

*OSHA's Respiratory Protection Standard:*

# CALCULATING REASONABLE EXPOSURE ESTIMATES

**Under OSHA's Respiratory Protection Standard, if an employer *can* monitor exposure or use other objective data to calculate a reasonable estimate, then that employer has a regulatory mandate to do so.**

By GARY HUBBARD

**A**re employee exposures to air contaminants fully evaluated before issuing respiratory protection? What if a process cannot be readily monitored using traditional sampling methodology? Under its revised Respiratory Protection Standard (29 CFR 1910.134) OSHA requires an employer to calculate a reasonable estimate of employee exposure or some other objective data as part of a sound written respiratory protection program.

#### THE REQUIREMENT

OSHA's expanded health standards for exposure to air contaminants (1910.1001 to 1910.1052) contain clear requirements for initial and periodic monitoring. However, the agency has cited exposure monitoring requirements found in its respiratory protection standard in cases where workers are exposed to air contaminants other than those found in the health standards.

For example, when construction employees were overexposed to silica-containing dust, OSHA's Special Emphasis Program Directive (SEP) instructed its industrial hygienists to use standards such as 29 CFR 1926.103(b)(2) to cite the employer's failure to evaluate exposure concentrations before determining the required level of respiratory protection (OSHA SEP 7).

According to 29 CFR 1926.103(b)(2), "*The nature and extent of the hazard, work requirements and conditions, as well as the limitations and characteristics of the available respirators, shall be factors considered in making the proper recommendation.*" According to its compliance directive, OSHA interprets "nature and extent" to mean that the employer has a duty to determine the level of exposure by conducting air monitoring of the operation prior to issuing respiratory protection (CPL 4).

Similarly, OSHA's previous respiratory protection standard for general indus-

try contained exposure determination requirements. 29 CFR 1910.134(b)(8) stated, "*Appropriate surveillance of the work area conditions and degree of employee exposure or stress shall be maintained.*"

Although neither standard specifically directed the employer to monitor employee exposure to air contaminants as clearly as do the expanded health standards, OSHA interpreted those paragraphs to require initial monitoring of employee exposure as part of a sound written respiratory protection program. In practice, however, the agency only cited these standards when an overexposure to an air contaminant found in 29 CFR 1926.55 or 1910.1000 had been documented during an inspection.

Although this was good practice—because it meant that not every employer with an ozone-emitting copier was cited for failure to monitor employee exposure—it also meant that most employers were never made aware of their duty to

monitor employee exposure to air contaminants (other than those found in the expanded health standards) prior to issuing respiratory protection. In fact, after evaluating approximately 300 workplaces, this author has found that air sampling was conducted in only 15 percent of those workplaces.

OSHA's new respiratory protection standard contains slightly different language regarding workplace evaluation. 29 CFR 1910.134(d)(1)(iii) states:

*The employer shall identify and evaluate the respiratory hazard(s) in the workplace; this evaluation shall include a reasonable estimate of employee exposures to respiratory hazard(s) and an identification of the contaminant's chemical state and physical form. Where the employer cannot identify or reasonably estimate the employee exposure, the employer shall consider the atmosphere to be IDLH.*

In other words, unless the employer has monitoring data or a reasonable estimate of employee exposure calculated, each employee wearing respiratory protection had better be wearing a self-contained breathing apparatus (SCBA), because SCBA is the only approved respirator for an atmosphere that is immediately dangerous to life and health (IDLH).

Furthermore, this language does not allow the employer to simply assume that the atmosphere will be IDLH and require employees to wear SCBAs. Read closely, the standard states "Where the employer cannot identify or reasonably estimate [emphasis added] the employee's exposure, the employer shall consider the atmosphere to be IDLH." Thus, if an employer can monitor exposure or use other objective data to calculate a reasonable estimate, then that employer has a regulatory mandate to do so.

#### THE EXERCISE

Consider this example. Many food processing industries use anhydrous ammonia (R-717) as a refrigerant. Like freon in an air conditioner, the ammonia is stored in a closed system. Since employee exposure typically occurs only during an accidental release, it is impractical to try to monitor employee exposure to ammonia as required by the new respiratory protection standard.

However, employee exposure can be calculated using a simple industrial hygiene exposure formula. To create the exposure scenario, Table 1 details a list of assump-

### TABLE 1 Assumptions and Data

- 1) A low-pressure leak would produce approximately 2 lbs./min. of ammonia vapor. That leak is roughly equivalent to emptying a 10,000-lb. ammonia receiver during an eight-hour shift. This release scenario is hypothetical; any rate may be used.
- 2) A high-pressure leak would produce approximately 50 lbs./min. of ammonia vapor. That leak is roughly equivalent to emptying a 10,000-lb. ammonia receiver in approximately 20 minutes. This release scenario is hypothetical; any rate may be used.
- 3) The volume of the ammonia engine room is 40 ft. x 60 ft. x 25 ft. = 60,000 ft.<sup>3</sup>. Insert the actual room volume here.
- 4) Refrigeration equipment occupies approximately 25 percent of the room volume. 60,000 ft.<sup>3</sup> - 25% = 45,000 ft.<sup>3</sup> available space for ammonia vapor to occupy. Subtract any space that cannot be occupied by vapor. A rough estimate or an exact calculation may be used.
- 5) The ventilation rate for the room is 34,000 cfm. Obtain this information from the manufacturer's specifications.

$$\frac{34,000 \text{ ft.}^3}{\text{min}} \times \frac{1 \text{ air change}}{45,000 \text{ ft.}^3} = \frac{0.75 \text{ air changes}}{\text{min.}}$$

- 6) Ammonia vapor = 18 ft.<sup>3</sup>/lb. at -28°F. Obtain this information from the material safety data sheet.
- 7) Ammonia concentration after one minute can be estimated by the formula:

$$N = \ln C_i - \ln C_a \quad \text{or} \quad C_a = e^{\ln C_i - N} \quad (\text{Stewart 85})$$

Where:

- N = air changes/min.
- C<sub>i</sub> = Initial concentration
- C<sub>a</sub> = Final Concentration
- ln = Natural logarithm
- e = Base e antilogarithm

### TABLE 2 Ammonia Generation Rate

$$C = G/V \times 10^6 \quad (\text{Stewart 82})$$

- Where: C = Concentration in ppm  
G = Generation rate in cfm  
V = Volume of room in ft.<sup>3</sup>

$$\frac{2 \text{ lbs.}}{\text{min.}} \times \frac{18 \text{ ft.}^3}{\text{lb.}} = \frac{36 \text{ ft.}^3}{\text{min.}} \times \frac{\text{room volume}}{45,000 \text{ ft.}^3} \times 1,000,000 = 800 \text{ ppm/min.}$$

tions made and data collected; the formula used to calculate the reasonable estimate of employee exposure is shown in item 7. Table 2 details the ammonia generation rate for a low-pressure release scenario using assumptions and data from Table 1.

Due to the logarithmic relationship between air contaminant concentration and time, eventually the ventilation rate and the ammonia generation rate will reach equilibrium, and the concentration will become fairly constant. To prove this point, reasonable estimate calculations can be completed showing the minute-by-minute dynamics of a hypothetical ammonia release (Table 3).

#### THE CONCLUSION

Based on this release scenario, one can conclude that a low-pressure leak which lasts at least six minutes in this ammonia engine room would result in an exposure concentration of approximately 700 to

720 ppm. The ammonia receiver can continue to release the entire 10,000 lbs. over the course of the eight-hour shift. Provided the generation rate does not increase, the concentration will never rise substantially above the calculated concentration of 716 ppm.

Purging time can also be determined by omitting the generation rate concentration from the calculation. In other words, in this scenario, the receiver eventually empties or the leak is repaired. The reasonable estimate calculation confirms that in slightly more than one minute, the concentration should be below the IDLH level of 300 ppm, and that in approximately four minutes, the concentration should be below the short-term exposure limit (STEL) of 35 ppm.

Although air mixing in most well-designed ammonia engine rooms is good, caution should be exercised before exposing employees to atmospheres with

**Completing this exercise may reveal additional ventilation needs that must be implemented. In addition, the results must be used to determine feasible engineering controls as well as the appropriate level of respiratory protection.**

unknown concentrations. The atmosphere should be monitored before respiratory protection is removed. These calculations should be used as pre-event guidance and planning by those trained in the discipline of industrial hygiene.

Calculations can also be completed for a high-pressure leak scenario in the same manner. Those results estimate that the terminal concentration, which would occur at the end of minute 13, is 17,904 ppm. So, for minutes 13 through 20 (when the hypothetical ammonia receiver empties in this scenario), concentration will never surpass 17,904 ppm. After the receiver empties, it would take approximately six minutes to lower the concentration below IDLH and approximately nine minutes to lower it below STEL.

A key piece of information surfaces in this reasonable estimate calculation: The terminal concentration produced is greater than 10 percent of the published lower explosive level (LEL) for ammonia. A concentration of approximately 1.8 percent was calculated; the published LEL value is 15 percent. Therefore, completing this exercise may reveal additional ventilation needs that must be implemented before a catastrophic incident occurs.

The fact that monitoring employee exposure is not practical in all cases does not release the employer from the mandate found in 29 CFR 1910.134(d)(1)(iii). If an exposure can be reasonably estimated, then a calculation of potential exposure must be performed as part of a sound written respiratory protection program. The calculation must then be used to determine feasible engineering controls as well as the appropriate level of respiratory protection. ■

**TABLE 3 The Calculation**

**Inserting the initial concentration determined from Table 2 into the formula from Table 1, ammonia concentration at the end of the first minute can be calculated as follows:**

$$C_a = e^{\ln C_i - N}$$

$$C_a = e^{\ln 800 \text{ ppm} - 0.75 \text{ air changes/min.}} = 378 \text{ ppm}$$

**Ammonia concentration at the end of the second minute can be calculated by combining the concentration at the end of the first minute with that generated during the second minute. This sum is the new initial concentration.**

$$C_i = 378 \text{ ppm} + 800 \text{ ppm} = 1178 \text{ ppm}$$

**The concentration resulting from a two-minute low-pressure release can be calculated using this new initial concentration.**

$$C_a = e^{\ln 1178 \text{ ppm} - 0.75 \text{ air changes/min.}} = 556 \text{ ppm}$$

This exercise can be continued through a series of minute-by-minute exposure concentrations until a near-constant or terminal exposure concentration is obtained.

**Dynamics of the third minute produce the following concentration:**

$$C_i = 556 \text{ ppm} + 800 \text{ ppm} = 1356 \text{ ppm}$$

$$C_a = e^{\ln 1356 \text{ ppm} - 0.75 \text{ air changes/min.}} = 640 \text{ ppm}$$

**Dynamics of the fourth minute result in the following concentration:**

$$C_i = 640 \text{ ppm} + 800 \text{ ppm} = 1440 \text{ ppm}$$

$$C_a = e^{\ln 1440 \text{ ppm} - 0.75 \text{ air changes/min.}} = 680 \text{ ppm}$$

**Dynamics of the fifth minute produce the following concentration:**

$$C_i = 680 \text{ ppm} + 800 \text{ ppm} = 1480 \text{ ppm}$$

$$C_a = e^{\ln 1480 \text{ ppm} - 0.75 \text{ air changes/min.}} = 699 \text{ ppm}$$

**Dynamics of the sixth minute result in the following concentration:**

$$C_i = 699 \text{ ppm} + 800 \text{ ppm} = 1499 \text{ ppm}$$

$$C_a = e^{\ln 1499 \text{ ppm} - 0.75 \text{ air changes/min.}} = 708 \text{ ppm}$$

Although in theory the concentration will continue to increase with time, sampling error cannot effectively differentiate between the very small increases in ammonia concentration that occur after the sixth minute of this release scenario. Continuing with the minute-by-minute calculations produces the following concentrations: end of minute seven=712 ppm; end of minute eight=714 ppm; end of minute nine=715 ppm; end of minute 10=716 ppm. Due to numerical rounding, the calculation continues to return a resultant concentration of 716 ppm for each subsequent minute.

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