In the U.S., important information about exposures to toxic substances can be found in the NIOSH Pocket Guide to Chemical Hazards: [http://www.cdc.gov/niosh/npg/pgintrod.html](http://www.cdc.gov/niosh/npg/pgintrod.html)

NIOSH stands for National Institute for Occupational Safety and Health. The NIOSH Pocket Guide includes current standards for workplace exposures recognized by the Occupational Safety and Health Administration (OSHA) and by NIOSH. The following terminology describes the meaning of these exposure standards.

1. **OSHA** permissible exposure limits (PELs) are *U.S. legal requirements* that must be observed as minimum standards:
   a. **Eight-hour time-weighted average (TWA)** concentrations for PELs must not be exceeded as an average for any 8-hour work shift exposure (assumes a 40-hour work week).
   b. **Short-term exposure limit (STEL or ST)** is a maximum 15-minute TWA exposure (unless noted otherwise) that must not be exceeded as an average during any 15-minute period in a work day.
   c. **Ceiling concentration (C)** is an instantaneous exposure (unless noted otherwise) that must not be exceeded at any moment in time. If instantaneous monitoring is not feasible, the ceiling must be assessed as a 15-minute TWA exposure. In addition, there are a number of substances from OSHA 29 CFR 1910.1000 Table Z-2 (e.g., beryllium, ethylene dibromide) that have PEL ceiling values that must not be exceeded except for specified excursions. For example, a "5-minute maximum peak in any 2 hours" means that a 5-minute exposure above the ceiling value, but never above the maximum peak, is allowed in any 2 hours during an 8-hour workday.
2. **NIOSH** recommended exposure limits (RELs) are *recommendations* consistent with recent research on the health effects of hazardous substances:

   a. **Ten-hour time-weighted average (TWA)** concentrations for RELs *should not* be exceeded as an average exposure for a workday of up to 10-hours during a 40-hour workweek.

   b. **Short-term exposure limit (STEL or ST)** is a maximum 15-minute TWA exposure (unless noted otherwise) that *should not* be exceeded as an average exposure during any 15-minute period during a workday.

   c. **Ceiling concentration (C)** is an instantaneous exposure (unless noted otherwise) that *should not* be exceeded at any moment in time.

3. Measurement of airborne contaminant concentrations for RELs and PELs:

   a. Concentrations are given in parts per million (ppm), milligrams per cubic meter (mg/m$^3$), millions of particles per cubic foot of air (mppcf), or fibers per cubic centimeter (fibers/cm$^3$). For particulates, “Total” means total particulate, while “resp” means the respirable fraction of the airborne particulate.

4. **Skin exposure** to contaminants (from direct contact with liquids, solids, contaminated surfaces, etc.):

   a. “**Skin**” indicates the potential for dermal absorption.

5. **Immediately Dangerous to Life and Health** (IDLH):

   a. **IDLH** is the maximum airborne concentration from which a worker may be expected to escape without injury or irreversible health effects. Unless special IDLH respiratory protection is worn, NIOSH says that when the IDLH is reached: “Every effort should be made to exit immediately!”

6. Potential Occupational **Carcinogens**:

   a. Any substance that NIOSH considers to be a potential occupational carcinogen is designated by the notation "Ca".

The following pages contain examples that will help clarify these important concepts.
To understand exposure limits, we’ll consider an example of a worker’s exposure to airborne ammonia.

The chart at left shows the results of personal exposure monitoring for the worker. As the chart shows, the airborne concentration of ammonia was about 10 ppm at the beginning of the monitoring period, and about 30 ppm at the end. The airborne concentration was at its high of about 60 ppm from 9:00 – 10:00 AM. The worker took a lunch break in an ammonia-free area at noon.

The calculated 8-hour time-weighted average (TWA) exposure indicates the worker was exposed to an average airborne ammonia concentration of 28.75 ppm during the 8-hour work period.

The TWA is calculated by multiplying each concentration on the chart by the amount of time that concentration existed. The results for each time period are then added together, and the sum is divided by the total time covered by the chart. (Do not include breaks in uncontaminated areas.) The formula is as follows:

$$\text{TWA} = \frac{(C_1*T_1) + (C_2*T_2) + \ldots + (C_n*T_n)}{(T_1 + T_2 + \ldots + T_n)}$$

Where:
- $C_i$ is the airborne concentration during the first time period, and $C_n$ is the airborne concentration during the $n^{th}$ time period.
- $T_i$ is the duration of the first time period, and $T_n$ is the duration of the $n^{th}$ time period.

When we apply the formula, the TWA in this case is as follows:

$$\text{TWA} = \frac{[(10*1) + (60*2) + (15*1) + (20*1) + (5*1) + (30*2)]}{(1 + 2 + 1 + 1 + 1 + 2)}$$

$$\text{TWA} = \frac{[230]}{(8)}$$

$$\text{TWA} = 28.75 \text{ ppm}$$
The 8-hr. OSHA Permissible Exposure Limit (PEL) for airborne ammonia is 50 ppm as a TWA.

The PEL is a legal requirement, carrying the force of law in the U.S. In other words, the worker’s exposure to ammonia must not exceed 50 ppm as an average 8-hour time-weighted average.

**Important:** Exposures can exceed 50 ppm for portions of the day—as long as the 8-hr. TWA remains below the PEL, and as long as no short-term exposure limits (STELs), ceilings (Cs) or immediately-dangerous-to-life-and health (IDLH) limits, are violated.

Since the measured exposure of 28.75 ppm is less than 50 ppm, our worker’s exposure did not exceed the OSHA PEL for an 8-hr. TWA—even though there was one 2-hour period when exposure peaked above 50 ppm.

Besides the OSHA PEL (which is the law in the U.S.), we should also consider NIOSH Recommended Exposure Limit (REL).

NIOSH RELs differ from OSHA PELs in some important ways: First, NIOSH RELs are not legal limits—instead, they are recommendations based on recent research regarding the health effects of hazardous substances. In addition, NIOSH RELs for daily TWAs are typically based on a workday of up to 10 hours in a 40-hr. week.

Once again, let’s consider our worker’s ammonia exposure of 28.75 as an 8-hr. TWA.
The NIOSH REL for daily exposure to airborne ammonia is 25 ppm as a TWA (for a workday up to 10 hours in a 40-hr. week).

In other words, to avoid adverse health effects, research indicates workers should not be exposed to an average daily airborne concentration above 25 ppm.

Our worker’s measured TWA of 28.75 ppm for the workday was greater than 25 ppm. Thus, exposure exceeded the NIOSH recommendation for the day.

The OSHA 8-hr. PEL and the NIOSH 10-hr. REL are useful for evaluating a worker’s average exposure during a workday; however, we must also consider short-term exposures that may be hazardous even when the 8-hr. or 10-hr. TWAs are within acceptable limits. OSHA and NIOSH have both established Short-Term Exposure Limits (STELs) and Ceilings (Cs) that serve as guidelines for brief exposures to high concentrations of toxic substances.

OSHA values carry the force of law; while NIOSH values are recommended to protect health (based on recent research).
For our example, we’ll consider the NIOSH STEL for airborne ammonia. The NIOSH STEL is 35 ppm as a 15-minute TWA. In other words, research indicates adverse health effects may occur if workers are exposed to airborne concentrations above 35 ppm as a TWA for any 15-minute period during the workday.

In the case of our worker, the measured 15-minute TWA did exceed 35 ppm for two periods during the day.

Thus, our worker was exposed—not just once, but twice—to short-term (15-minute average) exposures that NIOSH has determined may be hazardous to health.
As a final example, let’s consider another worker’s exposure to ammonia. Although airborne concentrations were low for most of the day, there was a period of about two hours when the worker was exposed to exceptionally high concentrations of 300-450 ppm.

When exposures are exceedingly high, as in this case, we must consider another NIOSH recommendation: the Immediately-Dangerous-to-Life-and-Health level (IDLH).

The IDLH is the maximum concentration from which an unprotected worker is likely to escape without injury, death, or irreversible health effects. In the case of ammonia, the NIOSH IDLH is 300 ppm.

At this level, NIOSH recommends that workers exit immediately; otherwise, they risk permanent harm…

…or even death.
Examples of Exposure Limits for Various Substances

Permissible and recommended exposure limits vary widely for different chemicals, so it is important to consult the NIOSH Pocket Guide for each substance to which workers may be exposed. The table below illustrates some exposure limits for a few of the hazardous substances listed in the Pocket Guide:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Agency</th>
<th>8-hr or 10-hr TWA</th>
<th>Short-term Exposure TWA</th>
<th>Ceiling Concentration</th>
<th>IDLH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>OSHA</td>
<td>50 ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIOSH</td>
<td>25 ppm</td>
<td>35 ppm</td>
<td></td>
<td>300 ppm</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>OSHA</td>
<td>50 ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIOSH</td>
<td>35 ppm</td>
<td>200 ppm</td>
<td>1,200 ppm</td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td>OSHA</td>
<td></td>
<td>1 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIOSH</td>
<td></td>
<td>0.5 ppm</td>
<td>10 ppm</td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>OSHA</td>
<td>1 mg/m$^3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIOSH</td>
<td>0.5 mg/m$^3$</td>
<td></td>
<td></td>
<td>250 mg/m$^3$</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>OSHA</td>
<td>0.75 ppm</td>
<td>2 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIOSH</td>
<td>0.016 ppm</td>
<td>0.1 ppm</td>
<td>20 ppm</td>
<td></td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>OSHA</td>
<td></td>
<td></td>
<td>5 ppm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIOSH</td>
<td></td>
<td>1 ppm</td>
<td>20 ppm</td>
<td></td>
</tr>
</tbody>
</table>

Other Standards

Many other standards exist for evaluating exposures to hazardous substances.

In the U.S., Threshold Limit Values (TLVs) have been established by the American Conference of Governmental Industrial Hygienists (ACGIH). TLVs represent air concentrations of contaminants that most healthy people can tolerate as an average exposure for 40 hours a week over a working lifetime without having any adverse health effects. Despite its name, the ACGIH is not a government agency and has no regulatory authority. Still, it is important to consider TLVs—especially for substances that do not have NIOSH RELs.