The Case of the
QUIETER WORKPLACE

By Mitch Ricketts

Math Toolbox is designed to help readers apply STEM principles to everyday safety issues. Many readers may feel apprehensive about math and science. This series employs various communication strategies to make the learning process easier and more accessible.

About one in six American workers is exposed to excessive noise on the job (Tak, Davis & Calvert, 2009). Overexposure to noise makes workers less productive and causes a wide variety of adverse health effects including hearing impairment, tinnitus, hypertension and ischemic heart disease (WHO, 2018). The good news is that safety professionals can help protect workers from excessive noise through engineering and other controls.

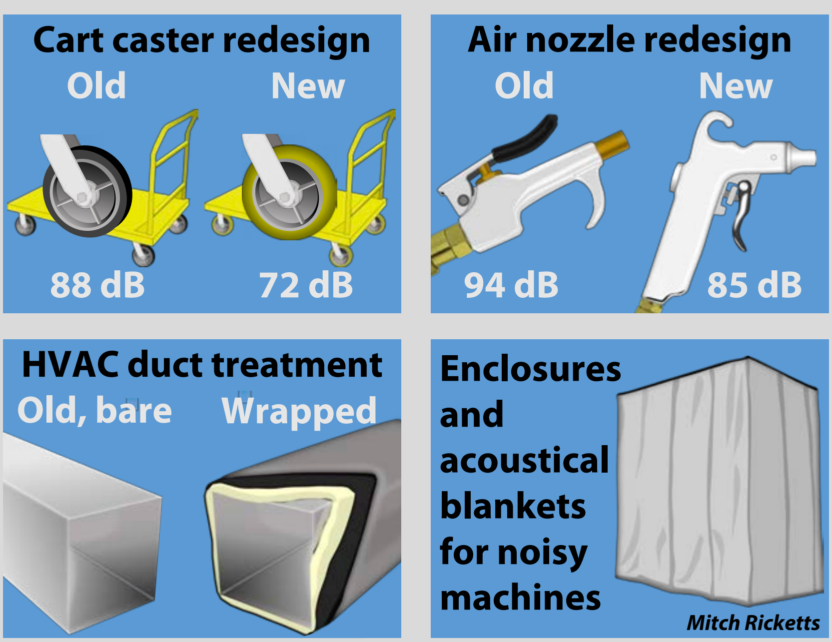
Figure 1 illustrates several controls used by one company, United Technologies Corp. (UTC), to dramatically reduce noise exposures at its facilities throughout the world. "The Case of the Noisy Workplace" (Math Toolbox, *PSJ* April 2020, pp. 45-48) explores sound pressure, which is easily measured in the environment. This article considers a different characteristic of sound, namely sound power, which better informs us of the dramatic health implications of small changes in sound levels at noisy workplaces.

Sound Power vs. Sound Pressure

Sound waves are comprised of alternating bands of high and low pressure. Sound pressure waves can travel through many materials including air, water and some solid objects such as steel. Although pressure change represents an important characteristic of sound, researchers typically focus on changes in sound power to quantify the risk of noise-induced hearing loss and other illnesses (WHO, 2018).

FIGURE 1
NOISE REDUCTION AT UTC

United Technologies Corp. (UTC) is a global company with more than 200,000 employees. In 2010, UTC identified elevated noise levels in the work areas of 10,000 employees. Between 2011 and 2015, UTC reduced 8-hour time-weighted-average exposures to 85 dBA or less for about 8,000 of these workers. Here are some examples from the 250 noise-reduction projects the company completed.

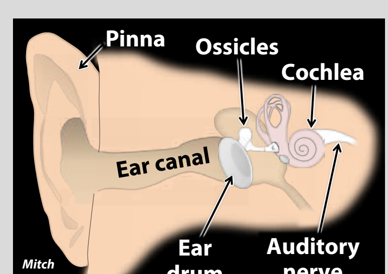


Note. Adapted from Excellence Award: United Technologies, Safe-in-Sound Excellence in Hearing Loss Prevention Award, 2015, www.safeinsound.us/swf/UTC/index.html.

Sound power is a measure of the rate at which sound waves transmit energy and perform work in the environment, for example, by causing vibrations in the tissue, bones and fluids of the auditory system. Work occurs anytime a force transfers energy to an object, displacing that object in the direction of the force. When sound waves transmit too much energy, our organs of hearing and balance may be damaged, resulting in hearing loss or permanent disruptions in the vestibular organs responsible for our sense of balance.

Figure 2 illustrates several key components of the auditory system that receive energy from sound waves. Energy transfer begins when sound interacts with the pinna (also called the auricle, the visible, external part of the ear). The shape of the pinna creates changes in sound waves that help us locate the direction of sound. Next, sound waves transfer energy and create resonant vibrations in the ear canal. These resonant vibrations amplify important sound frequencies in the range of speech. Sound waves may be best known for transferring energy to the ear drum, causing it to vibrate. Sound-induced vibrations in the eardrum are then amplified by the lever action of tiny bones called ossicles. The ossicles pass the vibrations to the fluid-filled cochlea. Waves in the cochlear fluid then bend delicate hair cells, triggering nerve impulses. The auditory nerve sends those nerve impulses to the brain where they are interpreted as sound. Many wavelengths of sound continue

FIGURE 2
AUDITORY SYSTEM



Note. Not to scale.

passing through the head, stimulating the opposite ear to further refine our perception of the sound's direction.

Since sound waves transfer energy to perform work, our calculations for sound power level (L_w) employ international units of power (i.e., watts or picowatts) divided by area (i.e., square meters). One watt per square meter (W/m^2) is equivalent to one trillion picowatts per square meter ($1\ W/m^2 = 1 \cdot 10^{12}\ pW/m^2$). We may calculate decibels from either W/m^2 or pW/m^2, as long as we maintain consistency throughout the following equation:

$$L_w = 10 \cdot log_{10} \frac{W}{W_0}$$

where:

L_w = sound power level in decibels (dB)

log_{10} = base-10 logarithm (i.e., common log)

W = actual sound power at a specified distance from a source (the sound power to which a worker is exposed), in watts per square meter (W/m^2) or in picowatts per square meter (pW/m^2)

W_0 = reference sound power (one trillionth of a watt per square meter; the threshold of hearing, equivalent to 0 dB, which is the softest sound the average person can distinguish at many important sound frequencies), $W_0 = 1 \cdot 10^{-12}\ W/m^2$ or, alternatively, $W_0 = 1\ pW/m^2$

Note: Be sure to use the same power metric (either W/m^2 or pW/m^2) to express variables W and W_0 throughout the equation.

Calculating Decibels Based on Sound Power

Our first mathematical problem may be encountered when designing engineering interventions to control noise. To begin, imagine a table saw that transmits a sound power of $0.006\ W/m^2$ (which equals $6 \cdot 10^9\ pW/m^2$) at a distance of 2 ft. We can calculate the sound power level (L_w) in dB at this same distance of 2 ft by inserting the following data into the equation:

•The sound power of the table saw at 2 ft is $0.006\ W/m^2$ (or $6 \cdot 10^9\ pW/m^2$), as stated in the problem. This is the value of W in the formula.

•As stated in the explanation of variables, the value of W_0 is $1 \cdot 10^{-12}\ W/m^2$ (or $1\ pW/m^2$). This is equivalent to 0 dB (the threshold of hearing).

With this information, we can solve the problem as follows:

Step 1: Start with the equation for decibels based on sound power:

$$L_w = 10 \cdot log_{10} \frac{W}{W_0}$$

Step 2: Insert the known values into the formula. We'll perform our calculations first using watts per square meter, then we'll recalculate using picowatts per square meter to confirm the two methods are equivalent.

In watts per square meter, $W = 0.006\ W/m^2$ and $W_0 = 1 \cdot 10^{-12}\ W/m^2$:

$$L_w = 10 \cdot log_{10} \frac{0.006}{1 \cdot 10^{-12}} = 97.78\ dB$$

Note: Most calculators have a *LOG* button, as well as a button for raising 10 to a power (often a button such as *INV*, *10X* or ^). Most calculators also have a dedicated button for creating negative numbers (as with -12 in this example). This negative button is often designated with a minus sign in parentheses: (-). If you are using spreadsheet software, the proper formula for this example is *=10*LOG10(0.006/(1*10^-12))*.

Step 3: Our calculation indicates a sound power (W) of $0.006\ W/m^2$ equals a sound power level (L_w) of 97.78 decibels (97.78 dB).

Solving the same example with sound power stated in picowatts per square meter: One watt per square meter equals one trillion picowatts per square meter ($1\ W/m^2 = 1 \cdot 10^{12}\ pW/m^2$). To convert from watts per square meter to picowatts per square meter, we multiply by $1 \cdot 10^{12}$, as follows:

$$pW/m^2 = W/m^2 \cdot 1 \cdot 10^{12}$$

Inserting the numbers from our example, we see that $0.006\ W/m^2$ equals $6 \cdot 10^9\ pW/m^2$:

$$pW/m^2 = 0.006 \cdot 1 \cdot 10^{12} = 6 \cdot 10^9\ pW/m^2$$

We can perform the same conversion to demonstrate that the reference sound power (W_0) of $1 \cdot 10^{-12}\ W/m^2$ equals $1\ pW/m^2$:

$$pW/m^2 = 1 \cdot 10^{-12} \cdot 1 \cdot 10^{12} = 1\ pW/m^2$$

To solve for sound power level (L_w) based on picowatts per square meter, we use the original equation:

$$L_w = 10 \cdot log_{10} \frac{W}{W_0}$$

We've converted sound power to picowatts per square meter, so W will now be $6 \cdot 10^9\ pW/m^2$ and W_0 will be $1\ pW/m^2$. We insert these values and solve the equation for sound power level in decibels (L_w):

$$L_w = 10 \cdot log_{10} \frac{6 \cdot 10^9}{1} = 97.78\ dB$$

The answer is the same as before (97.78 dB), since we made no changes other than converting W and W_0 to picowatts per square meter.

Note: If using a spreadsheet, the proper formula for this example is *=10*LOG10((6*10^9)/1)*.

Alternate example: Let's calculate the sound power level in decibels (L_w) for a different environmental noise. In this case, imagine a lawn mower that transmits a sound power of $0.00025\ W/m^2$ at a distance of 3 ft from the engine. We'll solve this example using watts per square meter, with $W = 0.00025\ W/m^2$ and $W_0 = 1 \cdot 10^{-12}\ W/m^2$).

$$L_w = 10 \cdot log_{10} \frac{0.00025}{1 \cdot 10^{-12}} = 83.98\ dB$$

The result indicates a sound power (W) of $0.00025\ W/m^2$ equals a sound power level (L_w) of 83.98 dB. We can also solve the formula using picowatts per square meter as our unit of sound power. To convert watts per square meter to picowatts per square meter, we multiply the sound power in W/m^2 by $1 \cdot 10^{12}$, as before:

$$W/m^2 = 0.00025 \cdot 1 \cdot 10^{12} = 2.5 \cdot 10^8\ pW/m^2$$

To solve for sound power level (L_w) based on picowatts per square meter, use the original equation and insert the known values: $W = 2.5 \cdot 10^8\ pW/m^2$ and $W_0 = 1$:

$$L_w = 10 \cdot log_{10} \frac{2.5 \cdot 10^8}{1} = 83.98\ dB$$

Again, we obtain the same results whether we employ watts or picowatts, providing we use them consistently throughout the equation.

You Do the Math

Apply your knowledge to the following questions. Answers are on p. 55.

1) A chain saw transfers a sound power of $0.03\ W/m^2$ ($3 \cdot 10^{10}\ pW/m^2$) in the operator's hearing zone. What is the sound power level (L_w) in dB in the operator's hearing zone? Be consistent with the use of sound power metrics. For example, if you use $0.03\ W/m^2$ as the sound power reaching the operator, be sure to use $1 \cdot 10^{-12}\ W/m^2$ as the reference sound power. Alternatively, if you use $3 \cdot 10^{10}\ pW/m^2$ as the environmental sound power, use $1\ pW/m^2$ as the reference.

2) A forklift transfers a sound power of $0.0001\ W/m^2$ in the operator's hearing zone. What is the sound power level (L_w) in dB in the operator's hearing zone? Again, be consistent with the use of sound power metrics.

Calculating Sound Power (W/m^2 or pW/m^2) From Sound Level in Decibels

In practice, most sound level meters and dosimeters respond to sound pressure (rather than sound power). However, since energy is proportional to the square of sound pressure, we can calculate watts (or picowatts) per square meter from decibels, regardless of whether decibels were derived from sound pressure or sound power.

The calculation from decibels to watts (or picowatts) per square meter is a practical on-the-job application of the formula because the results can help us understand the profound impact of small changes in decibels at noisy work sites.

We convert from decibels to actual sound power by rearranging the original formula, as follows:

Begin with the formula used earlier:

$$L_w = 10 \cdot log_{10} \frac{W}{W_0}$$

Rearrange the equation to solve for W. Keep in mind that we can perform any operation on one side of the equation as long as we perform that same operation on the other side. Let's begin by dividing both sides of the equation by 10:

$$L_w \div 10 = 10 \cdot log_{10} \frac{W}{W_0} \div 10$$

Next, cancel the 10 where you can:

$$L_w \div 10 = \cancel{10 \cdot} log_{10} \frac{W}{W_0} \cancel{\div 10}$$

Simplify by eliminating the canceled terms:

$$L_w \div 10 = log_{10} \frac{W}{W_0}$$

Continue rearranging by taking the inverse logarithm (antilogarithm) of each side of the equation:

$$10^{(L_w \div 10)} = 10^{\left(log_{10} \frac{W}{W_0}\right)}$$

Cancel where you can:

$$10^{(L_w \div 10)} = \cancel{10}^{\left(\cancel{log_{10}} \frac{W}{W_0}\right)}$$

Simplify:

$$10^{(L_w \div 10)} = \frac{W}{W_0}$$

Multiply both sides by W_0:

$$10^{(L_w \div 10)} \times W_0 = \frac{W}{W_0} \times W_0$$

Cancel where you can:

$$10^{(L_w \div 10)} \times W_0 = \frac{W}{\cancel{W_0}} \cancel{\times W_0}$$

Simplify:

$$10^{(L_w \div 10)} \times W_0 = W$$

Rearrange, and use the resulting equation to solve for W:

$$W = 10^{(L_w \div 10)} \times W_0$$

As in the UTC success story described in Figure 1, imagine the noise from a material cart exposes an employee to a sound level (L_w) of 88 dB. What sound power corresponds to this exposure, in watts per square meter?

Step 1: Start with the sound power level equation, modified to solve for W:

$$W = 10^{(L_w \div 10)} \times W_0$$

where:

W = actual sound power at a specified distance from a source, in watts per square meter (W/m^2) or in picowatts per square meter (pW/m^2)

L_w = sound power level in decibels (dB)

log_{10} = base-10 logarithm (i.e., common log)

W_0 = reference sound power, $W_0 = 1 \cdot 10^{-12}$ W/m^2, or alternatively W_0 = 1 pW/m^2

Note: Be sure to use the same power metric (either W/m^2 or pW/m^2) to express variables W and W_0 throughout the equation.

Step 2: The known value for the sound level exposure in decibels (L_w) is 88 dB. For this example, we'll use watts per square meter as our sound power metric. Thus, the reference sound power (W_0) is $1 \cdot 10^{-12}$ W/m^2. We insert the values of L_w and W_0. Then we solve for sound power (W):

$$W = 10^{(88 \div 10)} \cdot 1 \cdot 10^{-12} = 0.00063\ W/m^2$$

which is equivalent to $6.3 \cdot 10^{-4}$ W/m^2 in scientific notation.

Note: In a spreadsheet, the formula for this example is *=(10^(88/10))*(1*10^-12)*.

To solve the same problem using picowatts per square meter, use 1 pW/m^2 for the reference sound pressure (W_0), as follows:

$$W = 10^{(88 \div 10)} \cdot 1 = 630{,}957{,}344.5\ pW/m^2$$

which is equivalent to about $6.3 \cdot 10^8$ pW/m^2 in scientific notation.

Step 3: The result indicates a sound level exposure of 88 dB equals an actual sound power of 0.00063 W/m^2 (or $6.3 \cdot 10^8$ pW/m^2).

Alternate example: As in Figure 1, imagine new wheel assemblies are installed on a material cart to reduce noise. The noise from the altered cart now exposes an employee to a sound level (L_w) of 72 dB. What sound power corresponds to this reduced exposure, in watts per square meter? Again, we'll use watts per square meter as our sound power metric, so $W_0 = 1 \cdot 10^{-12}$ W/m^2.

Insert the known values for the new sound level in decibels (L_w = 72 dB) and reference sound power in units of watts per square meter ($W_0 = 1 \cdot 10^{-12}$ W/m^2). Then solve for sound power (W):

$$W = 10^{(72 \div 10)} \cdot 1 \cdot 10^{-12} = 0.000016\ W/m^2$$

which is equivalent to $1.6 \cdot 10^{-5}$ W/m^2 in scientific notation.

Alternatively, to solve for picowatts per square meter, we use 1 pW/m^2 for the reference sound pressure (W_0), as follows:

$$W = 10^{(72 \div 10)} \cdot 1 = 15{,}848{,}931.92\ pW/m^2$$

which is equivalent to about $1.6 \cdot 10^7$ pW/m^2 in scientific notation.

The result indicates the sound level of 72 dB equals an actual sound power of about 0.000016 W/m^2 (or $1.6 \cdot 10^7$ pW/m^2). This result, together with the previous result of about 0.00063 W/m^2 ($6.3 \cdot 10^8$ pW/m^2) for 88 dB, illustrates the full impact of the engineering intervention: A reduction of 16 dB resulted in a 97.5% reduction in the final sound power (said another way, the modified cart would expose a worker to only 2.5% of the original sound power).

You Do the Math

Apply your knowledge to the following questions. Answers are on p. 55.

3) As in Figure 1, imagine the air-hose nozzles at a workplace expose employees to a sound level (L_w) of 94 dB. What is the sound power of this exposure in watts per square meter (with $W_0 = 1 \cdot 10^{-12}$ W/m^2) and in picowatts per square meter (with W_0 = 1 pW/m^2)?

4) Again, as in Figure 1, imagine the air-hose nozzles are replaced and the new nozzles expose employees to a sound level (L_w) of 85 dB. What is the sound power of this reduced exposure in watts per square meter (with $W_0 = 1 \cdot 10^{-12}$ W/m^2) and in picowatts per square meter (with W_0 = 1 pW/m^2)?

More About Sound Power Level (L_w) & Sound Pressure Level (L_p)

As noted, sound power level (L_w) is calculated from sound power in watts (or picowatts) per square meter, while sound pressure level (L_p) is calculated from sound pressure in pascals (or micropascals). The different equations for L_w and L_p have been designed to ensure that we obtain the same sound level, whether we calculate dB from sound power (using this article's equation for L_w) or whether we calculate dB from sound pressure (using the equation for L_p discussed in Math Toolbox, April 2020). For example, 85 dB calculated as L_w from 0.00031628 W/m^2 is equivalent to 85 dB calculated as L_p from 0.35566 Pa (pascals of pressure). This means we can calculate sound power from dB regardless of whether decibels were originally calculated as L_w or L_p. This is fortunate because workplace sound levels are usually calculated as L_p. Consideration of sound power is important for noise reduction efforts because researchers have accumulated

FIGURE 3
SOUND POWER

Each bar represents a doubling of the sound power in watts per square meter (compared to the bar just below it). What difference in decibels corresponds to each doubling?

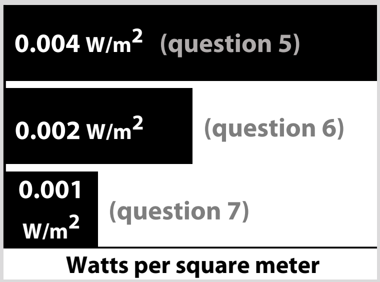
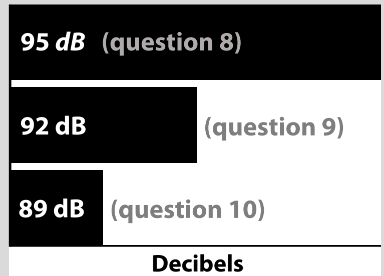


FIGURE 4
SOUND POWER LEVEL

Each bar represents an increase of 3 dB (compared to the bar just below it).



strong evidence that noise-induced hearing loss is correlated with sound power.

How Decibels Reflect Changes in Sound Power & Sound Pressure

The decibel scale is logarithmic and roughly reflects differences in sound intensities that can be detected by most people. This means there is not a 1:1 relationship between changes in decibels and changes in watts per square meter. Our auditory systems may detect small increases in sound power in a quiet room, but we detect only large sound power differences in noisy environments. Although every increase of 3 dB represents a doubling of sound power, the actual increase in W/m^2 (or pW/m^2) is relatively small in quiet environments, but large in noisy ones. For example, a doubling of sound power from 1 to 4 dB is inconsequential for our health because it represents an actual increase of only 0.00000000000125 W/m^2. On the other hand, a doubling of sound power from 91 to 94 dB represents a dramatic increase in hazard because it represents a change of 0.00125 W/m^2. (You can use the equations in this article to confirm the math.)

Astute readers may have noticed a different relationship between decibels and sound pressure while performing the calculations in Math Toolbox, April 2020. Namely, sound pressure (in μPa) doubles with every increase of 6 dB (instead of 3 dB). This relationship reflects differences in the two distinct characteristics of sound: Pressure (in μPa) represents the pressure changes in a sound wave, while power (in W/m^2) reflects the energy transfer or work done by the sound wave.

How Much Have I Learned?

The following problems are based on Figures 3 and 4, illustrating how differences in sound power correspond to changes in decibels. Try the problems on your own. Answers are on p. 55.

5) In Figure 3, the top bar indicates a sound power of 0.004 W/m^2. What is the sound power level (L_w) in dB?

6) In Figure 3, the middle bar indicates a sound power of 0.002 W/m^2 (half the sound power of the top bar). What is the sound power level (L_w) in dB?

7) In Figure 3, the bottom bar indicates a sound power of 0.001 W/m^2 (half the sound power of the middle bar, or one-quarter the sound power of the top bar). What is the sound power level (L_w) in dB?

8) In Figure 4, the top bar indicates a sound power level (L_w) of 95 dB. What is the sound power in watts per square meter (W/m^2)?

9) In Figure 4, the middle bar indicates a sound power level (L_w) of 92 dB (a reduction of 3 dB, compared to the top bar). What is the sound power in watts per square meter (W/m^2)?

10) In Figure 4, the bottom bar indicates a sound power level (L_w) of 89 dB (a reduction of 3 dB, compared to the middle bar). What is the sound power in watts per square meter (W/m^2)?

11) Based on your answers to questions 5 through 10, what change in dB corresponds to a doubling (or halving) of sound power in W/m^2?

The Language of Sound Power

Readers will encounter the following concepts in codes, certification exams and conversations with other professionals. Match the numbered concepts with their paraphrased definitions (lettered). All concepts have been explained in the text, formulas and illustrations. Answers are on p. 55.

Concepts
12) decibel (dB)
13) reference sound power (W_0)
14) sound power (W, W_0)
15) sound power level (L_w)
16) work

Definitions (in random order)
a) Transfer of energy to an object by a force that displaces the object in the direction of the force.
b) A direct measure of the rate at which sound waves transmit energy and perform work in the environment, for example, by causing vibrations in the tissues, bones and fluids of the auditory system. Usually expressed in watts (or picowatts) per square meter.
c) Sound level that can be calculated equivalently from sound power (using this article's equation for L_w) or from sound pressure (using the equation for L_p discussed in Math Toolbox, April 2020).
d) The threshold of hearing, equivalent to 0 dB, the softest sound the average person can distinguish at many important sound frequencies ($1 \cdot 10^{-12}$ W/m^2, or alternatively, 1 pW/m^2.
e) Indirect measure expressed in decibels, calculated from a logarithmic function applied to the ratio of the actual sound power and the reference sound power.

For Further Study

•*ASSP's ASP Examination Prep: Program Review and Exam Preparation*, edited by Joel M. Haight, 2016.

•National Institute on Deafness and Other Communication Disorders, **www.nidcd.nih.gov**.

•*OSHA Technical Manual* (TED 01-00-015), Section III, Chapter 5: Noise, by OSHA, 2013; **www.osha.gov/dts/osta/otm/new_noise/index.html**.

•*Criteria for a Recommended Standard: Occupational Noise Exposure (Revised Criteria)*, by NIOSH, 1998; **www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf**. PSJ

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Mitch Ricketts, Ph.D., CSP, is an associate professor of safety management at Northeastern State University (NSU) in Tahlequah, OK. He has worked in OSH since 1992, with experience in diverse settings such as agriculture, manufacturing, chemical/biological laboratories and school safety. Ricketts holds a Ph.D. in Cognitive and Human Factors Psychology from Kansas State University, an M.S. in Occupational Safety Management from University of Central Missouri, and a B.S. in Education from Pittsburg State University. He is a professional member and officer of ASSP's Tulsa Chapter, and faculty advisor for the Society's NSU Broken Arrow Student Section.

death rose to a new level. For you see, not only did I work in a field that had the power to influence safety, now I had the chance to work for the company where my grandfather died. The idea felt weird.

In November 2004, I accepted the health, safety and environmental regional manager position and began work with Fluor. When I walked through the doors of the corporate office in Greenville, SC, I could not help but wonder what my grandfather would think; yet another memory lost.

The irony does not end with my employment with Fluor. After being at the company for 3 months, the Tennessee Eastman project requested that I conduct a safety audit at its facility. I quickly learned that the project was in Kingsport, TN, and that small bit of information prompted me to ask, "How long have we been at this facility?" The answer was eerie: since the early 1960s. The answer did not confirm that this was where my grandfather died, but the response sure did pique my interest and the fact made me uneasy.

I arrived on site eager to do a good job with the audit, but I was unsure how I would satisfy my curiosity. After all, how do you tell a project that your grandfather may have been killed on this site years ago? Broaching the subject was a little awkward, but after I got to know the leadership team on site, I could not help but ask, "Is there anyone still around who worked here in 1961?" I shared the motivation behind the question and the leadership team responded positively. They helped me find a man who was there the day my grandfather died, James Johnson (J.J.). I did not think that was possible, and the reality shocked me. That was an interview that I never expected. What questions do you ask in such a situation? Despite my anxiety, I discovered that the unanticipated opportunity was a blessing that drew me closer to the memory that I was seeking.

J.J. told me that the incident did not happen at the Eastman plant. He said that it happened down the road at another Daniel International project. They were building a plant in Kingsport, TN, when the incident occurred. He said he did not witness the incident, but he was on site when it happened, and he remembered the project shut down for the day after. J.J. described how the cement truck was backing down a narrow portion of the building to make a pour around the base of a column, and for some unknown reason, my grandfather was unable to move out of the way. These simple details not only captured the essence of what I have always heard, but the conversation closed a loop in my curiosity. I had the opportunity to talk to someone who was there in 1961. That chance to build on a lost memory meant a lot to me.

As I drove back to Greenville after my visit, my lost memories began to take on new meaning. I thought about simple questions. What if there was barricade tape? What if they had a spotter? What if there was a backup alarm? What if they had completed a prejob brief? What if someone had warned him? In retrospect, the what-if questions paint a picture of regret that we cannot change. If you think forward, what-if questions are simple tools that impact the future.

Through the irony of my experiences, I have slowly begun to understand that memories are not only lost but they are created by asking "what if" at the right time. Memories are shaped by every individual's dedication and commitment to anticipate risk and execute the task with safety in mind. Every measure of safety excellence has the opportunity to shape our quality of life for the future and fashion memories that last generations.

Our vigilance to achieve zero injuries is not about a faceless number. The reality is that the finite number zero represents an infinite number of memories and experiences that bless the lives of people today. I challenge you today to consider the memory that I lost and make it your goal to create future memories for the people you work with every day. Your commitment to safety today creates memories tomorrow. **PSJ**

David G. Lynn, CSP, is president of Peak Safety Performance LLC. He is a professional speaker, published author, and performance consultant with a unique blend of work experiences at OSHA, Duracell, Owens Corning and Fluor. Lynn has worked in the field on construction projects, managed safety in manufacturing plants and served as a corporate safety director. With strategic planning, leadership development and project execution, Lynn helps clients solve problems and achieve their goals. He is a member of ASSP's Piedmont Chapter.

Math Toolbox, continued from pp. 46-49

Answers: The Case of the Quieter Workplace

You Do the Math

Your answers may vary slightly due to rounding.

1) $L_w = 10 \cdot log_{10} \frac{0.03}{1 \cdot 10^{-12}} = 104.77\ dB$

or $L_w = 10 \cdot log_{10} \frac{3 \cdot 10^{10}}{1} = 104.77\ dB$

2) $L_w = 10 \cdot log_{10} \frac{0.0001}{1 \cdot 10^{-12}} = 80\ dB$

or $L_w = 10 \cdot log_{10} \frac{1 \cdot 10^{8}}{1} = 80\ dB$

3) $W = 10^{(94 \div 10)} \cdot 1 \cdot 10^{-12} = 0.00251\ W/m^2$

or $W = 10^{(94 \div 10)} \cdot 1 = 2{,}511{,}886{,}432\ pW/m^2$,

equivalent to about $2.51 \cdot 10^9$ pW/m^2

4) $W = 10^{(85 \div 10)} \cdot 1 \cdot 10^{-12} = 0.000316\ W/m^2$

or $W = 10^{(85 \div 10)} \cdot 1 = 316{,}227{,}766\ pW/m^2$,

equivalent to about $3.16 \cdot 10^8$ pW/m^2

How Much Have I Learned?

Your answers may vary slightly due to rounding.

5) $L_w = 10 \cdot log_{10} \frac{0.004}{1 \cdot 10^{-12}} = 96\ dB$

6) $L_w = 10 \cdot log_{10} \frac{0.002}{1 \cdot 10^{-12}} = 93\ dB$

7) $L_w = 10 \cdot log_{10} \frac{0.001}{1 \cdot 10^{-12}} = 90\ dB$

8) $W = 10^{(95 \div 10)} \cdot 1 \cdot 10^{-12} = 0.0032\ W/m^2$

9) $W = 10^{(92 \div 10)} \cdot 1 \cdot 10^{-12} = 0.0016\ W/m^2$

10) $W = 10^{(89 \div 10)} \cdot 1 \cdot 10^{-12} = 0.0008\ W/m^2$

11) A change of 3 dB corresponds to a doubling (or halving) of sound power.

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12) c; 13) d; 14) b; 15) e; 16) a.