiplicity of such data sets among TLVs as a whole which is most disturbing and which requires explanation.

Three striking results emerged from this work, namely, that the TLVs were poorly correlated with the incidence of adverse effects (Figs. 1, 3), that the TLVs were well correlated with the exposure levels which had been reported at the time the limits were adopted (Figs. 2, 4), and that interpretations of exposure-response relationships were inconsistent between the authors of studies cited in the 1976 *Documentation* and the TLV Committee. Taken together these observations suggest that the TLVs could not have been based purely on considerations of health.

While factors other than health appear to have influenced assignments of particular TLVs, the precise nature of such considerations is a matter of conjecture. However, we note that one interpretation is consistent with the above results, namely, that the TLVs represent levels of exposure which were perceived by the Committee to be realistic and attainable at the time. Such an interpretation was voiced by the past chairman of the Committee, H. Stokinger. The most illuminating example of this is the following quotation from a 1968 paper [Stokinger, 1984]:

> Some TLVs . . . have been based on a decade or two of industrial experience (acetone, butanol and several other alcohols, many halogenated hydrocarbon solvents, several hydrocarbon solvents, lead, mercury, etc.). Clearly, such procedures can yield indisputable data on which realistic TLVs can be derived, unsurrounded by that uncertainty and doubt which requires incorporation of large safety factors, leading to wasteful over-engineering of plant processes.

Here the key word "realistic" suggests that such TLVs represent levels which had already been achieved in the industries which harbored the contaminants. In fact, Figures 2 and 4 indicate that the typical TLV was generally within a factor of 2 of the average exposure reported in studies cited in the *Documentation*. Consideration of feasibility in the setting of occupational limits is properly embodied in the OSH Act regarding the development of official standards [Rappaport, 1984]. However, we doubt whether, given its very limited resources, a voluntary body such as the ACGIH Chemical Substances TLV Committee is capable of accurately determining the levels of control which are achievable across the range of industries which experience a particular contaminant.

A past Chairman of the Committee, V. Carter, indicated that the TLV Committee ". . . must cooperate with and solicit information from all available sources including industry" [Carter, 1982]. Although it is difficult to argue with this position, one presumes that such cooperation would be restricted to the solicitation of data regarding exposures and health effects. Yet, Castleman and Ziem [1988] presented a more sinister role for industry by suggesting that industrial influence extended to the actual deliberations of the Committee. This view was recently, and surprisingly, supported by the reflections of a past Chairman of the Committee who hinted at "chicanery" on the part of industry consultants [Elkins, 1988]. While the extent to which such manipulations cannot be known, it is difficult to escape the implication that at least some TLVs have been influenced by vested interests.

Our conclusion is that TLVs for chemical substances are a compromise between health-based considerations and strictly practical industrial considerations, with the balance seeming to strongly favor the latter. In other words, most TLVs may represent guides of levels which have been achieved *but they are not thresholds*. We, therefore, regard the definition of the ACGIH TLV as incorrect and the term "threshold" in the name of the limits as singularly inappropriate.

In the days before the OSH Act, and similar pieces of legislation in other countries, the TLVs served as useful guidelines. Today, however, official governmental bodies, such as OSHA, set and enforce legal limits for exposure to chemicals. Thus, the TLV Committee has become an anachronism with no clear role to play in the development of exposure limits. The National Institute for Occupational Safety and Health (NIOSH), on the other hand, includes a full-time group, independent of industry and organized labor, charged with preparing Criteria Documents on hazardous chemicals. Each of 129 draft Criteria Documents prepared up to 1988 has been reviewed by experts representing affected industries, organized labor, and trade or health professionals with related experience in academia, government, or industry [Millar, 1988]. Since NIOSH appears to be the proper organization to develop criteria for chemical exposure in the U.S., we were concerned to see OSHA rely so heavily

upon the ACGIH TLVs, rather than information supplied by NIOSH, as the basis for recently updating its standards [OHSA, 1989].

The dependence of other countries on ACGIH TLVs should lessen as the particular counterparts to OSHA and NIOSH increasingly develop their own national limits appropriate to their economic and technical capabilities. International agencies such as the World Health Organization and the International Labor Office should be encouraged to develop exposure guidance for use in developing countries which are not currently able to generate their own limits.

RECOMMENDATION

Since so many TLVs for chemical substances appear to offer relatively little protection, we recommend that occupational hygienists and other health professionals routinely investigate the *Documentation* and, more importantly, the reference materials pertaining to particular contaminants rather than accepting on faith that every TLV provides the protection claimed by the ACGIH. This is in keeping with the sentiments expressed in the TLV booklet that " . . . the best practice is to maintain concentrations of all atmospheric contaminants as low as practical" [ACGIH, 1988]. Whenever possible, the exposure of employees in a particular process should be so controlled that during each work-shift the atmospheric exposure of nearly all the employees is kept below the TLV. As a general principle, it would be prudent to keep the average exposure of the employees below a small fraction of the TLV, say of 1/4 to 1/10. If this were done, and assuming exposure distributions to be quasi-log-normal, then fewer than 1–5% of exposures would be expected to exceed the TLV [Rappaport et al., 1988].

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APPENDIXES

APPENDIX A. Documentation of 1976 TLVs Based Upon References to Human Experience: Hazard—"Impairment of Health"

Substance	Air concentration: Exposure	Air concentration: TLV	(Exposure/TLV)	Individuals affected	Organ affected
Acetonitrile[1]	160 ppm	40 ppm	4.0	1/2	Lungs
	80 ppm	40 ppm	2.0	0/2	Lungs
	40 ppm	40 ppm	1.0	1/3	Lungs
Aldrin[2]	1–2.6 mg/m^3	0.25 mg/m^3	4–10.4	0/34	—
Anisidine[3]	1.9 mg/m^3	0.5 mg/m^3	3.8	0/23	—
Antimony[4,5]	10.9 mg/m^3	0.5 mg/m^3	21.9	69/78	URT
	3.1–5.6 mg/m^3	0.5 mg/m^3	6.2–11.2	8/125	(Death)
	3.1–5.6 mg/m^3	0.5 mg/m^3	6.2–11.2	37/75	Heart
Arsine[6,7]	70–300 ppm	0.05 ppm	1,400–6,000	2/2	(Death)
	5 ppm	0.05 ppm	100	5/5	Blood
Asbestos[8]	11–27 f/cc	5 f/cc	2.2–5.4	14/153	Lungs
	11 f/cc	5 f/cc	2.2	1/58	Lungs
	3.5–6.0 f/cc	5 f/cc	0.7–1.2	1/57	Lungs
	3.5 f/cc	5 f/cc	0.7	0/22	—
Benzene[9–11]	208 ppm	25 ppm	8.3	130/332	Blood
	100–150 ppm	25 ppm	4.0–6.0	3/12	Blood
	0–100 ppm	25 ppm	2.8–4.0	2/4	Blood
	18 ppm	25 ppm	0.7	6/47	Blood
Beryllium[12,13]	0.018–0.060 mg/m^3	0.002 mg/m^3	9–30	0/50	—
	> 0.002 mg/m^3	0.002 mg/m^3	> 1	93/372	Lungs
Cadmium cpds. dust[14,15]	0.02–0.24 mg/m^3	0.05 mg/m^3	0.4–4.8	12/19	Kidney/lungs
	0.13 mg/m^3	0.05 mg/m^3	2.5	4/27	Kidney/lungs
	0.07 mg/m^3	0.05 mg/m^3	1.4	14/22	Kidney/lungs

(*continued*)

APPENDIX A. Documentation of 1976 TLVs Based Upon References to Human Experience: Hazard—"Impairment of Health" (continued)

Substance	Air concentration: Exposure	Air concentration: TLV	(Exposure/TLV)	Individuals affected	Organ affected
Carbon disulfide[16,17]	20 ppm	20 ppm	1.0	16/16	CNS
	3–26 ppm	20 ppm	0.15–1.3	53/100	CNS
	< 10 ppm	20 ppm	< 0.5	39/100	CNS
Carbon tetrachloride[18,19]	85 ppm	10 ppm	8.5	4/4	Liver/kidney
	45–97 ppm	10 ppm	4.5–9.7	15/17	Liver/kidney
	49 ppm	10 ppm	4.9	3/6	Liver/kidney
	10 ppm	10 ppm	1.0	0/6	—
Chlordane[2]	14 mg/m^3	0.5 mg/m^3	28.0	0/22	—
Chlorine dioxide[20,21]	0.2–ppm	0.1 ppm	0–20	25/69	Lungs
	< 0.1 ppm	0.1 ppm	< 1.0	7/12	Lungs
Chlorodiphenyl-42% chlorine[22]	0.1 mg/m^3	1 mg/m^3	0.1	7/14	Skin/liver
Cobalt[23,24]	0.1–1.7 mg/m^3	0.1 mg/m^3	1.0–17.0	1,352/1,802	Lungs
	0.1–0.2 mg/m^3	0.1 mg/m^3	1–2	3/1,500	Lungs
Cotton dust[25–27]	2.6 mg/m^3	0.2 mg/m^3	13.0	142/277	Lungs
	0.6 mg/m^3	0.2 mg/m^3	3.0	203/793	Lungs
	0.3 mg/m^3	0.2 mg/m^3	1.5	160/566	Lungs
Ethylene chlorohydrin[28]	300–500 ppm	1 ppm	300–500	6/6	Liver/CNS
Ethylene oxide[29]	5–10 ppm	50 ppm	0.1–0.2	0.37	—
Fluoride[30,31]	2.81 mg/m^3	2.5 mg/m^3	1.1	17/74	Bones
	0.14–3.13 mg/m^3	2.5 mg/m^3	0.06–1.25	48/189	Bones
Fluorine[32]	1.2 ppm	1 ppm	1.2	0.61	—
Hexane[33]	500 ppm	100 ppm	5.0	0/10	—
Hydrogen selenide[34]	< 0.2 ppm	0.05 ppm	< 4.0	5/25	Lungs
Lead[35]	5.0 mg/m^3	0.15 mg/m^3	33	27/28	Blood/kidney
	2.0 mg/m^3	0.15 mg/m^3	13.3	24/31	Blood/kidney
	1.0 mg/m^3	0.15 mg/m^3	6.7	56/69	Blood/kidney
	0.14 mg/m^3	0.15 mg/m^3	0.93	21/143	Blood/kidney
	0.5 mg/m^3	0.15 mg/m^3	3.3	15/32	Blood/kidney
Magnesium oxide fume[36]	5.8 mg/m^3	10 mg/m^3	0.6	1/4	Lungs
	4.1 mg/m^3	10 mg/m^3	0.4	2/4	Lungs
Mercury (Inorganic)[37]	0.40 mg/m^3	0.05 mg/m^3	8.0	1/5	CNS
	0.27 mg/m^3	0.05 mg/m^3	5.4	6/26	CNS
	0.19 mg/m^3	0.05 mg/m^3	3.8	8/11	CNS
	0.13 mg/m^3	0.05 mg/m^3	2.6	9/32	CNS
	0.08 mg/m^3	0.05 mg/m^3	1.6	2/17	CNS
	0.04 mg/m^3	0.05 mg/m^3	0.8	0/3	CNS
	0.02 mg/m^3	0.05 mg/m^3	0.4	1/9	CNS
Methylene chloride[38]	985 ppm	200 ppm	4.9	2/3	CNS/blood
	690 ppm	200 ppm	3.5	1/3	CNS/blood
	515 ppm	200 ppm	2.6	0.8	—
	213 ppm	200 ppm	1.1	0/1	—
Mica[39,40]	80 mppcf	20 mppcf	4.0	3/47	Lungs
	42 mppcf	20 mppcf	2.1	1/12	Lungs
	10 mppcf	20 mppcf	0.5	20/61	Lungs
	2 mppcf	20 mppcf	0.1	1/109	Lungs

(*continued*)

APPENDIX A. Documentation of 1976 TLVs Based Upon References to Human Experience: Hazard—"Impairment of Health" (continued)

Substance	Air concentration		(Exposure/TLV)	Individuals affected	Organ affected
	Exposure	TLV			
Nitrobenzene[3]	6 ppm	1 ppm	6.0	0.39	—
p-Nitrochloro-benzene[3]	20 mg/m^3	1 mg/m^3	20	0/39	—
Nitrogen dioxide[41]	196 ppm	5 ppm	39	4/4	Lungs
	80 ppm	5 ppm	16	1/1	Lungs
2-Nitropropane[46]	20–45 ppm	25 ppm	0.8–1.8	5/5	CNS
	10–30 ppm	25 ppm	0.4–1.2	0/2	—
Phosphine[42]	3–35 ppm	0.3 ppm	10–120	35/67	Lungs
Picric acid[43]	0.009–0.194 mg/m^3	0.1 mg/m^3	0.09–1.9	7/71	Skin
Platinum soluble salts[44,45]	0.007 mg/m^3	0.002 mg/m^3	3.5	52/91	Lungs
Silicon carbide[47]	100 mppcf	30 mppcf	3.3	19/53	Lungs
Sulfuric acid[48,49]	3–16.6 mg/m^3	1 mg/m^3	3–17	57/63	Lungs/teeth
	< 0.8–2.5 mg/m^3	1 mg/m^3	0.8–2.5	9/15	Lungs/teeth
	0.35–0.5 mg/m^3	1 mg/m^3	0.35–0.5	0/15	—
Tetrabromo-ethane[50]	< 14 ppm	1 ppm	< 14	6/6	Liver
1,1,2,2-Tetra-chloroethane[51]	53 ppm	5 ppm	10.6	54/86	CNS
	43 ppm	5 ppm	8.6	39/107	CNS
	14 ppm	5 ppm	2.8	14/52	CNS
Tetryl[52]	1.5 mg/m^3	1.5 mg/m^3	1.0	50/1,182	Skin
Toluene[53]	800 ppm	100 ppm	8.0	3/3	Blood/CNS
	600 ppm	100 ppm	6.0	3/3	Blood/CNS
	400 ppm	100 ppm	4.0	3/3	Blood/CNS
	300 ppm	100 ppm	3.0	3/3	Blood/CNS
	200 ppm	100 ppm	2.0	3/3	Blood/CNS
	100 ppm	100 ppm	1.0	1/3	Blood/CNS
	50 ppm	100 ppm	0.5	1/2	Blood/CNS
Toluene-2,4-diisocyanate (TDI)[54,55]	0.05 ppm	0.02 ppm	2.5	19/260	Lungs
	0.03–0.07 ppm	0.02 ppm	1.5–3.5	12/12	Lungs
	0.01–0.03 ppm	0.02 ppm	0.5–1.5	0.12	—

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APPENDIX B. Documentation of 1976 TLVs Based Upon References to Human Experience: Hazard—"Irritation"

Substance	Air concentration		(Exposure/ TLV)	Individuals affected	Organ affected
	Exposure	TLV			
Allyl alcohol[1]	25 ppm	2 ppm	12.5	5/5	Eyes/nose
	12.5 ppm	2 ppm	6.3	4/7	Eyes/nose
	6.25 ppm	2 ppm	3.1	3/6	Eyes/nose
	0.78 ppm	2 ppm	0.4	2/6	Eyes/nose
2-Butoxy ethanol[2]	195 ppm	50 ppm	3.9	3/3	Eyes/blood
	113 ppm	50 ppm	2.3	6/6	Eyes/blood
n-Butyl acetate[3]	300 ppm	150 ppm	2.0	10/10	Eyes/URT
	200 ppm	150 ppm	1.3	10/10	Eyes/URT
Butyl alcohol (n-butanol)[3]	50 ppm	50 ppm	1.0	10/10	Eyes/URT
	25 ppm	50 ppm	0.5	10/10	Eyes/URT
α-Chloroaceto-phenone[4]	213 ppm	0.05 ppm	4,260	2/4	Eyes
	119 ppm	0.05 ppm	2,380	2/4	Eyes
	93 ppm	0.05 ppm	1,860	2/4	Eyes
Chlorobenzilidene malonitrile[5]	0.2 ppm	0.05 ppm	4.0	4/4	Eyes/skin
Cyanogen[6]	16 ppm	10 ppm	1.6	7/7	Eyes/URT
	16 ppm	10 ppm	1.6	5/7	Eyes/URT
	8 ppm	10 ppm	0.8	0/5	—
Cyclohexanol[3]	100 ppm	50 ppm	2.0	10/10	Eyes/URT
Ethyl acetate[3]	400 ppm	400 ppm	1.0	10/10	Eyes
Ethyl ether[3]	300 ppm	400 ppm	0.75	10/10	URT

(*continued*)

APPENDIX B. Documentation of 1976 TLVs Based Upon References to Human Experience: Hazard—"Irritation" (continued)

Substance	Air concentration		(Exposure/ TLV)	Individuals affected	Organ affected
	Exposure	TLV			
Hydrogen sulfide[7,8]	50–80 ppm	10 ppm	5–8	88/125	Eyes
	18–28 ppm	10 ppm	1.8–2.8	25/78	Eyes
Iodine[9]	1.63 ppm	0.1 ppm	16.3	4/4	Eyes/URT
	0.57 ppm	0.1 ppm	5.7	0/4	—
Isoamyl alcohol[3]	200 ppm	100 ppm	2.0	10/10	Eyes/URT
Isophorone[10]	25 ppm	5 ppm	5.0	8/12	Eyes/URT
	10 ppm	5 ppm	2.0	5/12	Eyes/URT
Mesityl oxide[10]	50 ppm	25 ppm	2.0	6/12	Eyes/URT
Methyl-2-cyano-acrylate[11]	20 ppm	2 ppm	10	14/14	Eyes/URT
Osmium tetroxide[12]	0.1–0.6 mg/m^3	0.002 mg/m^3	50–300	7/7	Eyes/URT
Ozone[13,14]	2 ppm	0.1 ppm	20.0	1/1	Lungs
	0.8–1.7 ppm	0.1 ppm	8–17	11/14	Lungs
Propylene glycol monomethyl ether[15]	95 ppm	100 ppm	0.95	4/6	URT
	47 ppm	100 ppm	0.47	0/1	—
Selenium[16]	0.007–0.05 mg/m^3	0.2 mg/m^3	0.035–0.25	9/62	Eyes/URT
Stoddard solvent[17,18]	984–1,054 ppm	100 ppm	9.8–10.5	19/30	Eyes
	497–528 ppm	100 ppm	5.0–5.3	18/30	Eyes
	270 ppm	100 ppm	2.7	9/13	Eyes
	164–200 ppm	100 ppm	1.6–2.0	7/30	Eyes
	160 ppm	100 ppm	1.6	4/8	Eyes
Styrene monomer[19]	376 ppm	100 ppm	3.8	4/5	Eyes/CNC
	216 ppm	100 ppm	2.2	1/3	Eyes/CNC
	117 ppm	100 ppm	1.2	0/1	—
	99 ppm	100 ppm	1.0	3/6	Eyes/CNC
	51 ppm	100 ppm	0.5	0/3	—
Vanadium pentoxide dust[20,21]	1 mg/m^3	0.5 mg/m^3	2.0	2/2	URT
	0.36 mg/m^3	0.5 mg/m^3	0.7	8/8	URT
	0.1–0.3 mg/m^3	0.5 mg/m^3	0.20–0.6	20/24	URT
	0.20 mg/m^3	0.5 mg/m^3	0.4	5/5	URT
	0.1 mg/m^3	0.5 mg/m^3	0.2	2/2	URT
Vinyl chloride[22]	460–490 ppm	200 ppm	2.3–2.5	2/11	Eyes
	260 ppm	200 ppm	1.3	0/4	—
	60 ppm	200 ppm	0.3	0/6	—

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APPENDIX C. Documentation of 1976 TLVs Based Upon References to Human Experience: Hazard—"Narcosis"

Substance	Air concentration		(Exposure/TLV)	Individuals affected	Organ affected
	Exposure	TLV			
Chloroform[1]	77–237 ppm	25 ppm	3.1–9.5	9/10	Brain
	21–77 ppm	25 ppm	0.8–3.1	8/10	Brain
Methyl cellosolve[2]	61–3,960 ppm	25 ppm	2.4–158	6/38	Brain
Methyl chloroform[3]	560 ppm	350 ppm	1.6	4/5	Brain
	520 ppm	350 ppm	1.5	5/7	Brain
	490 ppm	350 ppm	1.4	7/7	Brain
	440 ppm	350 ppm	1.3	6/7	Brain
Perchloroethylene[4]	104 ppm	100 ppm	1.0	2/6	Brain
	96 ppm	100 ppm	1.0	2/8	Brain

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APPENDIX D. Documentation of 1986 TLVs Based Upon References to Human Experience: Hazard—"Impairment of Health"

Substance	Air concentration		(Exposure/TLV)	Individuals affected	Organ affected
	Exposure	TLV			
Acetonitrile[1]	160 ppm	40 ppm	4.0	1/2	Lungs
	80 ppm	40 ppm	2.0	0/2	—
	40 ppm	40 ppm	1.0	1/3	Lungs
Carbon	20 ppm	10 ppm	2.0	16/16	CNS
disulfide[2,3]	3–26 ppm	10 ppm	0.3–2.6	53/100	CNS
	< 10 ppm	10 ppm	< 1.0	39/100	CNS
Chlorine	0–2 ppm	0.1 ppm	0–20	25/69	Lungs
dioxide[4,5]	< 0.1 ppm	0.1 ppm	< 1.0	7/12	Lungs
Chlorodiphenyl[6]	0.1 mg/m^3	1 mg/m^3	0.10	7/14	Skin
Cyclonite[7]	0.28 mg/m^3	1.5 mg/m^3	0.19	0/558	—
Fluoride[8,9]	2.81 mg/m^3	2.5 mg/m^3	1.1	17/74	Bones
	0.14–3.13 mg/m^3	2.5 mg/m^3	0.6–1.25	48/189	Bones
Hexane[11]	500 ppm	500 ppm	1.0	0/10	—
Lead[10]	5.0 mg/m^3	0.15 mg/m^3	33	27/28	Blood/kidney
	2.0 mg/m^3	0.15 mg/m^3	13.3	24/31	Blood/kidney
	1.0 mg/m^3	0.15 mg/m^3	6.7	56/69	Blood/kidney
	0.5 mg/m^3	0.15 mg/m^3	3.3	15/32	Blood/kidney
	0.14 mg/m^3	0.15 mg/m^3	.93	21/143	Blood/kidney
Magnesium	5.8 mg/m^3	10 mg/m^3	0.6	1/4	Lungs
oxide fume[12]	4.1 mg/m^3	10 mg/m^3	0.4	2/4	Lungs
Manganese[13]	6.23 mg/m^3	5 mg/m^3	1.25	15/373	CNS
Mercury	0.09 mg/m^3	0.05 mg/m^3	1.6–2.0	0/21	—
(Inorganic)[14–16]	0.08 mg/m^3	0.05 mg/m^3	1.6	1/75	CNS
	0.004–0.022 mg/m^3	0.05 mg/m^3	0.2–0.6	0/18	—
	0.40 mg/m^3	0.05 mg/m^3	8.0	1/5	CNS
	0.27 mg/m^3	0.05 mg/m^3	5.4	6/26	CNS
	0.19 mg/m^3	0.05 mg/m^3	3.8	8/11	CNS
	0.13 mg/m^3	0.05 mg/m^3	2.6	9/32	CNS
	0.08 mg/m^3	0.05 mg/m^3	1.6	2/17	CNS
	0.04 mg/m^3	0.05 mg/m^3	0.8	0/3	CNS
	0.02 mg/m^3	0.05 mg/m^3	0.4	1/9	CNS
Nitroglycerin[17]	2.0 mg/m^3	0.5 mg/m^3	4.0	5/6	Headache/CVS
	0.7 mg/m^3	0.5 mg/m^3	1.4	10/10	Headache/CVS
	0.5 mg/m^3	0.5 mg/m^3	1.0	6/7	Headache/CVS
	0.36 mg/m^3	0.5 mg/m^3	0.72	7/8	Headache/CVS
Di-sec-octyl-phthalate[18]	1.7–66 mg/m^3	5 mg/m^3	0.34–13.2	69/147	CNS
Propylene glycol	1.35 ppm	0.05 ppm	27	6/6	CNS
dinitrate[19]	0.26 ppm	0.05 ppm	5.2	6/12	CNS
	0.1 ppm	0.05 ppm	2.0	1/3	CNS
	0.01–0.03 ppm	0.05 ppm	0.2–0.6	0/3	—
Quartz[20,21]	0.05 mg/m^3	0.1 mg/m^3	0.5	233/784	Lungs
Sulfur	1 ppm	2 ppm	0.5	0/3	—
dioxide[22]	0.3 ppm	2 ppm	0.15	0/3	—
Sulfuric	3–16.6 mg/m^3	1 mg/m^3	3–17	57/63	Lungs/teeth
acid[23,24]	< 0.8–2.5 mg/m^3	1 mg/m^3	0.8–2.5	9/15	Lungs/teeth
	0.35–0.5 mg/m^3	1 mg/m^3	0.35–0.5	0/15	—
Tetryl[25]	1.5 mg/m^3	1.5 mg/m^3	1.0	50/1,182	Skin
Toluene[26]	800 ppm	100 ppm	8.0	3/3	Blood/CNS
	600 ppm	100 ppm	6.0	3/3	Blood/CNS
	400 ppm	100 ppm	4.0	3/3	Blood/CNS

(*continued*)

APPENDIX D. Documentation of 1986 TLVs Based Upon References to Human Experience: Hazard—"Impairment of Health" (continued)

Substance	Air concentration		(Exposure/TLV)	Individuals affected	Organ affected
	Exposure	TLV			
Toluene[26]	300 ppm	100 ppm	3.0	3/3	Blood/CNS
(continued)	200 ppm	100 ppm	2.0	3/3	Blood/CNS
	100 ppm	100 ppm	1.0	1/3	Blood/CNS
	50 ppm	100 ppm	0.5	1/2	Blood/CNS

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APPENDIX E. Documentation of 1986 TLVs Based Upon References to Human Experience. Hazard—"Irritation"

Substance	Air Concentration		(Exposure/ TLV)	Individuals affected	Organ affected
	Exposure	TLV			
Acetone[1,2]	1,006 ppm	750 ppm	1.34	7/9	Eyes/URT/brain
	100 ppm	750 ppm	0.13	0/4	—
	500 ppm	750 ppm	0.67	0/4	—
Allyl alcohol[3]	25 ppm	2 ppm	12.5	5/5	Eyes/nose
	12.5	2 ppm	6.3	7/7	Eyes/nose
	6.25	2 ppm	3.1	3/6	Eyes/nose
	0.78	2 ppm	0.4	2/6	Eyes/nose
Camphor[4]	59 mg/m^3	12 mg/m^3	4.9	4/6	URT
Cyanogen[5]	16 ppm	10 ppm	1.6	7/7	Eyes/URT
	16 ppm	10 ppm	1.6	5/7	Eyes/URT
	8 ppm	10 ppm	0.8	0/5	Eyes/URT
Ethyl acetate[6]	400 ppm	400 ppm	1.0	10/10	Eyes/URT
Ethyl alcohol[7]	1,300–1,700 mg/m^3	1,900 mg/m^3	0.68–0.89	3/3	Eyes/URT
Ethyl ether[6]	300 ppm	400 ppm	0.75	10/10	URT
Propylene glycol monethyl ether[8]	95 ppm	100 ppm	0.95	4/6	URT
	47 ppm	100 ppm	0.47	0/1	URT
Selenium[9]	0.007–0.05 mg/m^3	0.2 mg/m^3	0.035–0.25	9/62	Eyes/URT
1,1,2-Trichloro-1,2,2,Trifluoroethane[10]	669 ppm	1000 ppm	0.67	0/50	—

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