Understanding Workplace Vapor Exposure Limits

Introduction

Establishing human exposure limits for hazardous chemicals is complicated by the various forms substances can take, such as vapor, aerosol or dust, and by the various possible exposure routes, including inhalation, skin absorption and eye entry. At the highest concentrations in the Volume % range, one is mostly concerned about lack of oxygen or an explosion, which could cause immediate death. At somewhat lower levels (but still high), Immediately Dangerous to Life and Health (IDLH) values define the concentration at which a worker can become disabled or suffer severe harm in a short time of several minutes. At lower concentrations typical of the workplace, usually in the ppm range, one is concerned with long-term health effects that could take days or many years to manifest. This TA-Note focuses on these TWA, STEL and Ceiling workplace exposure limits, defined for a 40-hour work week, because they are somewhat complicated and often poorly understood. Recommended limits for indoor air quality (IAQ) are even lower than workplace limits, because of the longer, more continuous exposures when at home.

Ceiling:

The Ceiling is the concentration that should never be exceeded for any instant during the working day, without personal protective equipment (PPE). Note that personnel may work in an atmosphere above the Ceiling concentration if PPE is worn, but if the compound has a Skin designation, a simple respirator may not be enough, and full skin & eye protection must be part of the PPE.

STEL: Short-Term Exposure Limit

The STEL is the average concentration over any 15-minute interval. The instantaneous concentration may exceed the TWA and STEL limits (but not the Ceiling) until the 15-minute average calculation reaches the STEL limit. At that point, exposure must be stopped by either leaving the area, donning PPE, or performing operating controls that reduce the chemical concentration. At most four such STEL exposures may occur in a single workday as long as there is at least one hour between them.

TWA: Time-Weighted Average

TWA values are established as the concentration limit that causes minimal health risk when a worker is exposed for a typical 40-hour work week over 40-year working life. Although the TWA is given as a single value in concentration units, it actually has dual meanings:

- An *instantaneous concentration* (units of ppm) it is desired to stay beneath for *most* of the day
- An *exposure dose* (units of ppm-days) that should never be exceeded in one working day

The TWA Dose is calculated as follows, for an 8-hour working day:*

$$TWA\ Dose\ = Average\ Concentration\ \text{x}\ \frac{Hours\ exposed}{8\ hours/day}$$

In contrast to a running average concentration, which may go up or down during the course of a day, the TWA never decreases until it is re-set to zero at the end of the work day. If work and exposure continue beyond 8 hours, the TWA dose continues to increase. For example, if a worker is exposed to a steady concentration of 10 ppm, the TWA dose calculated would be 5 ppm after 4 hours, 10 ppm after 8 hours, and 15 ppm after 12 hours.

* NIOSH defines a working day as 10 hours, so that the denominator in the equation becomes 10 instead of 8.

TWA for Extended Run Times

Note that because the TWA Dose is an accumulated value, the calculated TWA continues to increase as long as work continues or a monitor is left on. Thus it is possible for a monitor to go into TWA alarm even if readings remain well below the TWA, but do so for very long times such as several days. To re-set the TWA, the user must exit the workplace exposure area and/or turn the monitor off.

mPower Monitor TWA and STEL Calculations near Sensor Dead Bands

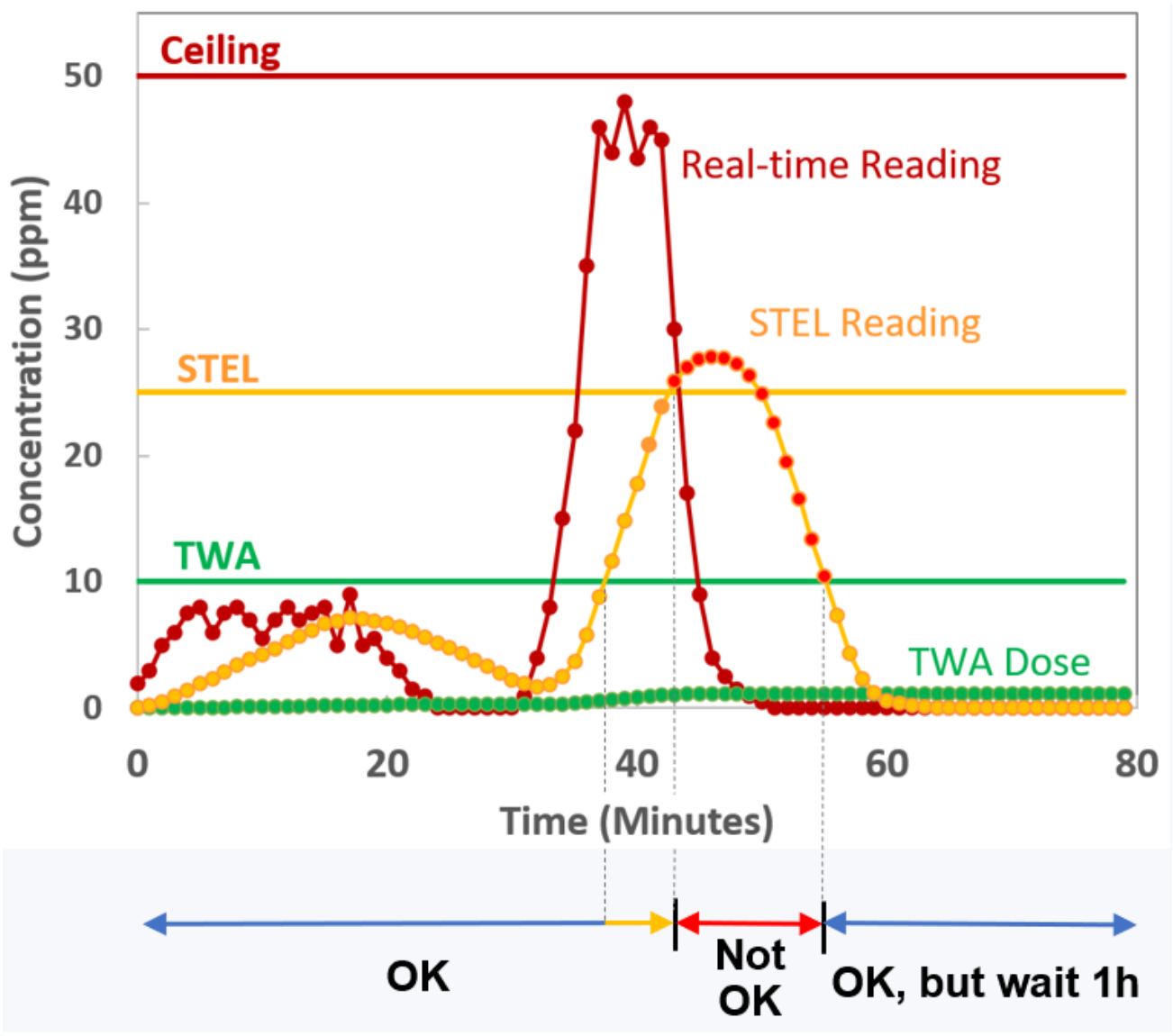
mPower monitors often have dead bands on the display to avoid confusing noisy readings at very low concentrations. The dead band is often a bit larger as concentrations rise to the detection limit and smaller as they fall back to a zero display. Thus, for example the UNI O_3 sensor with a 0.08 ppm rising dead band will display 0.00 until it rises above 0.08 ppm but may read 0.07, 0.05, 0.04 etc. as a it drops back below the falling dead band of 0.03 and reads 0.00. Only concentrations above 0.08 ppm are used for calculations of STEL and TWA. Therefore, in this example if the readings are always at 0.06 ppm, the STEL/TWA will be '0.00'. However, if readings fluctuate above and below 0.08 ppm, the average STEL/TWA calculation can give a value of 0.06 ppm or as low as 0.01 ppm.

Compounds with no STELor Ceiling Values Available

Some chemicals have established TWA values but no STEL or Ceiling values. In these cases, a rough estimate for STEL is 3 times the TWA value, and for Ceiling roughly 5 times the TWA.

Summary of TWA-STEL-Ceiling Use in Practice

1) The preferred goal is to maintain the chemical concentration below the TWA Concentration Limit for as much of the workday as possible
2) Any number of instantaneous excursions over the TWA up to the Ceiling are allowed as long as the calculated 15-min average (STEL Reading) does not exceed the TWA.
3) STEL Readings may exceed the TWA as long as they do not exceed the STEL Concentration limit, and may remain there for at most 15 minutes and then must drop again below the TWA.
4) Once the STEL Reading has exceeded the TWA, a STEL Excursion has occurred. Up to four STEL Excursions may occur during the work day as long as one hour has elapsed between the end of one excursion and the beginning of the next.
5) If at any time the instantaneous reading exceeds the Ceiling, or the STEL Reading exceeds the STEL limit, the exposure must be stopped until the concentration is reduced below the TWA.
6) As soon as the TWA Exposure Dose has exceeded the TWA, all exposure must be halted for the rest of the work day.

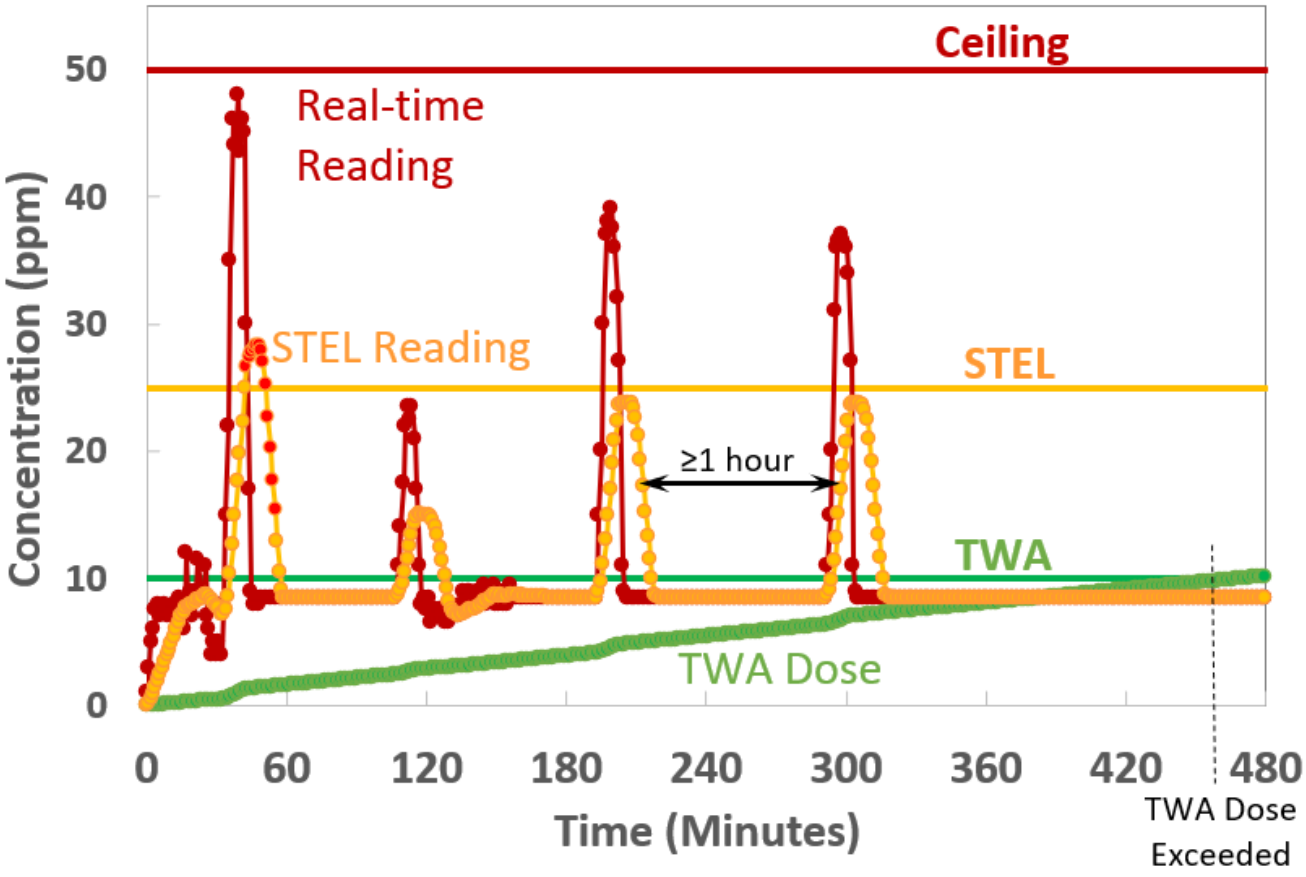


Example

The figure above illustrates how exposure limits are applied, using a hypothetical compound with TWA of 10 ppm, STEL of 25 ppm and Ceiling of 50 ppm. The red dots are simulated real-time concentration readings, which can never be allowed to exceed the Ceiling. The STEL readings lag the real-time readings because of the 15-minute averaging delay. The bar graph beneath the main plot indicates that exposures are acceptable up to about 38 minutes, when the STEL readings exceed the TWA and a 15-minute countdown begins for the readings to drop back below the TWA. But in this example, the STEL readings exceed the STEL limit, and workers must either leave the exposure area or don PPE. Work may resume (or PPE removed) at about 55 minutes when the STEL reading drops back below the TWA. The exposure between 38 and 42 minutes is considered a STEL Exposure, which may not be allowed to occur again until at least one hour has passed at sub-STEL concentrations. During this whole time the TWA exposure dose (green dots) is low compared to the real-time concentrations because the exposure time is only a small fraction of an 8-hour day.

The figure below is another example, continuing to 8 hours, showing four STEL excursions above the TWA. Work may continue through the last three excursions because the STEL readings remain below the STEL limit and they are spaced by at least one hour. Note that the brief spikes above the TWA at about 25 minutes do not count as STEL excursions because the 15-minute average

remained below the STEL limit. Finally, at about 460 min (7.7 hours), the TWA dose reaches the TWA limit and all exposure must stop until the next day.



OCCUPATIONAL EXPOSURE VALUES 2

SUBSTANCE / CAS#	ACGIH® TLVs® TWA ppm	ACGIH® TLVs® TWA mg/m³	ACGIH® TLVs® STEL/CEIL(C) ppm	ACGIH® TLVs® STEL/CEIL(C) mg/m³	OSHA PELs TWA ppm	OSHA PELs TWA mg/m³	OSHA PELs STEL/CEIL(C) ppm	OSHA PELs STEL/CEIL(C) mg/m³	NIOSH RELs TWA ppm	NIOSH RELs TWA mg/m³	NIOSH RELs STEL/CEIL(C) ppm	NIOSH RELs STEL/CEIL(C) mg/m³	DFG MAKs TWA ppm	DFG MAKs TWA mg/m³	DFG MAKs PEAK/CEIL(C) ppm	DFG MAKs PEAK/CEIL(C) mg/m³	AIHA WEELs TWA ppm	AIHA WEELs TWA mg/m³	AIHA WEELs STEL/CEIL(C) ppm	AIHA WEELs STEL/CEIL(C) mg/m³	CARCINOGENICITY CATEGORY
Acetic anhydride 108-24-7	1	4	C 3		5	20					C 5	C 20	0.1	0.42	I (2) C						TLV-A4
Acetone 67-64-1	250	594	500	1187 BEI	1000	2400			250	590			500	1200	I (2) B						EPA-I TLV-A4
Acetone cyanohydrin 75-86-5			C 5* *as CN Skin								C 1* *15-min	C 4*					2 Skin		5		
Acetonitrile 75-05-8	20	34 Skin			40	70			20	34			10	17 Skin; C	II (2)						EPA-CBD; D TLV-A4
Acetophenone 98-86-2	10	49															10				EPA-D

- TLV = Threshold Limit Value (ACGIH)
- PEL = Permissible Exposure Limit (OSHA)
- REL = Recommended Exposure Limit (NIOSH) (10-hour TWA)
- MAK = Maximal Akzeptable Konzentration (Germany)
- WEEL = Worker Environmental Exposure Level (AIHA)

Occupational Exposure Limit Lists

An excellent comprehensive list of exposure limits from various agencies is provided by the ACGIH (American Conference of Government Industrial Hygienists) *Guide to Occupational Exposure Values.*

An extract from the 2019 version of this guidebook is shown in the figure above. Different agencies often give different limits and sometimes have slightly different meanings. Although the terms TWA, STEL and Ceiling are used in common, each agency gives a different name to the exposure limits, as indicated in the table footnotes. OSHA Permissible Exposure Limits (PELs) are the only ones strictly enforceable by law in the U.S. OSHA does not differentiate between Ceiling and STEL, but rather lists Ceiling values as 15-minute averages instead of instantaneous values. Many companies follow the TLV limits recommended by the ACGIH because these are usually the most restrictive and their list is the most comprehensive. As noted earlier, NIOSH uses 10-hour days for TWA calculations, while most of the others use 8-hour TWAs. Several other lists, such as the British EH40 Workplace Exposure Limits (https://www.hse.gov.uk/pubns/priced/eh40.pdf) and OSHA Z-list (https://www.osha.gov/dsg/annotated-pels/tablez-1.html) are also available.