APPENDIX B—SAMPLE EQUATIONS AND CALCULATIONS

B.1 Sound Pressure Level

The human ear can hear a broad range of sound pressures. Because of this, the sound pressure level (L_p) is measured in decibels (dB) on a logarithmic scale that compresses the values into a manageable range. In contrast, direct pressure is measured in pascals (Pa). L_p is calculated as 10 times the logarithm of the square of the ratio of the instantaneous pressure fluctuations (above and below atmospheric pressure) to the reference pressure:

$$L_p = 10 \times \log_{10}(P/P_{ref})^2$$

Where P is the instantaneous sound pressure, in units Pa, and P_{ref} is the reference pressure level, defined as the quietest noise a healthy young person can hear (20 µPa).

Example: *If a piece of equipment has a sound pressure of 2 Pa, the sound pressure level is calculated:*

$$L_p = 20 \log_{10} (2/0.00002) = 20 \log_{10}(100{,}000) = 20 \times 5.0 = 100 \text{ dB}$$

B.2 Sound Power Level

Sound power level (L_w) is similar in concept to the wattage of a light bulb. In fact, L_w is measured in watts (W). Unlike L_p, L_w does not depend on the distance from the noise source. The sound power level is calculated using the following equation:

$$L_w = 10 \times \log_{10}(W/W_{ref})$$

Where W is the acoustic power in watts and W_{ref} is the reference acoustic power, 10^{-12}.

Example: *The sound power level associated with a typical face-to-face conversation, which may have a sound power of 0.00001 W, is calculated:*

$$L_w = 10 \times \log_{10}(0.00001/10^{-12}) = 70 \text{ dB}$$

B.3 Combining and Averaging Sound Levels

Decibels are measured using a logarithmic scale, which means decibels cannot be added arithmetically. For example, if two noise sources are each producing 90 dB right next to each other, the combined noise sound level will be 93 dB, as opposed to 180 dB. The following equation should be used to calculate the sum of sound pressure levels, sound intensity levels, or sound power levels:

$$\text{Total } L = 10 \times \log_{10}\left(\sum_1^n 10^{Ln/10}\right)$$

Often, using this equation to quickly sum sound levels when there is no calculator or computer available is difficult. The following table can be used to estimate a sum of various sound levels:

Difference Between Two Levels to Be Added	Amount to Add to Higher Level to Find the Sum
0–1 dB	*3 dB*
2–4 dB	*2 dB*
5–9 dB	*1 dB*
10 dB	*0 dB*

Example: *There are three noise sources immediately adjacent to one another, each producing a sound level of 95 dB. The combined sound level can be found using the table above. The difference between the first two noise sources is 0 dB, which means the sum will be 95 + 3 = 98 dB. The difference between 98 dB and the remaining noise source (95 dB) is 3, which means the sum will be 98 + 2 = 100 dB.*

B.4 Adding Noise Exposure Durations to Determine Compliance with OSHA Standards

Under OSHA standards, workers are not permitted to be exposed to an 8-hour TWA equal to or greater than 90 dBA. OSHA uses a 5-dBA exchange rate, meaning the noise level doubles with each additional 5 dBA. The following chart shows how long workers are permitted to be exposed to specific noise levels:

Permissible Duration (Hours per Day)	Sound Level (dBA, Slow Response)
16	*85*
8	*90*
4	*95*
2	*100*
1½	*102*
1	*105*
½	*110*
¼ or less	*115*

The values in the chart above are from Table G-16 in the general industry standard, 29 CFR 1910.95. To calculate a permissible duration that is not addressed in this chart, use the following equation:

$$T = \frac{8}{2^{(L-90)/5}}$$

Where T is the permissible duration (in hours) and L is the measured sound level (in dBA).

A worker's daily noise exposure typically comes from multiple sources, which have different noise levels for different durations. When adding different noise levels from various noise sources, only noise levels exceeding 80 dBA should be considered. The combined effect of these noise sources can be estimated using the following equation:

$$Sum = C_1/T_1 + C_2/T_2 + C_3/T_3 + C_n/T_n$$

Where C_n is the total duration of exposure at a specific noise level, and T_n is the total duration of noise permitted at that decibel level. If the sum equals or exceeds "1," the combined noise level is greater than the allowable level. If the sum is less than "1," the combined noise level is less than the allowable level.

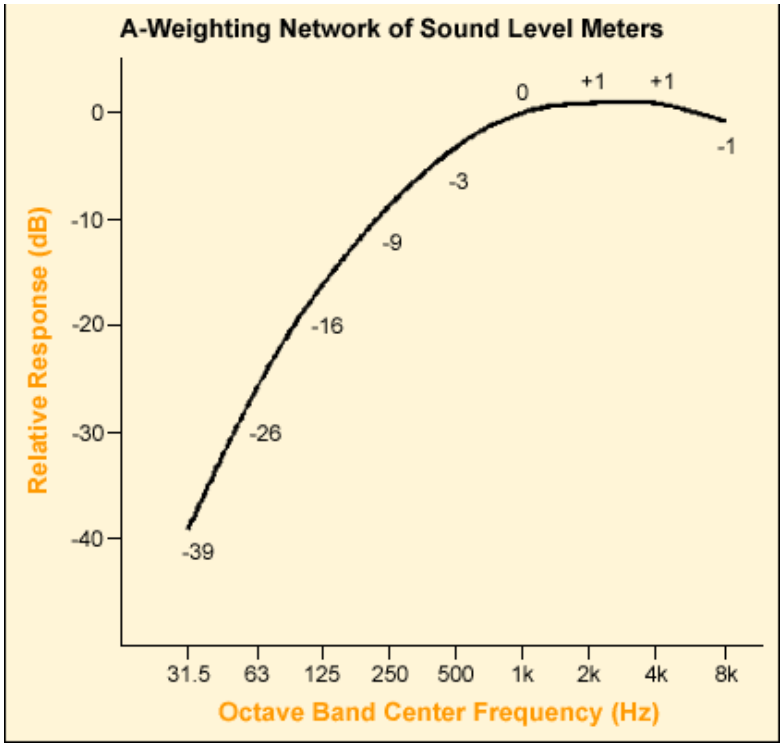
Example: *A worker in a machine shop is exposed to 95 dBA for 2 hours, 69 to 78 dBA for 4 hours (including a 15-minute break and 45-minute lunch), and 90 dBA for 3 additional hours.*

Example: Worker's Activity	Time	Measured Sound Level
Milling machine	*6:00 a.m.–8:00 a.m.*	*95 dBA*
Break room	*8:00 a.m.–8:15 a.m.*	*69 dBA*
Parts department	*8:15 a.m.–11:15 a.m.*	*78 dBA*
Lunch (in break room, 45 min.)	*11:15 a.m.–12:00 noon*	*69 dBA*
Milling assist	*12:00 noon–3:00 p.m.*	*90 dBA*

To determine if the worker's noise exposure exceeds a 90 dBA TWA, use the previous equation. Because the noise levels in the break room (69 dBA) and parts department (78 dBA) are below 80 dBA, these periods of the day are not included in the calculation. According to the chart above, workers are permitted to be exposed to 95 dBA for 4 hours per day and 90 dBA for 8 hours per day. Calculate the ratio of actual exposure duration to permissible exposure duration for each time segment and add them: 2/4 + 3/8 = 7/8. The resulting value (7/8) is less than 1; therefore, this worker's exposure does not exceed the 90 dBA TWA. However, a separate calculation would be required to determine if a hearing conservation program is required.

B.5 Calculating the Equivalent A-Weighted Sound Level (L_A)

Occasionally, it is necessary to convert a set of octave band sound pressure levels into an equivalent A-weighted sound level. This is easily done by applying the A-scale correction factors for the nine standard octave center frequencies and combining the corrected values by decibel addition. The A-scale correction factors are the values of the A-weighting network at the center of each particular octave band. The value derived by combining the corrected values for each octave band is designated the A-weighted sound level (dBA).



Example:

Octave Band Center Frequency (Hz)	Example L_p (dB)	A-Scale Correction Factor (dB) *	Corrected Values (dB)**
31.5	*94*	*-39*	*55*
63	*95*	*-26*	*69*
125	*92*	*-16*	*76*
250	*95*	*-9*	*86*
500	*97*	*-3*	*94*
1,000	*97*	*0*	*97*
2,000	*102*	*+1*	*103*
4,000	*97*	*+1*	*98*
8,000	*92*	*-1*	*91*

* *Look up on A-weighted network chart for each value L_p.*
** *L_p corrected to the A-scale = Li.*

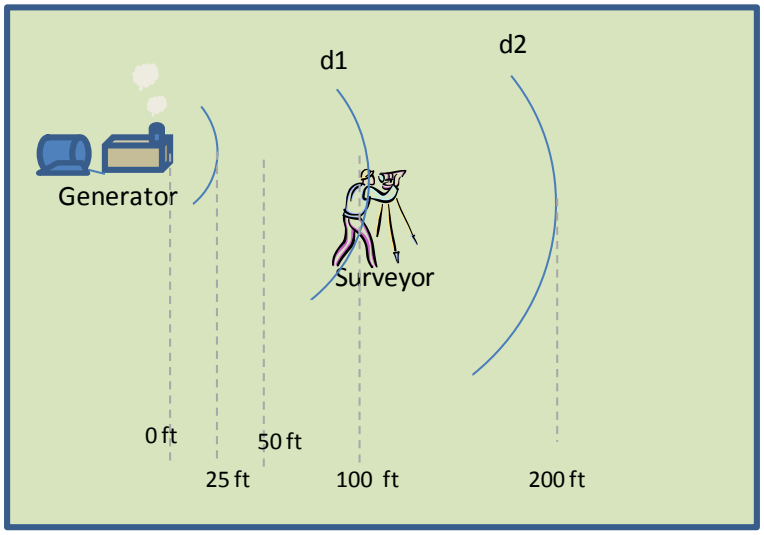
The A-weighted sound level is calculated by combining the corrected band levels:

$$L_A = 10 \times \log_{10}\left(\sum_1^n 10^{Li/10}\right) = 10 \times \log\left(10^{5.5} + 10^{6.9} + 10^{7.6} + 10^{8.6} + 10^{9.4} + 10^{9.7} + 10^{10.3} + 10^{9.8} + 10^{9.1}\right) = 105 \text{ dBA}$$

Where L_A is the A-weighted sound level and Li is the corrected decibel level value for each individual octave band.

B.6 Calculating Sound Pressure Level at a Distance

If a sound is generated at a point source in a free field, meaning there are no walls or other obstructions, the sound pressure level, L_p, will be reduced by 6 dB each time the distance from the noise source is doubled. Alternatively, L_p will increase by 6 dB in a free field each time the distance to the noise source is halved. Consider the following example:



Example: *A worker is surveying an open field, which has a diesel generator running in the middle of it. The worker is 100 ft from the generator and is exposed to a noise level of 85 dBA. When the worker is 25 ft from the generator, the noise level will be 97 dBA. At 200 ft from the generator the worker will be exposed to a noise level of 79 dBA.*

Calculating the sound pressure level at a specific distance from a noise source is often useful. The following equation allows one to calculate the sound pressure level at any distance from a noise source in a free field:

$L_{pd2} = L_{pd1} + 20 \times \log(d1/d2)$

Where L_{pd2} is the sound pressure level at the new distance from the noise source, L_{pd1} is the sound pressure level at the original distance, d1 is the original distance, and d2 is the new distance.

Example: *The sound pressure level of an aircraft engine in the middle of an open runway is 120 dBA at a distance of 50 ft from the receiver. The sound pressure level at a distance of 80 ft is calculated using the equation above. L_{pd1} is 120 dBA, d1 is 50 ft, and d2 is 80 ft. Therefore, L_{pd2} is 120 + 20 × log(50/80), which is 116 dBA.*

B.7 Reducing the Action Level for Extended Workshifts

If a worker works longer than an 8-hour shift, the action level (AL) for hearing conservation is reduced proportionally from 85 dBA using the following equation:

$$AL = 16.61 \log_{10}\left(\frac{50}{12.5 \times hours\ worked}\right) + 90$$

Example: *A worker works a 10.75-hour shift in a car parts manufacturing plant. What will be the worker's reduced AL?*

$$AL = 16.61\log_{10}\left(\frac{50}{12.5 \times 10.75}\right) + 90 = 82.9\ dBA$$

B.8 *<u>Converting a Single Dose Measurement to an 8-hour TWA Sound Level</u>*

A dose measurement can be converted to an 8-hour TWA sound level using the following equation:

$$TWA = 16.61\log_{10}\frac{dose}{100} + 90$$

Where the dose is a percentage and the TWA is on an A-weighted scale.

A factory hires a health and safety consultant to measure the noise exposure of the workers. The consultant writes a report that states that workers are exposed to a 183% dose, according to the general industry standard, CFR 29 1910.95. Convert this dose into an 8-hour TWA.

$$TWA = 16.61\log_{10}\frac{183}{100} + 90 = 94.4\ dBA$$