Toxic limits*

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The foundation of modern science and modern technique is the process of weighing, measuring and counting. The step from the empirical state to modern science, from skilled handiwork to mechanical performance was possible only after methods for specific weighing and measuring had been found. Exact examinations of air and its contaminants in factories were great rarities even 20 and 15 years ago; indeed determinations of dust concentrations were the only such measurements made to any appreciable extent and these were done in English speaking countries alone. No other instruments were available for investigations in factories except those for determining the dust contents. (In the United States, the sugar-tube, Palmer apparatus, Greenburg-Smith impinger; in England Owens dust counter; in South Africa, Kotze konimeter.) The methods and instruments used in laboratories have also been used in factories, instruments difficult to handle and transport often not accurate. All this is different today.

We now have various instruments suitable for use in factories, although the truly exact instrument and the precise method is still lacking for certain purposes. On the contrary we even suffer from too many offers of instruments made by firms and scientists. Their only small deviation from already existing instruments makes it more difficult to compare the results, since the new instruments often do not guarantee any greater accuracy.

RR Sayers[1] published in 1927 data about the most important poisons, briefly summarizing them. AS far as I know, Zangger[2] in 1928 was the first author to compile a table "about the effect of irritant and poisonous gases and vapors." For many gases he specified the exact concentration in milligrams per liter which would kill immediately or be fatal after 0.3 to 1.0 hour. He defined which concentration may be borne with large, small or no damaging effect for a period of time. The compilation is supported for the largest part by animal experiments, made by KB. Lehmann and his collaborators, Zangger, US. Bureau of Mines, Haldane, Henderson and Haggard. Experiments on human beings (experiments on the author himself) are rarely reffered to. An extension and completion of this table maybe found in the book, *Noxious Gases*, by Flury and Zernik.[3]

The table, "Maximum Allowable Concentrations," compiled by Bowditch[4,5] was especially meritorious as it included tabulation of regulations of other governmental authorities in addition to those suggested for Massachusetts. These had been referred for criticism to more than a score of the leading authorities in this country and abroad prior to their promulgation. This table has been revised and extended by himself, CK Drinker, P. Drinker, HH. Haggard and A Hamilton.[6] By formulating the problem into *"allowable concentrations"* it has been taken out of the field of theoretical research and transferred to the practical industrial hygiene. But the ready availability of apparatus easy to handle and of tables of toxic limits established by well known scientists to which the results can be referred for interpretation may lead to the undesirable situation that men not well trained in industrial hygiene will underestimate the difficulties of obtaining truly representative results. In addition there is the danger that they will employ these results beyond their limits of usefulness and so draw unjustifiable conclusions.

Therefore the *value of the limits*, the *practical purpose* and the *limitations* of their use may be discussed in the following lines.

A sharp distinction must be drawn between acute and chronic action which must be applied especially to those materials which produce acute and chronic occupational poisoning (benzol, toluene, xylene, carbon disulfide, trichloroethylene, aniline, ozone, etc.). The "allowable concentration" is much higher where there is danger of acute poisoning than under conditions where there is

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continuous inhalation for a long time. It is evident that it would be out of place to demand the same limiting value of contamination where the workers are *only occasionally exposed* to the danger of acute poisoning (transferring benzol. trichloroethylene, carbon bisulfide, etc., or similar intermittent work performed at extended intervals) as in places where there is danger of continuous inhalation for a period of weeks or months.

The Massachusetts publication quoted above seems to give the "allowable concentrations" for those actions which are most important in industrial hygigne: the chronic influence of benzol and its homologues, the acute poisoning by CO. Although the expert knows or is able to find out for which situation the given value is applicable. it would be expedient *to specify in the table the limits for acute and those for chronic poisonings.* If that is not possible or not necessary for some substances, it should be stated clearly whether the quoted value refers to acute or chronic action.

Of course, the conceptions of "acute" and "chronic" are not sharply differentiated. But generally we may call poisonings and damages acute when they can take place within a working day; and we may call them chronic when they need a longer time to develop — usually weeks or even years.

A specification of the concentration fatal in a half hour or less, although scientifically interesting, is of little value for practical industrial hygiene as pointed out below.

As examples of the damages which arise after harmful action of years or decades may be mentioned silicosis, bladder *cancer* of aniline workers. the symptoms of chronic alcoholism, certain damages by X-rays and radium, some serious forms of carbon bisulfide poisonings, mercury shakes, the changes of the vessels and as a rule the pareses as a result of lead poisoning.

But if a man working with lead for many years falls ill with lead colic, i.e., the subacute form of lead poisoning, it is correct to suspect that he has recently absorbed an exceptionally large amount The same cause — a larger amount of absorbed poison — may also be considered in case a man working with mercury for many years acquires gingivitis and diarrhea; and if serious blood change in a man working *many* years with benzol is not started by infectious disease, it is possible that it was caused by a larger recent absorption of benzol.

Many animal experiments are at hand concerning concentration and duration of air contaminations which cause temporary or lasting injury — but their application to man is either not feasible or to be done only very cautiously.

There are important differences between the different species of animals. The fatal concentration of carbon monoxide poisoning at 32°C is above 0.12% by volume for the rat; above 0.25%, for the guinea pig and above 0.38% for the rabbit

Flury and Zernik[3] tell us that cats, mice, rats are very sensitive to phosgene; dogs are less sensitive, rabbit still less. Horses are less sensitive than human beings. When the driver died in gas attacks during the World War, the horses sometimes *showed* only slight symptoms of poisoning.

Our conclusions therefore on acute poisonings have to be based preferably on the experiences we have had with man. For chronic poisoning and damages the animal experiments fail entirely to be useful for our purpose because it is impossible to determine the comparability of the tlme required for injury to develop in animal and in man.

A study of conditons which may produce chronic poisonings presents a number of difficulties. The contamination of the *air can* be determined during the whole working shift very well, but is it impossible to ascertain the circumstances under which the injurious material was absorbed during months and years gone by.

If it is admitted that the conditions affecting industrial health have improved in the course of years — which is true in general, but not in every single *case* — or that the working time is shortened, then the amount of injurious material absorbed in a working *day* was larger in former times than it is now. But it may also be that the damaging material is not used such a long time, as the *case* history *may* tell us, or that its concentration has been increased recently; such as unnoticed substitution of benzol for benzine or a benzine-benzol mixture, or substituion of lead for color containing little or no lead.

Therefore it must be remembered that all results are approximate values *only.* But the most important materials, especially in regard to thdr chronic poisonings (benzol, carbon disulfide, lead) have been studied with such thoroughness and skill by our best industrial hygienists that the obtained figures are actually practicable as limits.

But the observations about some other substances (cadmium, chlorine (chronic), dichloroethylene and many others) are too limited in number and not clear and reliable enough to make even partly safe conclusions. If figures about such substances are included in the list at all a mark of interrogation has to be added.

The limits are approximate, not only on account of the difficulty of most of the observations, but also on account of differences in sensitivity of individual persons and on account of different amounts of the contaminated air absorbed by the worker under different circumstances For instance, the worker when working hard Inhales much more of the contaminated air (up to 50-60 liters per minute) than when doing light work (8-10 liters per minute).

But these lists of toxic limits give the practical industrial hygienist essential data for his work. they save laborious studies of literature and give him the results obtained by those carrying on research and basic investigation. *Therefore we have to be thankful for the compilations of the limits by their* authors.

How are the "limits" to be utilized? For which purposes may they be used? What is their immediate practical advantage and when may they be applied?

First of all: The limits strongly support the industrial hygienist in arriving at an opinion as to whether the exposure is or is not excessive, and, if so, in convincing incredulous employers and engineers (under *certain* circumstances) that the contaminated air in their rooms is injurious even though the contamination cannot be readily seen or smelled. The data on the exposures, if properly substantiated, act as impartial arbitrators between the man recommending control measures and the man persisting in the present situation.

The limits are useful in construction and testing exhaust systems. Naturally you will try to remove every contamination of the air, because only that gives complete security. If that is not possible, you must insist that the ventilation has at least such an effect as to reduce the exposure to less than the "allowable concentration" in the breathing zone. If that is impossible, you have to try to bring about hygienic conditions by changing the operation or by abandoning the use of the poisonous substance.

I might indicate that exhaust ventilation seems to be considered too much as the principal remedy nowadays, as the respirator was considered some years ago though with much less foundation. Other procedures mentioned above are sometimes forgotten today, although they have attained great success in industrial hygiene.

If the limits are used, it must be definitely ascertained that *the evaluation of the contamination in the air is reliable.*

Because the testing devices are reasonably priced, easy to handle and because the methods of examination in laboratories are frequently simplified, there is (as marked previously) the danger of unqualified men using them. Therefore the following has to be stressed:

Serious acute poisonings, expecially fatal ones, arise through unforeseen accidents — as leaking of vessels, pipe lines, or by unexpected formation of gases in larger amounts or by other abnormal events. *Also,* by exceptional atmospheric conditions where the removal of gases is not effected by strong mechanically driven exhaust systems.

A locksmith was found dead beside his forge fire where he had been *seen* working *20* minutes before. *As* an exhaust pipe has been installed in this place and the man had worked here for many years, the technician thought a CO poisoning impossible — the blood of the dead man however was found to be saturated with CO. Abnormal cold and severe storms had interfered with the natural up-draft existing at other times. I have seen CO poisoning with unconsciousness in some working places of a large plant in presence of such abnormal weather; the workers *had* worked in these places Without disturbance of health for months.

I have seen poisonings by arsine as a result of using too strong an acid so that the solution was not neutralized; as a result of too much zinc powder being added; and as a result of an exhaust pipe being obstructed by the formation of foam.

Such circumstances caused by abnormal accidental events cannot be investigated by air examination because we do not know all contributing factors and therefore we are not able to reproduce these circumstances (to say nothing of the danger to the investigator). Therefore, as mentioned above, data about the deadly concentration would be of little practical value.

In all other circumstances it is self evident that only numerous samples of air give a true picture of the existing conditions, if taken at different times and during different working processes and in the exact working place at the breathing level of the worker. Samples taken off-hand are without any value.

The investigator has to be certain that the working processes during the time of examination are the same as at other times. The investigator can be misled intentionally or unintentionally. The occurrence of illness should of course induce the improvement of the working conditions. When we investigate we have to know if such changes have taken place or not. It is sometimes difficult to find that out.

Another difficulty which may be overcome only by patience is the fact that all persons concerned — even involuntarily — work more "according to prescription" if observers and supervisors are present.

In addition it must be taken into consideration that little variations — produced intentionally or not — are able to change the whole picture; small changes hardly detectable in the process produce considerable differences in the amount of contamination in the air; season (open or closed windows), and weather also influence the picture.

An electrolytic nickel plating bath delivers more hydrocyanic acid gas, a chrome plating bath more chromic acid mist, when the current is heavier or the treated objects larger. The amount of lead fumes depends, among other factors, on the temperature of the lead bath, the zinc oxide fumes on the temperature of the molten alloy. More vapor escapes in an apparatus for degreasing by trichloroethylene if the trichloroethylene is heated more and if it is not cooled before emptying. The quantity of excaping vapors changes in the usual degreasing apparatus with the temperature of the water used in the cooling coil, with the size of the objects and their number and with the frequency and speed with which they are taken out.

Ball mills pulverizing rock have often been submitted to my inspection and I was shown they were working without escape of dust — it was soon after loading large rock. But half an hour later, when the material has been reduced to fine powder, much dust was escaping into the breathing zone.

To give some examples of numerical differences: Dust concentrations found in my investigations in grinding shops[7] in the summer by the Owens dust counter have averaged between 600 and 1500 particles per cm^3 in the same room, at the same speed of rotation of the sandstone wheels but grinding different kinds of knives. In winter, when the windows were closed, the figures ran up to 3700 at the breathing level of the worker. In the air of the room in general the dust figures averaged to 560 in summertime, 3300 in winter. Bowditch and Elkins[8] found in the coating room of an artificial leather factory on different days in March 130-200 parts per million of benzol; concentrations of 300-1300 ppm of naphtha vapor were detected during the work done by one worker in a factory using rubber cement. Greenburg and corroborators found in a rotogravure printing plant 50-1060 ppm of benzol in different parts of the press room.

I think it is not necessary to stress that all the difficulties mentioned above have to be regarded especially if there is a compensaton case, or if there is a question of negligence.

Summarizing

A well-trained industrial hygienist only is able to make investigations in industrial hygiene and especially for answering the question, if, when or haw often limits are transgressed; and besides he can answer only after a long-lasting and exact examination.

It should never be forgotten, that all our limits have their origin from health examination of workers and that only from comparison between the results of these physical examinations and the content of contamination in the air do the limits result. All the mentioned uncertainties and difficulties can be avoided in many cases if we refer to this origin. If there is a danger of chronic poisoning the thorough investigation and examination of the workers especially for early symptoms give us a sure answer in cases where the time is long enough for acquiring symptoms of chronic poisoning.

We may also see if the contamination is able to produce acute poisoning by examining the workers at the end of the daily working time.

A special consideration must be given to the question if and how far the results of air examinations and their relation to the limits are able to contribute in determing the occurence of an occupational disease.

The question of whether there is an occupational disease presents itself as a medical question. A physician only is able to answer it after considering all the clinical symptoms and after a thorough medical examination executed with all necessary aids.

The clinical pictures (and the pathological one in the autopsy) of the more frequent occupatonal diseases (chronic poisonings - by lead, mercury, benzol, silicosis, to some extent carbon disulfide, and certain acute poisonings as CO) have been studied so carefully and are so well established that the diagnosis can be made with greatest certainty — by a physician experienced in this field as is the case with every other medical diagnosis.

We have mentioned above the difficulties and uncertainties of air examinations. We cannot guarantee that the air contamination during the investigation was the same as in the time before the poisoning occurred. Therefore negative findings in air contaminations or findings below the limits are never able to shake such a positive medical diagnosis though under certain circumstances it is possible that a former occupation may have been responsible for the disease. Positive findings on the other hand are able to support it. Furthermore if we have a clinical picture that according to medical opinion does not correspond with the well known picture of this poisoning nor with signs of its rare varieties and therefore the physician denies an occupational disease, then the findings of air contamination above the limits is no proof of a causal connection between the illness and the contamination; the illness may have originated entirely independently of the contamination because of an internal or another external cause.

But there is another method which gives us an insight into the circumstances under which the ill man worked prior to his disability and which should be practiced in chronic poisonings if it can be done shortly after the beginning of his illness: The physical examination of the fellow-workers (still working, disabled and dismissed). If the symptoms of the same illness are found, it confirms our diagnosis of the case in question. Negative findings are of small value, because the sick man many have been more exposed to the damaging substance or may be more sensitive.

In acute poisonings the examination of the fellow-workers should be made at the end of the shift.

There is however, a long list of less explored substances (most at present rarely used), the clinical pictures of which are not clearly worked out as yet — nor are their toxic limits. We are able to conclude that there is a causal connection if certain substances are found in the air and contemporarily symptoms of illness determined in a worker and if these symptoms agree with those mentioned in the literature as a consequence of this poison or if similar pictures are to be seen among the fellow-workers.

But cases occur when a positive medical diagnosis alone is not sufficient. For compensation cases and for prophylaxis it may be of greatest importance to know through which kind of work the illness is acquired.

If the examination of the air fails to give exact proof, then all chemical and other processes should be subjected to the opinion of experienced experts in technology, chemistry and industrial hygiene. In such cases all the impurities possible present in the substances used are to be considered.

I wrote about "experienced physicians." The universities (medical schools) should give better instructions to students of medicine in industrial hygiene and in occupational diseases. Especially in the latter field, there should be established short courses for physicians also. The legislation, the industrial commissions, the insurance companies, the employers and the employees should take advantage first of all such trained physicians and thus give them occasion to acquire still great experience.

Summary

1. To define toxic limits of the greatest scientific and ofthe greatest practical value.
2. It should be made evident whether the toxic limit applies to acute or chronic poisoning, if it is well founded or doubtful.
3. The limits are valuable help in showing the

necessity of prophylactic measures in a plant for the construction of new and for testing and existing installations. But the examinations should be made very carefully and by experienced industrial hygienists. In determining the severity of exposures resulting from existing installations, the medical examination of workers often gives a better insight

4. It is the field of medical diagnosis to ascertain the presence or absence of an occupational disease. This diagnosis made by an expert physician cannot be shaken by a contrary result of air examinaton, but if this result is certainly representative of the worker's exposure, it may point to the desirability of further investigations.

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