Understanding Noise Exposure Measurements

To establish and maintain a hearing conservation program and comply with regulatory requirements, determination of the degree and nature of potential unprotected exposure to noise in the workplace is necessary. What must be measured, the capabilities of contemporary measuring instruments, procedures and precautions are detailed in this article.

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Two types of noise having potential for hearing damage are separated under short and long duration categories. The short duration category presents a risk for damage following a single or small number of exposures. It includes impulses and very short duration segments of steady or slowly varying noise. Impulses are qualitatively identified as transient sound waveforms which have durations of less than one second and are either isolated in occurrence or, if repeated, have repetition periods greater than one second. Unprotected exposure to such noise is limited at 140 dB and is identified in the OSHA standard[1], and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values.[2] To measure such impulses, instruments having the capability to measure peak sound levels of impulses as short as 100 microseconds are required.[3] Note that instruments having IMPULSE[3] response are not suitable. Such a setting has improper dynamics and is only used for some community noise measurements.

The maximum levels of short duration segments of noise that are not classified as impulses must be measured with instruments having ANSI SLOW response.[1] These are designated as maximum rather than peak sound levels. This second category of noise includes all types of waveforms occurring over protracted periods (i.e., impulses, short segments, slowly varying and continuous). For this category, limits are placed on the cumulative exposure established by integrating the contributions from all waveforms into a single measure. Under the OSHA standard it pertains to daily (24 hrs) exposures and is defined in terms of a criterion level (90 dB) and a criterion time (8 hrs). This baseline stipulates that unprotected exposure at 90 dB must be limited to 8 hours. Such a limit is generally not directly applied since noise levels normally vary continuously. Departures are therefore stated in terms of exchange rates defining changes in permissible noise levels versus changes in duration. For OSHA, the exchange rate is 5 dB decrease or increase in permissible level respectively per halving or doubling of exposure time.

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Artifacts and Interference

To understand the underlying physical interpretation of the exposure limit, note that a decibel sound level corresponds to a specific sound intensity which has the dimensions of sound power flowing through a unit area. In turn, power has the dimensions of energy transfer per unit time. When exposure to a noise level for 8 hours is stipulated as a limit, it is equivalent to limiting an exposure to the intensity of the noise level for 8 hours. Such an exposure corresponds dimensionally to an accumulated sound energy, the limit of which must not be exceeded.

The stipulation of a criterion level and a criterion time identify a quantity of energy which constitutes a 100% noise dose. Accordingly, accumulation of a smaller amount of energy constitutes a lesser dose and vice versa. Accumulation of a noise dose for exposure to a fixed noise level is directly proportional to exposure time. For example, exposure to noise level, L_1, for t_1 hours would accumulate a dose, D_1. Without changing the noise level, extending the exposure to $2t_1$ hours will accumulate twice the noise dose, $2D_1$.

Consider now applying the exchange rate concept. To maintain the accumulated dose constant when the noise level is increased by the number of decibels stipulated for a time-sound level exchange rate, the exposure duration must be cut in half. Applying the OSHA standard to the prior example, if L_1 is increased by 5 dB, the duration must be cut in half to maintain the same noise dose. Conversely, it is evident that the accumulated noise dose for a fixed exposure time will *double* if the noise level is raised by 5 dB or will be *halved* if the level is reduced by 5 dB.

The principles involved are the same for all exchange rates. However, strict mathematical interpretation of the concept only applies to a 3 dB exchange. Such application is specifically identified as equal energy, time-sound level exchange. Other exchange rates produce biased results which are justified by alternative interpretations of epidemiological and research data. Note that there is no fundamental physical law that rigorously mandates application of the 3 dB equal energy exchange rate.

At present, OSHA and MSHA in the U.S. require use of 5 dB exchange. The exchange rate in the ACGIH guidelines and many countries throughout the world is 3 dB, as is the newly issued "Criteria for a Recommended Standard–Occupational Exposure to Noise" by the National Institute for Occupational Safety and Health (NIOSH).[5] Of the two, the 3 dB exchange rate relates to more conservative exposure limits. Considering the existence of multiple guidelines and mandates, in making measurements it is necessary that the criteria and exchange rates pertinent to a selected application be observed.

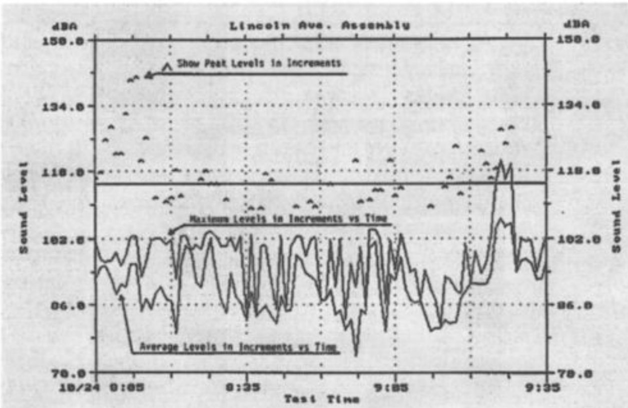

Fig. 1. *Exposure profile obtained with dosimeter—1 minute increments (1 1/2 hour portion of work shift).*

Determination of Exposure

Fundamentally, determination of exposure requires measurement of incremental sound levels for corresponding durations. This has traditionally been done with a sound level meter making time-related measurements—an unwieldy, time consuming and in some situations impossible process when extreme variations in noise levels are encountered.

Such obstacles are surmounted through the use of integrating/averaging sound level meters and dosimeters.[4] Both types of instruments process measurements continuously, and when properly selected, accommodate appropriate exchange rates and other parameters stipulated by regulations or particular guidelines. These types of instruments commonly generate hard copy and computer records. Such documentation supports regulatory compliance and conduct of hearing conservation programs.

All component frequencies of noise contributing to hearing damage are not equally hazardous, thus measurement of noise is first processed through frequency-selective filters specified by an "A" weighting network. Functionally, such filters can be viewed as tone controls. Their specific characteristics were derived from the Fletcher-Munson equal loudness contours which represent changes in pure tone sound levels required to maintain equal loudness as the frequency of a stimulus is varied. The required changes are referenced to levels at 1 kHz and are sometimes erroneously interpreted to demonstrate the frequency response of hearing. Since perception of loudness relative to frequency varies depending on the magnitude of the stimulus, no single frequency response plot is pertinent. Rather a family of curves describes the response. Of this family, the equal loudness contour for low level sound has been used as a model for the "A-weighting" filter response. Similarly, the equal loudness contour for high level sound models the "C-weighting" filter response. The basis for using such filtering for assessing hazardous exposures is not related to loudness perception but is derived from empirical findings on damage effects.

Measurements of exposures to noise are made with A-weighting filters, with the exception of true peak levels (i.e., the peak sound pressure levels of impulses). The latter may use several different frequency weighting filters. There is no universal consistency among instrument specifications and regulatory guidelines. Strictly interpreted, OSHA stipulates no frequency weighting, and ACGIH stipulates C-weighting. Many instruments have A-weighting for impulses. Under frequently encountered conditions, simultaneous measurements using the different frequency weightings will yield similar results although differences can arise depending on the waveform of the noise. Considering the variations in guidelines and instrument capabilities, use of true peak measurements for regulations or protective purposes requires careful evaluation of the causative waveforms and instruments used.

To establish what the unprotected noise exposure of an individual would be, it is necessary to make measurements of the noise field in the hearing zone of the individual under consideration. The noise field is defined as the surface of a sphere of radius approximately 1 foot centered in the head of the worker. Such a determination may be quite simple and can be made with a sound level meter if the level of the noise does not vary rapidly or significantly during a work shift either over time or by the worker's instantaneous work location. In the more general case, however, there is substantial variation in the noise to which a worker is exposed both over time as well as work location. Measurements with a sound level meter are then difficult and time consuming and may not be possible.

Obstacles can be surmounted by the use of a dosimeter placed on the worker. The microphone is placed in the hearing zone and a preferred position is on the top middle of a shoulder. Such a location is mandatory under Mine Safety and Health Administration (MSHA) requirements. Dosimeters monitor the noise continuously and process the data to document the worker's exposure. The simplest basic noise dosimeters in use simply accumulate a noise dose for the period of observation. In contrast, dosimeters incorporating microprocessors have extensive data processing and retention capabilities. Accumulated records are ultimately retrieved by direct printout to hard copy or are transferred to a computer for retention and further analysis.

Using Advanced Dosimeters

Dosimeters of current design have as a minimum the capability of measuring noise levels between 80 and 140 dB and must also correctly integrate impulsive noise components. Performance requirements for dosimeters are described in the ANSI "Specification for Personal Noise Dosimeters."[6] Calibration of dosimeters must be performed with acoustical calibrators that conform to the ANSI "Specification for Acoustical Calibrators."[7] Good practice requires such calibration before and after a measurement period.

Modern dosimeters have extensive resources to generate and store detailed data profiles of exposures to noise. Fig. 1

is a representative plot of a typical exposure measurement made on a worker during a work shift. For clarity, the shift record has been expanded to show approximately a one and a half hour segment. Monitoring and collection of data are continuous. However, for convenient interpretation of data, the selected mode in this example is in increments of 1 minute. For each, the incremental average level is shown as well as the maximum level observed with ANSI SLOW response.[3] The arrow points show maximum instantaneous peak levels occurring within each minute. The duration of time increments is selectable and is normally preprogrammed at the beginning of a survey.

A very useful feature with recently developed instruments is the ability to store as independent records the exposures measured over successive shifts without downloading. This is useful at a plant where operations may have a 2- or 3-shift schedule. The microphone and dosimeter are initially placed on a worker at the beginning of the first shift. At termination of the shift, the dosimeter is simply reset and along with the microphone is placed on the next shift worker at the job site. No downloading of data takes place and downloading to a computer is performed eventually. This avoids work delays and possible missed intervals. Commonly, control of the dosimeter and display of data are protected by security settings to prevent tampering and viewing of results. Completed surveys, however, are reported and revealed to the person monitored.

Another feature of dosimeters particularly useful in surveys when the surveyor cannot be present, is the ability to preset starting and stopping by means of an internal time clock. In such a procedure, the instrument is placed on a worker by a supervisor or other person who is not required to actually operate the instrument. After completion of the overall survey, the dosimeter can be read-out sometime later or sent by courier to a remote location for processing. In the interim, instruments can retain stored data for many days.

Artifacts and Interference

Artifacts may be produced during measurements with dosimeters as well as sound level meters. One source is electromagnetic interference from radio transmitters or electrical arcing. The latter is produced by arc welding, arc furnaces or very poorly shielded motor ignition systems. Care must be taken to detect the presence of such interference.

One approach when the suspected source is under the control of the surveyor is to turn the transmitter or arcing source on and off and observe readings in the dosimeter or sound level meter. However, the mere presence of readings in the instruments does not necessarily render measurements unacceptable. The levels so produced should be noted and it should be established whether they are within the range of noise levels that could produce excessive exposures. For example, if turning a transmitter on and off generates levels in the dosimeter or sound level meter of 75 dBA, such interference would not be significant in measurements to determine noise exposure because such levels contribute very small incremental noise doses. On the other hand, indications in the high-80 or 90s would in fact be suspect and could affect the findings.

In circumstances where the source is not under control of the surveyor, a simple scheme to investigate potential interference is to use an unpowered acoustical calibrator as an acoustic shield. At the location where the interference is suspected, note first the reading of the sound level in the instrument. Next place the microphone in the unpowered calibrator. If the level is dominated by the interference, little change should be observed. On the other hand, if the actual acoustical noise source dominates, there should be a significant reduction in the indicated level. As a rough guideline, reduction of 10 dB or more would be considered significant. Another consideration that should be investigated is the possibility that readings of instantaneous peak levels are caused either by radio interference or by touching or rubbing the microphone inadvertently.

If unacceptable hand-held radio interference is observed, an effort should be made to increase the distance between the source and the measuring instrument by placing the microphone and dosimeter on the opposite side of the body from that in which the hand-held transmitter is positioned. At short distances, even a small increase can be significant. If interference cannot be avoided, potential exposure levels will have to be inferred or estimated analytically. In the future, susceptibility to electromagnetic interference will be greatly reduced because improvements to comply with a new standard pertaining to susceptibility will be developed.[8]

Artifacts caused by rubbing or tapping can be substantially minimized by careful placement and treatment of the microphone and cord. The microphone should be enclosed in a windscreen provided by the manufacturer and its attachment to the shoulder should be firm. Starting immediately at the base of the microphone, it is very desirable to immobilize the cord by pasting it down with surgical or duct tape. Such treatment should preferably extend as far as the dosimeter case itself. This is also a good safety enhancement to eliminate loops or loose cords which can snag the microphone.

Corruption of records is possible by introduction of artifacts and false inputs by sabotage and horseplay. The surveyor should be very familiar with noise patterns and levels occurring throughout the workplace. Careful review of time history data profiles provides a useful tool for determining validity of a survey. Departures from expected noise profiles should arouse suspicion for further investigation. If artifacts and suspected sabotage are observed, the validity and utility of a survey are not necessarily eliminated. Software programs are available for editing dosimeter record files to remove or modify suspected portions and the effect on the overall exposure determined. Exploratory investigations have been done to examine the extent to which commonly encountered artifacts and results of horseplay affect the overall exposure determination.[9] It is encouraging that in many instances the net effects have not been significant.

As a contribution to an occupational hearing conservation program, modern dosimeters provide a powerful tool, not only to identify potential hazards but also to lay foundations for mitigation. ◆

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