# HEALTH-BASED RISK ASSESSMENT FOR EXPOSURE TO AIRBORNE MOLD IN RESIDENTIAL PROPERTIE3S

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## INTRODUCTION

The purpose of this article is to describe one possible approach to estimating the concentration of indoor mold that may be associated with the initiation of adverse health effects. Although numerical values are discussed, they are only presented as the basis for example calculations. In addition, a decision-logic for small sample sizes is discussed.

With reference to mold investigations, the three primary tasks of the Indoor Environmental Professional (IEP) may be described as encompassing an exposure assessment, a risk assessment, and risk management. The focus of the inspection may be on determining if the structure is contaminated [exposure assessment], if the occupants are potentially at risk of adverse health effects [risk assessment], or both. If either the exposure assessment or the risk assessment is "unacceptable", then risk management [remediation] is implemented.

There has typically been an emphasis on measuring the concentration of contaminant fungal spores detected in water-damaged indoor environments. Elevated concentration is useful as an indicator of structural contamination, but may not be appropriate for assessing occupant exposure.

A high concentration of mold may be associated with short-term, acute exposures that may elicit an immediate allergic/asthmatic response from sensitized individuals or hypersensitivity. However, long-term, chronic exposures to lower concentrations of mold may also result in adverse health effects such as immuno-suppression, a decrease in respiratory efficiency, or toxic effects. The adverse health effects resulting from chronic exposures to indoor mold are typically associated with "dose", which is proportional to the "concentration" as well as the "contact time" (Equation 1).

**[1]** $\text{DOSE} \approx C \times BR \times CT$ [spores/$m^3$ x $m^3$/hour x hours = spores]

| | |
|---|---|
| C | Concentration (contaminant; spores/$m^3$) |
| BR | Breathing Rate (occupant; $m^3$/hour) |
| CT | Contact Time (duration of exposure; hours) |

If the average airborne concentration of mold is 1,000 spores/$m^3$, the normal breathing volume for an adult is six liters per minute (360 liters per hour, or 0.36 $m^3$/hour), and the duration of exposure is 8 hours; then 2.9 $m^3$ of air would be inhaled in 8 hours, and 2,900 spores would be inhaled during the 8-hour exposure.

**OCCUPATIONAL EXPOSURE LIMITS**

Consensus exposure limits (OEL) are available for a number of airborne contaminants that are commonly present in the workplace. Examples of single-shift, time-weighted average occupational exposure limits (TWA-OEL) include Threshold Limit Values (TLV) established by the American Conference of Governmental Hygienists (ACGIH); as well as Permissible Exposure Limits (PEL) published by the Occupational Safety and Health Administration (OSHA).

Calculating a time-weighted average (TWA) exposure requires knowledge of (1) the concentration of the contaminant; (2) the contact time, or duration of the exposure; and (3) the averaging time. In an occupational setting, the averaging time is the typical 8-hour work shift. The TWA exposure is calculated using Equation [2].

**[2]** TWA = (C x CT) / AT

| | |
|---|---|
| TWA | Time-weighted average exposure |
| C | Concentration of contaminant |
| CT | Contact Time (hours of exposure during work shift) |
| AT | Averaging Time (8 hours in a work shift) |

A TWA-OEL for airborne contaminants is expressed as a concentration, such as parts per million (ppm) or milligrams per cubic meter ($mg/m^3$). For example, assume the TLV for hydrogen sulfide (rotten egg odor) is 1 ppm for an 8-hour exposure. The decision logic for the time-weighted average (TWA) exposure would be:

| | |
|---|---|
| 0.7 ppm x 8 hours / 8 hours = 0.70 ppm | [Acceptable; less than 1 ppm] |
| 1.5 ppm x 4 hours / 8 hours = 0.75 ppm | [Acceptable; less than 1 ppm] |
| 1.5 ppm x 8 hours / 8 hours = 1.50 ppm | [Unacceptable; greater than 1 ppm] |

However, reporting exposures as a percentage of the TWA-OEL tends to provide more information to the non-technical person and simplifies communication. For example, unless it is known that the TLV for hydrogen sulfide is 1 ppm, simply reporting an average exposure of 0.7 ppm or 1.5 ppm would be difficult to interpret. Interpretation of the sample result is easier if the exposure in this example is reported as either 70 % or 150 % of the TWA-OEL. Therefore, exposures are presented as percentages in the following examples.

The TWA exposure, as a percentage of the TWA-OEL, is calculated using Equation [3]. A %TWA-OEL of 100% or less would be an acceptable exposure.

**[3]** %TWA = (TWA / TWA-OEL) x 100%

*Hydrogen sulfide example:*

%TWA = (0.70 ppm / 1.0 ppm) x 100% = 70%

%TWA = (1.50 ppm / 1.0 ppm) x 100% = 150%

## RESIDENTIAL EXPOSURES

TWA-OEL values are typically applied to employee exposures occurring during a single 8-hour work shift. Residential exposures continue for as long as the occupant is in the contaminated indoor environment. Therefore, occupant exposures to airborne mold spores in residential environments, unlike single-shift occupational exposures, may be long-term, chronic exposures. Therefore, a TWA-OEL should not be applied (without modification) to a 10-hour work shift; or to long-term chronic exposures typical of residential environments.

Simply reporting the contaminant concentration, without a consideration of the contact time, does not adequately characterize these long-term exposures. In addition, a one-day averaging time does not adequately account for the chronic nature of the exposure. A more appropriate averaging time would be 30 days, 3 months, or even longer. When an extended averaging time is used, the exposure parameter is referred to as a long-term average (LTA) exposure as opposed to a short-term TWA exposure; and the long-term average exposure limit is the LTA-EL.

Establishing an exposure limit for long-term exposures (LTA-EL), such as mold in the residential environment, is often based on an assessment of dose-response relationships. A review article by Eduard describes the response of individuals with sick building syndrome to inhalation of a single dose of mold spores.(1) A solution containing a known number of spores was placed directly into the nostrils of the test subjects. The average concentration equivalent to an 8-hour exposure was then calculated and reported in units of spores/$m^3$.

The "no observed effect level" (NOEL) was 4,000 spores/$m^3$ for *Trichoderma harzianum* and 8,000 spores/$m^3$ for *Penicillium chrysogenum*. In asthmatic patients, the "lowest observed effect level" (LOEL) for a single dose of *Penicillium* sp. was 10,000 spores/$m^3$. Respiratory distress began to appear in highly exposed industrial workers [possibly a self-selecting population] at an LOEL of 100,000 spores/$m^3$, although the responses to mycotoxin-producing and pathogenic fungi were reported to be much stronger.

The single-shift TWA-OEL for an agent is often based on the "no observed effect level" (NOEL) or the "lowest observed effect level" (LOEL) concentrations reported in the literature. NOEL concentrations reported in the literature are often considered when establishing a single-shift TWA-OEL. Therefore, the NOEL of 4,000 spores/$m^3$ for *Trichoderma harzianum* and 8,000 spores/$m^3$ for *Penicillium chrysogenum* may be useful for estimating a single-shift TWA-OEL for airborne fungal spores. Based on these data, a concentration of 5,000 spores/$m^3$ of total toxigenic airborne fungal spores was assumed to be a reasonable approximation of the health-based TWA-OEL for mold spores.

### Long-Term Average Exposures

As previously indicated, occupant exposures in water-damaged homes may continue until the structure is adequately remediated, a process that may take several months to complete. Therefore, the long-term average (LTA) exposure, which is based on the concept of dose rather than concentration, may be a better parameter for assessing the health-based risk associated with chronic exposures. In the following discussions, an averaging time of 30 days (720 hours) is arbitrarily used to calculate the LTA exposure for airborne mold. The LTA exposure is calculated using Equation [4], which is similar to Equation [2].

**[4]** LTA = ((C x CT) / AT

For example, assuming an average concentration of 1,000 spores/$m^3$ and a contact time of 630 hours a month (87% occupancy), the LTA exposure would be 875 spores/$m^3$.

LTA = ((1,000 spores/$m^3$ x 630 hours) / 720 hours = 875 spores/$m^3$

The acceptable exposure is defined as the long-term average exposure limit (LTA-EL), which is often set at ¼ (25%) or **a** (33%) of the short-term TWA-OEL.(2-5) However, if sensitive individuals are exposed, then a %LTA-EL of 10% may be appropriate.(4) Obviously, using 25% as the assessment criterion is more conservative than using 33%. Since the TWA-OEL was assumed to be 5,000 spores/$m^3$, the $LTA\text{-}EL_{(25\%)}$ is 1,250 spores/$m^3$ and the $LTA\text{-}EL_{(33\%)}$ is 1,665 spores/$m^3$. In the following examples, the assessment criterion is assumed to be 25% of the LTA-EL.

When the LTA exposure is expressed as a percentage of the LTA-EL, it is defined as the %LTA-EL. The Equation for the %LTA-EL is illustrated in Equation [5]. The LTA exposure is considered to be acceptable if it is less than the LTA-EL.

**[5]** $\%LTA\text{-}EL_{(25\%)}$ = (((C x CT) / AT) / LTA-EL) x 100%

$\%LTA\text{-}EL_{(25\%)}$ = (((1,000 spores/$m^3$ x 630 hrs) / 720 hrs) / 1,250 spores/$m^3$) x 100%
= 70.0%

The concentration equivalent to a particular %LTA-EL may be calculated using Equation [6].

**[6]** C = [(%LTA-EL) x (TWA-OEL) x (AT)] / [(CT) x (100%)]

C = ((100% x 1,250 spores/$m^3$ x 720 hr) / (630 hrs x 100%)) = 1,430 spores/$m^3$
C = ((100% x 1,250 spores/$m^3$ x 720 hr) / (400 hrs x 100%)) = 2,250 spores/$m^3$

The example calculations in Table 1 describe the contaminant concentrations resulting in representative %LTA values for (1) stay-at-home and (2) working occupants. A CT% of 87% assumes 21 hours per day are spent indoors. This assumption is representative of stay-at-home occupants such as homemakers, infants, the elderly, etc. A working occupant or student who leaves at 8:00 AM and returns at 6:00 PM, spends an hour outdoors each weekday, then has a similar schedule on the weekends would spend about 55% of their time indoors. The parameters used to calculate the values in Table 1 are contact times of 630 hours (87% occupancy) and 400 hours (55% 0ccupancy), respectively. The risk assessment for concentrations corresponding to $\%LTA\text{-}EL_{(25\%)}$ values exceeding 100% would be “unacceptable”.

**Table 1a. Contaminant concentrations resulting in representative %LTA-EL$_{(25\%)}$ values for stay-at-home occupants.**

| C (spores/m$^3$) | %LTA-EL (%) |
|---|---|
| 500 | 35 |
| 715 | 50 |
| 1,000 | 70 |
| 1,430 | 100 |
| 1,500 | 105 |

**Table 1b. Contaminant concentrations resulting in representative %LTA-EL$_{(25\%)}$ values for working and student occupants.**

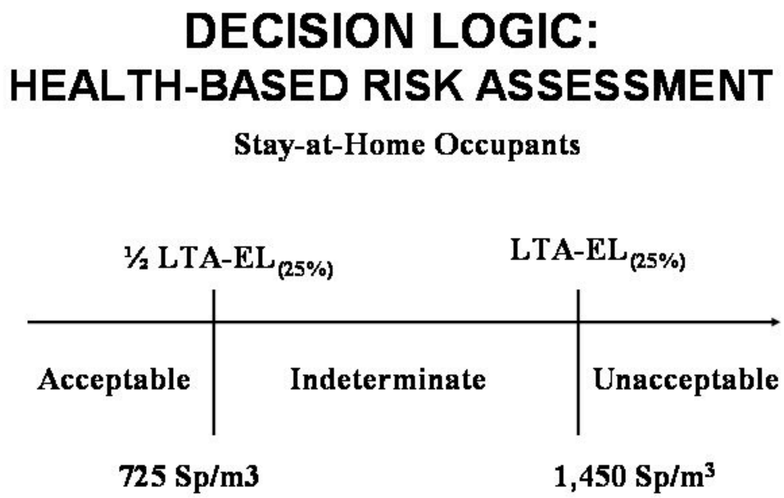
| C (spores/m$^3$) | %LTA-EL (%) |
|---|---|
| 1,000 | 44 |
| 1,125 | 50 |
| 1,500 | 67 |
| 2,000 | 89 |
| 2,250 | 100 |
| 2,500 | 111 |

**DECISION LOGIC**

The purpose of this discussion is to explore the application of health-based decision logic to the interpretation of airborne samples when only a limited number of samples, possibly only one sample in a particular area, have been collected. The following is the decision logic that is frequently applied to environmental samples:

> If the concentration is less than half the LTA-EL, then conclude that the risk assessment is “acceptable” [%LTA-EL less than 50%].
>
> If the concentration is greater than the LTA, then conclude that the risk assessment is “unacceptable” [%LTA-EL greater than 100%].

The decision logic is summarized in Figure 1.



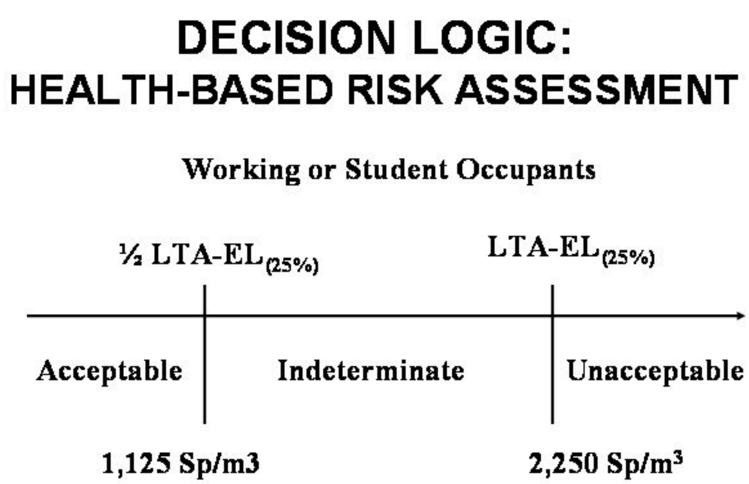




**Figure 1. Decision logic for a health-based risk assessment when only small sample sizes are available.**

**SUMMARY**

The approximated concentrations employed in these discussions may or may not be appropriate; and they should not be the primary focus. The interesting result is the estimated range of airborne toxigenic mold concentrations resulting in an "unacceptable" health-based risk assessment. The concentrations vary from 1,430 spores/$m^3$ for stay-at-home occupants to 2,250 spores/$m^3$ for working occupants. This range is relatively low compared to the concentrations of airborne fungal spore concentrations detected during many indoor air quality investigations.

**REFERENCES**

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